Teaching and Learning Technology Concepts in Secondary Schools: a Study of Psychological Factors Affecting Pupil Performance

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Abstract

This thesis reports the findings of a study that attempted to apply an information processing model to assess and improve the teaching and learning in a secondary school technology course. Two cognitive factors believed to have an important influence on pupil performance were measured, namely: working memory capacity (X-space) and field-dependence/independence (F.IND/F.D). The research involved 71 pupils form St. Stephen's High School in Port Glasgow and a 105 pupils from St. Columba's High School in Clydebank whose ages ranged from 13 to 14 years.

Initially, the working memory capacities and field-dependent/independent learning styles of the sample from St. Stephen's High School were ascertained using a new version of the digit span test and the hidden figure test (H.F.T) respectively. These tests had been developed at the Centre for Science Education in the University of Glasgow. The results of the digit span test divided the sample into groups of low, intermediate and high working memory capacity (X=5, X=6 and X=7). The pupil's learning style categories were established from the hidden figure test, i.e. field-dependent, field-intermediate and field-independent. A technology course that focussed on gear and belt driven mechanisms was then taught to the pupils over a period of about 4 weeks. On completion of the course a test was given with questions that had been assessed for the demand (Z) which they placed on the pupils X-capacity.

The information processing model was applied to the mechanisms course so that problem areas might be identified and eradicated. It was discovered that a substantial number of changes were required to remove the material thought to have caused difficulties for the pupils (noise) and to improve the general quality (signal) of the course. After considering the amount of modifications necessary it was decided that a completely **new course** on mechanisms had to be written. This was presented to the pupils from St. Columba's High School after the two psychological factors had been measured. A comparison of the results from both schools was then made in an effort to assess the effectiveness of the new technology course and to test the hypotheses that working memory and field-dependence/independence were related to pupil performance.

An analysis of the psychological factors and pupil performance in the mechanisms tests from both schools suggested that a relationship existed between X-capacity and the Z-demand of the technology questions. It appeared that pupils who were considered to be field-dependent had inefficient memory processes and performed less effectively in the mechanisms tests. The findings implied that field-independent, high X-capacity pupils were the most successful of all the candidates in answering questions of greater complexity. Furthermore, the application of the information processing model seemed to have helped in improving pupil attainment in technology concepts.

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Introduction

In May 1996 the Scottish Consultative Council on the Curriculum (SCCC) asked teachers to look into the nature of progression in technological education. It was suggested that there was a 'dearth' of research in this curriculum area. This appeal prompted the Author to investigate the teaching and learning in a secondary school technology course that involved gear and belt driven mechanisms. The application of an information processing model to improve the effectiveness of the course and the influence of two cognitive factors on pupil attainment will form the main body of the study.

In the first chapter of this work some developments in educational psychology will be addressed. The application of an information processing model for learning and the consequences of overloading working memory capacity will then be covered. The report will go onto investigate the performance of pupils in technology questions involving gear and belt driven systems. The pupils working memory capacities will be measured using a new version of the digit span test so that a comparison of these results can be made. The information processing model will then be applied to the mechanisms course to identify any aspects that might have caused difficulties for the learners. In the subsequent chapters the design of a new technology course and its presentation to another sample of secondary school pupils will be discussed. The working memory capacities of this group will also be determined and analysed with the results of a new test on mechanisms.

In the later parts of the report, individual learning styles will be ascertained and their effects on pupil understanding of technology concepts will be considered. Finally, the performance of both samples of secondary school pupils in the mechanisms tests will be compared and the impact of the information processing model on the learning that occurred will be evaluated.

Chapter One

Intellectual Development Theory as applied in **Piagetian, Brunerian**, **Ausubelian** **New-Piagetian** schools

Piaget's theory of Cognitive Development

ı Piaget[1] is best known as a developmental psychologist, but also as a philosopher, cian and educator. For a considerable time his work virtually defined the field of nitive development. He was the first European to be given the American chological Association's award for distinguished scientific contribution. His early ıing in biology influenced the approach he took to child psychology. An interest in sical development processes, eventually led to a study of the psychology of thinking intelligence. Although many new theories have emerged over the years, it could be ıed that no alternative ideas have influenced educators more.

Piaget's world the child is perceived as an organism, growing in an environment that cts its development, adapting to the surroundings, absorbing (assimilation) what was ıired for growth and necessarily changing its behaviour (accommodation) at the same e. The thought process that brings about this adaptation is described by Piaget as ema[2]. As the child grows older it constantly creates schemata to deal with the ferent circumstances and situations that arise. Through time, these become rnalised and are organised into complex thought structures. The child's ability to ıprehend and manipulate abstract verbal symbols and relationships and to employ tract classificatory schemata is also thought to increase with age.

general hypothesis[3] asserted that cognitive development was a logical course of cessive equilibrations (a constant adjustment of balance between assimilation and ommodation) of cognitive structure, each structure deriving from the previous one. ey consist of information stored within an organism about relationships and events t have occurred. Piaget believed, that patterns emerged from the child as these ctures become integrated and internalised, for example, movement and language. He gested that it was following a system that was subject to a set of internal laws. The

Although Piaget's theory[3] has been a powerful source for researchers in educational psychology, his findings have also caused a good deal of controversy over the years. These hypothetical stages of cognitive development, have not been easily accepted by many[5] for various reasons. He was accused of using unsystematic and faulty methods when carrying out his research. It appeared that he did not consider well enough the problems related to sampling, statistical significance and reliability. Apparently, there was a lack of normative data on age level, IQ differences and gender. Instead of using statistical analysis of data and standard tests of statistical significance, he offered carefully chosen illustrations that seemed to substantiate his theory of cognitive development. In fact, the size of the samples used in Piaget's experiments were very small indeed, with little or no statistical analysis possible.

Cross-sectional studies were used by Piaget (looking at different age groups) to measure cognitive changes, that really required longitudinal studies (following the same group over a number of years) to produce authentic results. Some psychologists[6] also believed that the child's experience and environment, had a much greater influence on their intellectual development, than was accepted by Piaget's. Nonetheless, theorists[7] still considered him to be among some of the most outstanding cognitive and developmental psychologists of all time.

1.3 Jerome Bruner

Jerome Bruner[8] is a respected American psychologist who was thought to be one of the leading figures in what has been described as the 'cognitive revolution' in psychology. Many educationalists believed that his work since the 1950's on cognition and perception contributed much to our understanding of childhood and the acquisition of language. His interest in the development of mind stemmed from the influence of both, Jean Piaget and Lev Semyonovich Vygotsky. He found their differing views on cognitive psychology very intriguing. Apparently, one of the main areas of contention between the findings of these two great mentors, was that Piaget did not accept that life's experiences played as significant a role in the child's cognitive development, as Vygotsky's work suggested.

Although greatly impressed by Piaget, Bruner was not very enamoured with his idea of stages. This position was reflected[8] in an autobiography where he discussed his children:

> "It never occurred to me to believe in stages of development in the Piagetian sense. There was always some way in which anything could be made clear to them, given patience, willing dialogue, and the power of metaphor." (Bruner[8])

Bruner was greatly inspired by Vygotsky's idea that thought and language were instruments for planning and carrying out actions. Vygotsky believed[9] that humans had what he called a Zone of Proximal Development (ZPD). This theory dealt with the individual's capacity to recognise ways to go beyond the limitations of their own knowledge. Apparently, children had an inherent ability to take advantage of others helping them organise their thought processes. He asserted that experienced individuals were in a position to assist the young in reaching a higher plane, from which they could reflect more abstractly on a particular subject.

Vygotsky proposed that the ZPD was the distance between the development level determined by independent problem solving and the level of potential development, ascertained through problem solving under adult guidance, or in collaboration with more competent peers. He thought that human learning had a social characteristic and that children grew into the intellectual life of their fellows. Therefore, 'good learning' happened before intellectual development and also occurred within the zone of proximal development. For example, when children were faced with a problem they did not understand and were unable to bring the concepts required for the solution into their minds, tutors used their consciousness to enable the children to comprehend the situation.

It seemed, that within this zone of proximal development, teachers had the ability to share their consciousness, so to speak, with the learner. This process was described[9] as 'building a scaffolding' that will support the child cognitively, until full understanding of the task was reached. In a tutoring situation, work was kept to a size that the child could understand and therefore, recognise solutions as they appear. Learners took over when they had mastered the problems set before them. In a manner of speaking, the individual used the zone of proximal development, to borrow consciousness from the tutor until they could generate ideas of their own.

Bruner took a different approach to cognitive psychology than that of Piaget. He believed that cognitive science had taken too narrow a view of the logical systematic aspects of internal life. In his theory[9], development of thinking was seen as a function of experience and was apparently independent of maturational factors. The key concept was 'representation', which was the way that humans represent their knowledge. There were three distinct modes of representation, i.e. enactive, iconic and symbolic. In the enactive mode, the representation was in the muscles, that is knowing what actions to perform. Whilst, in the iconic mode, the representation was through internal visual imagery that depicted events and relations. The symbolic representation was through recognition by a symbol system as in mathematics and language. For an individual to make progress a concept would usually pass through each mode in turn. Knowledge and understanding was then increased by using all three modes together.

The three modes of representation could also be related to Piaget's stages of cognitive development. The enactive corresponded to the sensori motor stage, the iconic to the preoperational substage and the symbolic to the concrete operational stage. However, the symbolic mode was in conflict with Piaget's characterisation of behaviour after five years of age and has been consistently more controversial. This implied that it was the availability of symbolic processes rather than organisational structures, that were responsible for cognitive growth.

Piaget's apparent unwillingness to fully accept the influence of experience on the child's cognitive development was a major bone of contention for Bruner. He described[9] Piaget's children as 'little intellectuals detached from the hurly burly of life'. Bruner thought that a significant difference could be made to a child's intellectual development by careful curriculum design and skilful teaching. He had been involved in a number of successful projects that allowed underachieving children to, 'leap to higher ground' as he put it. In a report entitled[10] 'The Process of Education' he made the controversial statement that, 'any subject could be taught to anybody at any stage in some form that was honest'.

During the summer of 1965, Bruner and his team of curriculum reformers, presented a course entitled[8] 'Man: A Course of Study' to 75 children, at the Underwood School in Newton, Massachusetts. The 61 members of staff involved included: 17 teachers, 7 research assistants, 12 scholars, 10 researchers, 4 audio-visual experts and 11 administrators. Their objective was to try out new ideas and materials on teaching that had been developed by working parties in the months leading up to the experiment. They engaged the pupils in a rigorous course of study that lasted over a month. Years later many of the individuals involved said that it had been one of the most stimulating experiences in their academic lives.

Despite his obvious reservations about cognitive development stages, Bruner recommended that Piaget's theory[3] be considered during any curriculum design. He thought[10] that if some educator had a pedagogical objective in mind, then they should teach at a level appropriate to that stage of cognitive development. This principle was applied[8] by his team of researchers when choosing topics for the pupils at the Underwood school. Nevertheless, there were many differences in these two great theorists beliefs, especially regarding the ways that internal and the external factors affected cognitive growth. Bruner was primarily interested in social issues such as language and culture, whereas Piaget was more concerned with maturational factors. It appeared that Bruner[11] was convinced that psychologists alone could not construct a theory that assisted the development of the mind:

> "The task belongs to the whole intellectual community: the behavioural scientists, and the artists, scientists, and scholars who are custodians of skill, taste and knowledge in our culture". (Bruner[11])

1.4 David P. Ausubel's theory of learning

In Ausubel's theory[12], a clear distinction was made between the principal kinds of learning that could take place and the ways that knowledge was presented in the classroom. These types of learning were divided into two main categories, namely, rote learning and meaningful learning. The different ways that knowledge was made available to the learner was described as being reception or discovery learning. Four basic types of learning could be derived from the above postulation, viz: meaningful-reception, rote-reception, meaningful-discovery, rote-discovery.

1.4.1 Meaningful and Rote learning

Ausubel[5] suggested, that the basis of meaningful learning was the quality and organisation of what the learner already knew. He believed that this existing knowledge was the most important single factor affecting the learning process. In meaningful learning, as opposed to rote learning, what was being learned was substantive and nonarbitrary. This meant that the learner had grasped the essence or substance of new material being taught and could relate it to existing ideas, in a sensible and nonverbatum fashion. Any loss of any part of the new material could be reconstructed from a combination of old knowledge and what had been remembered from the new information. The learner could do this only if the new knowledge and old knowledge were in some way related. For example, although students have only remembered the outline from a recent lecture, they were still capable of expressing the main concepts involved in their own words, or in some paraphrased form.

According to Ausubel[12] three important conditions must exist before meaningful learning could take place:

- the material itself must be relatable to some hypothetical cognitive structure in a nonarbitrary and substantive fashion;
- the learner must possess relevant ideas which relate to the material;
- the learner must possess the intent to relate these ideas to cognitive structure in a nonarbitrary and substantive fashion.

Rote learning revered to learning that was verbatim, sequential and generally not related to the learners previous knowledge. The following criteria were used[12] to describe the circumstances thought most likely to produce learning that was rote:

- the material to be learned lacks logical meaningfulness;
- the learner lacks the relevant ideas in his own cognitive structure;
- the individual lacks a meaningful learning set.

It was important to appreciate that rote learning and meaningful learning are not considered to be true dichotomies. Nonetheless, if any of the last three conditions was encountered in an educational experience, then the learning that transpired would probably have been more or less rote. For example, it was not possible to retain strings of nonsense syllables in any really meaningful sense. Characteristically, in this situation an individual would rely on reproducing the words in the order that they were originally given. If any of the sequence was forgotten, then the individual might be unable to retrieve the syllables that had followed.

Schools are necessarily interested in teaching approaches that assist the learner in integrating new and old knowledge in a way that is essentially meaningful. This task is made even more difficult because of the large number of variables that can affect the individual and ultimately the type of learning, if any, that occurs in the classroom. For example, the differences that exist in children's capacity to absorb information and the amount of new material that they are presented with during their schooling.

1.4.2 Reception and discovery learning

Reception learning[12] in schools is mainly associated with didactic forms of teaching. Here the teacher presents the whole content of the lesson to the children in some coherent form. Under such circumstances the pupils are not engaged in any real independent discovery learning, because everything they need to know about the chosen topic is given to them. Subsequently, questions are asked by teachers which are supposed to indicate the child's competency in that subject area. Generally, in these circumstances, the pupils are only required to remember what has been taught during that particular lesson.

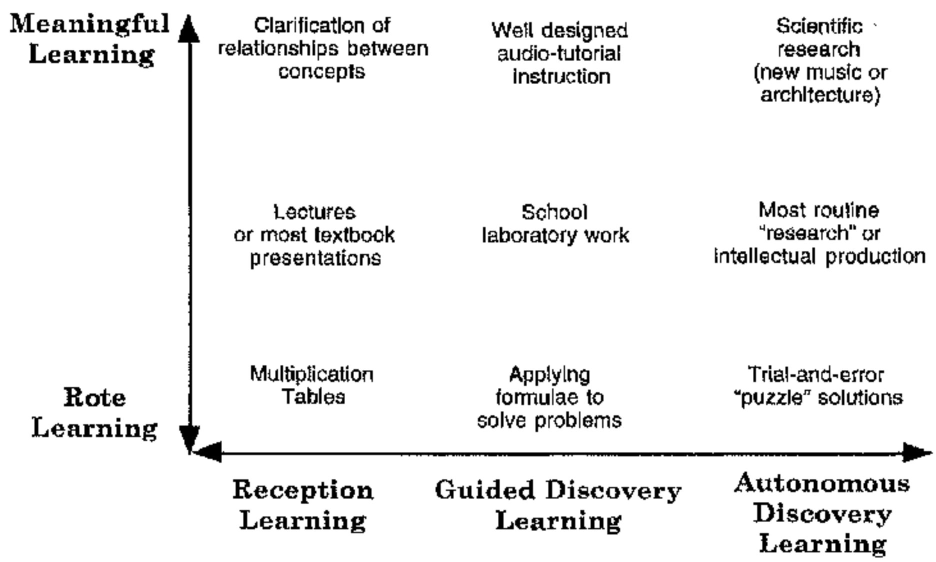
With discovery learning, the main content of the lesson is not presented directly to the class. This means that pupils are left to find the concepts that the teacher has hidden within the work they have been given. Meaningful learning occurrs when the child has rearranged, combined and integrated the new information with their existing knowledge. From this, hypotheses are raised and hopefully, logical and appropriate conclusions are drawn. It was thought[12] that discovery learning was a psychologically more involved process than reception learning, since the individual engages in a problem solving stage. Nonetheless, reception learning was associated with a greater degree of maturity and appeared later on in cognitive development.

There are also transitional types of learning that share some of the characteristics of meaningful and rote learning. Furthermore, both kinds of learning can happen simultaneously during an educational experience. This same situation arises when making the distinction between reception and discovery learning. By applying a variety of teaching approaches and materials, a combination of the above would probably be generated in a course or even one lesson. However, it might be a difficult task to define where and when each category, if any, took place during a teaching incident.

It should be understood that although a distinction has been made between reception and discovery learning, they were not related to rote and meaningful learning in any cognitive sense. It was merely implied that certain teaching strategies and circumstances were more likely to produce meaningful learning and others were more inclined to result in rote learning. It has been suggested[5] that meaningful learning varied along a continuum from more or less total rote, to highly meaningful. Reception and discovery learning were also on a continuum distinct from rote learning and meaningful learning. Ausubel illustrated a number of teaching approaches in relation to the types of learning they might engender diagrammatically. The patterns he generated to describe these teaching and learning situations can be seen in figure 1.1 overleaf.

Figure 1.1

Reception learning and discovery learning are on a different continuum from rote learning and meaningful learning.



(From, Ausubel[5])

According to Ausubel[5], some educators believed that reception learning was predominantly rote and discovery learning was inherently meaningful. He rejected this hypothesis completely, explaining that these distinctions, rote versus meaningful and reception versus discovery, were independent dimensions of learning. Indeed, depending on the circumstances, reception and discovery learning could produce either rote or meaningful learning. In both cases if pupils were set to learn then it was likely that meaningful learning would be achieved, when the new material being taught was related to their existing knowledge in a nonarbitrary and substantive way.

1.4.3 Using Organisers to set pupils

In schools a number of strategies are adopted to organise the pupils learning so that they are prepared (set) for the new material that was to be presented. For example, teaching them to use metaphors, or linking new words to the old words they already know. Specially prepared handouts that capitalise on existing knowledge and highlight the important points in the forthcoming lesson can help to integrate new and old knowledge.

All of these approaches are designed to manipulate the learner's cognitive structures, so that they are ready for new information to be transferred meaningfully.

Ausubel[13] called these introductory meaningful statements advance organisers and believed that they assisted in bridging the gap between what a student already knows and the information being taught. Advance organisers help the learner to see that new knowledge can be meaningfully learned if it relates to their existing cognitive structures. Apparently, these organisers provided 'ideational scaffolding' for the incorporation and retention of the materials that were to follow in a lesson. In this theory of learning the acquisition of knowledge clearly depended on the information already stored in the learner's cognitive structures. Furthermore, meaningful learning would transpire if the new material being taught interacted with relevant existing knowledge. This hypothesis[13] was supported by other[14] educational psychologists:

> "The acquisition of knowledge is a process in which every new capability builds on a foundation established by previously learned capabilities". (Gagne[14])

This cognitive interaction was an assimilation of old and new knowledge and should provide the learner with cognitive structures that were more highly differentiated.

1.4.4 Assimilation theory of learning

The assimilation hypothesis[13] of learning was based on the notion that if new information was linked to relevant existing ideas, then cognitive structure would be modified accordingly. Ausubel[5] believed that the majority of meaningful learning happened through this process of assimilation. He suggested that new ideas were learned by being subsumed in existing cognitive structures. The term subsumption was used to describe the concept of linking or anchoring new materials to relevant aspects of the individual's prior knowledge. Two fundamentally different kinds of subsumption could take place during meaningful learning namely, derivative subsumption and correlative subsumption.

Derivative subsumption happened when a new idea constituted a special case of some existing knowledge. The new learning was comprehended by being derived from concepts or propositions that were already established in the learner's mind. For example, understanding that volts, amperes and ohms were units of measurement that were associated with electrical circuits. In correlative subsumption, new learning material was an extension, qualification or modification, of previously learned information. The new information interacted with the relevant and more comprehensive subsumers that were held in cognitive structure. However, its meaning was not expressed in and could not be adequately described by, these latter subsumers. The realisation that travelling by public transport, constitutes a method of conserving energy, might serve as an example of correlative subsumption.

When the learner failed to retain newly acquired information it was attributed to a process called obliterative subsumption. This occured in the case of derivative subsumption when the new knowledge was easily represented by more general established meanings. Information was forgotten in correlative subsumption when the new material lacked discrimination, or if the subsumers were vague, unstable or irrelevant.

According to this theory [13], cognitive structure was hierarchically arranged with respect to the level of abstraction, generality and comprehensiveness of ideas. New learning adopted a subordinate relationship to existing knowledge when it was subsumed under the more inclusive concepts stored in cognitive structure. This was the most common kind of relationship that took place between new knowledge and old knowledge. Subordinate relationships happened in derivative subsumption when the new material could be derived from an already established and more inclusive idea. For example, if a child has learned that dogs can bark then the specific proposition that a guard dog was barking, would be subsumed under that knowledge.

In correlative subsumption a subordinate relationship occurred when the new material was an extension, qualification or modification of previously learned information.

However, when a student was confronted with an inclusive new proposition, under which many established ideas were already subsumed, then this knowledge would establish a superordinate relationship to any previous learning. For instance, when a child has learned that the familiar concepts of car, bus, bicycle, truck, train, ship or aircraft can be subsumed under the term vehicle. Nonetheless, the learning may have neither a subordinate nor a superordinate relationship to the existing knowledge and in this case a combination of the two has been established.

Correlative types of meaningful learning are unattainable at early stages (pre-operational) in cognitive development when the child was not capable of relating ideas internally. Conservation of mass for example, (the idea that the mass of an object stays the same if its shape changes) was not understood until a later stage (concrete operations) in intellectual growth. Nonetheless, it was thought[13] that although children could not internally manipulate concepts, the derivative type of meaningful learning was compatible with their mental capacity at an early stage of intellectual development.

1.4.5 Stages of cognitive development

Over the years Ausubel et. al[15], have been extremely critical of Piaget's description of the concrete/abstract dimension of intellectual development. A number of points that disputed his discoveries were raised by educators, viz:

- The transitions between the stages occurred gradually rather than abruptly;
- Variability existed between different cultures and within a given culture with respect to the age at which the transition occurred;
- Fluctuations happened over time according to the level of cognitive fluctuation manifested by a child;
- The transition to the abstract stage took place at varying ages;
- Later stages of development were not found in certain cultures or particular individuals within a certain culture;
- Environmental as well as endogeneous factors had an influence on the rate of cognitive development.

It was concluded[15] that stages in intellectual development of some description did seem to occur during maturation. Nonetheless, they were no more than a sequence in a natural progression that was distinguishable only in quality, between the majority of children in a broad age band. Therefore, it appeared that Piaget's hypothesis[3] could be reduced to an astute set of observations, regarding the changes that took place in human behaviour, during the period of physical and intellectual growth.

1.5 New-Piagetian theories

A number of researchers have striven hard to put Piaget's theory on cognitive development, into a framework that was compatible with their own conception of the ways that the human mind handled information. One of the most respected of these educational psychologist is the neo-Piagetian Juan Pascual-Leone. He did not try to challenge or disprove Piaget's findings, but rather to develop 'comprehensive general psychological theories', that were capable of explaining the facts that were discovered[16] in Geneva by Piaget and his followers.

In Pascual-Leone's neo-Piagetian theory[17] of intellectual development, an individual's performance on any cognitive task was considered to be a function of three parameters that illustrate the psychological system, viz: the mental strategy that was applied to the task (repertoire H), the demand that the strategy placed on the mental capacity (M-demand) and the individual's own available mental capacity (central computing space, M-space or M operator).

In this hypothesis[17] the structure of Piaget's stages of intellectual development were taken as qualitative indications of the subject's M-capacity or internal computing system as it was sometimes referred. In other words, M-capacity was thought to increase with age in a manner that corresponded to the Piagetian Stages of cognitive development. However, it appeared that exam performance, for example, might be improved by involving the learner in specific experiences that provided better mental strategies to apply in particular problem solving situations. Nonetheless, it was also believed that mental capacity could not be increased in this way and the only changes that did occur in the subject's mental capacity (M-space) were in response to genetic or maturational influences.

1.5.1 Repertoire

Case[18] suggested that the basic construct that was used in Pascual-Leone's theory was the Piagetian idea of schemata. These were considered to be subjective units of thought that were like 'mental blueprints' which represented experience and were responsible for human behaviour. It was believed that a considerable number of schemata capable of releasing responses were available to the individual in a designated 'repertoire', that could be divided into three main categories, namely: figurative, operative and executive.

Figurative schemata were the internal representations of pieces of information that were familiar to the individual and had the capability of releasing responses from other superordinate schemata. They also took the form of perceptual configurations that were easily recognisable. If, for example, some object was presented to the learner and it was immediately identified, then they have assimilated it into an existing figurative schema of that particular object.

Operative schemata were internal representations of orders that could be applied to a particular set of figurative schemata to produce another set of figurative schemata. They illustrated a transformation in experience that involved the extension and adaptation of previous ideas, to facilitate knew patterns of knowledge.

Executive schemata were internal representations of procedures that were applied in specific problem solving situations to obtain a particular objective. To a great extent they took responsibility in deciding which figurative and operative schemata, were utilised by a subject in any set of circumstances.

It was thought[18] that although these schemata were divided into three distinct categories, a number of similarities existed between them. Firstly, they were all highly active phenomena that were not simply triggered by an input, but rather, acted on the input and change it. Secondly, although they differed in content and structure they were all functional units. Finally, each category was made up of two separate parts: an initial set of conditions to which they might apply and a second set of conditions that were created by them.

This theory[18] implied that children entered the world with an innate repertoire of sensory motor schemata. The repertoire was thought to increase in size after continuous use with new schemata being generated in two primary ways, viz:

- the modification of old schemata as new components became incorporated into their releasing and affecting components;
- the combination and consolidation of a number of old schemata to produce permanently fixed and higher order functional units.

1.5.2 The central processor M

According to Pascual-Leone's theory[17] the computing space (M) and repertoire were responsible for the transformation and coordination of information held within the cognitive structure. A distinction was made between the individual's maximum mental capacity or 'structural capacity' (M_s) and the functional capacity (M_f) which was the amount of M space actually utilised in solving a problem. This difference was accounted for by a number of influential factors, for example, motivation, fatigue and Witkin's[19] 'field-dependence/independence' variable. Briefly, this cognitive variable was concerned with human perception and will be discussed in greater detail in the chapters that follow.

It was suggested[18], that when a problem was presented to an individual, information had to be processed so that new schemata were obtained. This procedure was carried out by putting schemata that represented the problem along with existing relevant schemata into one of the channels of the central processor M. Subsequently, new schemata that represent the solution to the problem were established within the individual's repertoire.

1.5.3 The involvement of thought processes

It was believed[18] that individuals continually applied and modified their repertoire of schemata whilst interacting with the world in everyday life. The sum of the schemata operating at any instant was considered to be the content of the individual's thought. The first step taken in a problem solving situation was to activate the appropriate executive schema. The schema being engaged would depend on several factors including: the emotional reaction, the perceptual field, the type of the problem and past experience. The moment a specific executive schema has been activated it begins to control the activation of a sequence of figurative and operative schemata.

The arrangement of figurative and operative schemata that were generated during a cognitive strategy for problem solving was composed of a number of discrete 'mental steps'. The action of these steps was to trigger an operative schema which in turn acted on one or more figurative schemata to create another figurative schema. These new schemata that were the result of previous operations were then carried forward or 'rehearsed' so that they might be engaged in future applications.

The stimulation or rehearsal of any schema generally demanded a certain amount of 'mental effort'. However, the amount of mental effort that could be applied at any time was limited and therefore, the number or schemata available for one mental step was also limited. When a schema had finally been created that matched the individual's original objective, then the executive schema directed the terminal responses that were needed to make it deactivate. When schemata were activated that were incompatible then assimilation and accommodation; as in Piaget's process of equilibration[3], was thought to have taken place.

1.5.4 Scale for M-Space and Piagetian substages

The maximum number of schemata or 'chunks' of information that M could handle at a time was considered to increase proportionally with age, in an 'all-or-none' fashion. In another study Case[20], used the scale represented in table 1.1 overleaf to show the relationship that was thought to exist between M-power (maximum number of schemata available to the individual) and the age related Piagetian substages of the child.

Table 1.1

Relationship between developmental substage and M-power.

Piagetian substage	age (yr)	Value of M (a+k)
Early preoperational	(3-4)	(a+1)
Late preoperational	(5-6)	(a+2)
Early concrete	(7-8)	(a+3)
Late concrete	(9-10)	(a+4)
Early formal	(11-12)	(a+5)
Middle formal	(13-14)	(a+6)
Late formal	(15-16)	(a+7)

In the notation above (table 1.1) the constant (a) was used to represent the space that was taken up by the mental strategy (executive schema) that was applied to a task. The M capacity was thought to increase by one schema for every two years, from childhood until maturity. However, the individual's ability to solve problems was thought[18] to depend on a number of other factors that included:

- the repertoire of schemata that was applied to the task;
- the maximum number of schemata that were attainable in the cognitive structure (mental effort);
- the tendency to use full M-capacity (some individuals were considered to be 'low-processor');
- the relative weight that was given to cues from the perceptual field, as opposed to task instructions in choosing executive schemata.

Apart from giving an outline of Pascual-Leone's cognitive theory, Case[18] also asserted that:

- the acquisition of knowledge did not depend on matching the structure of the new knowledge with the structure of the individual's original knowledge;
- learning depended on the functional limitations of an individual's thought processes when a particular item of knowledge was first encountered;
- the pragmatic structure of the circumstances that existed when a specific item of knowledge was initially constructed, affected the cognitive structure that developed as a result of an additional encounter, with that particular type of knowledge.

1.6 Summary

It appeared[18], that Pascual-Leone's theory was more concerned with the 'functional mechanisms' of cognitive development than Piaget's and was able to generate 'performance models' of greater predictive power. The results of this work[18] implied that it was possible to forecast the age at which an individual acquired a particular cognitive structure, if a specific type of learning experience had occurred. Case[20] believed, that although children could be taught sophisticated strategies for problem solving, their mental capacity (M-power) could not be increased through instruction. Furthermore, the greatest predictive power of Pascual-Leone's model might be in the field of instruction and development. The neo-Piagetian theory[17] came under quite severe criticism from Trabasso and Foellinger[21] where it was statistically rejected under a number of goodness-to-fit tests. Nonetheless, it has formed the basis of several studies on human information processing capacity and task demand.

Chapter Two

A review of some **Information Processing** Models of Learning and their Application

2.1 Studies involving Pascual-Leone's Information Processing Model

Scardamalia[22] believed that Pascual-Leone's model could be used to predict the presence or absence of *horizontal decalages*. This expression was adopted by Piaget to describe the asynchronous appearance of variations of the same cognitive structure. For example, conservation of weight was thought to follow conservation of substance. Evidently an unlimited number of factors have the capability of causing one task to be more developmentally advanced than another of the same logical structure. Occasionally, during Piagetian experiments, individuals have solved problems considered to be out with their designated stage of cognitive development.

It was argued[22] that a significant factor of this phenomenon of *horizontal decalage* was the information processing demand of the tasks presented to the learner. Here an attempt was made to show that the difference in performance in problem solving across a broad age range, depended mainly on the task demand and could not simply be explained as qualitatively distinct solutions given at varying ages. Furthermore, that by reducing the demand of a problem, children below the age of formal operations could perform qualitatively like adults.

As discussed earlier[17], the information processing load of a task in Pascual-Leone's theory was represented by M-demand. The information processing capacity of the individuals involved in this study[22] was ascertained using the figure intersection and the digit span backward tests. In the figure intersection test the intersecting area of a number of simple overlapping geometric shapes must be identified. With the digit span backward test, the highest number of digits recalled by an individual in reverse order, was used to confirm their previously determined M-capacity. The information processing load or M-demand of the problems set in this experiment was also determined. The researcher[22] hoped that knowledge of these two factors would enable predictions to be made of performance in problem solving.

As a prerequisite the sample[22] were also required to be field independent, since only this category were considered capable of utilising full M-capacity. Apparently, in some problem solving situations, field-dependent subjects pay too much attention to perceptual cues, rather than the cues provided by the task instructions. In general, this class are thought to be low M-processors, whereas field-independent subjects are usually high M-processors. It was also believed that the latter are capable of recognising the task instructions more easily.

The individuals taking part in this study[22] were considered to be at three different M-capacity levels. These were represented in Pascual-Leone's theory[17] as: a+4, a+5 and a+7, with corresponding age ranges of 9-10, 11-12 and 15+ years. The tasks applied in the experiment required all the possible combinations in a selection of cards that varied in colour, shape and pattern to be produced. The cards were grouped by placing cutout shapes on top of coloured cards to produce, for example, a blue triangle. Patterned transparent acetates were used to provide further dimensions to these assignments. Initially, each individual was given a task at a predetermined M-capacity level that they were expected to fail. This was followed by six practice tasks, beginning at a lower level and progressing to within one unit of their established M-capacity level. Finally, a retest at the initial level and at one unit beyond that point was applied.

The main purpose of this work[22] was to determine whether or not a subject's success or failure in a particular task could be predicted using the M-operator model. The researcher concluded that it was possible to predict exactly which tasks children of M-capacity 4 and 5 could accomplish. It was also shown that subjects could successfully undertake combinatorial tasks of increasing M-demand up to their estimated M-capacity level. In most cases failure occurred when tasks were set at one increment beyond that level. Table 2.1 overleaf shows the percentage of subjects who passed tasks in relation to their particular M-capacity levels.

Table 2.1

Percentage of Subjects Passing Tasks at Levels Relative to M-Capacity

M-Capacity Levels of Subjects	Task at M-Capacity Level (Initial task)	Task(s) M-Capacity (after practice)	Tasks One Level Beyond M-Capacity
4	6.7	86.7	13.3
5	0	73.3	13.3
6	0	30	0

(Adapted from Scardamalia[22])

This phenomenon of passing and failing tasks of the same logical structure was what Piagetians interpreted as *horizontal decalages*. The work[22] also seemed to confirm Scardamalia's hypothesis, that when the M-demand of a combinatorial task is set at an appropriate level, whilst preserving its logical structure, children of eight years of age could develop and successfully apply a strategy to the task. Nonetheless, it could be argued that these problems were structured so that the children involved did not require formal operations to reach a solution.

2.2 M-Space versus M-demand in chemistry questions

Niaz[23] also showed that a relationship existed between the mental capacity or M-space of students and the M-demand of questions, in a study involving fifty-five freshmen, in an introductory chemistry course. The sample were given a number of tests including: the Figure Intersection Test (FIT) to measure M-space and the Group Embedded Figure Test (GEFT), Witken et al[24], to determine the degree of field dependence (FD) and field independence (FI). The Figure Intersection Test will be discussed later in this chapter. Briefly, in the Group Embedded Figure Test, individuals were asked to identify a simple shape hidden within a complex pattern. The field dependent students would experience difficulty or be unable to discriminate a required item from its context, whereas the field independent students would identify the item more easily. This area will be addressed more fully in the subsequent chapters.

Individual performances in the chemistry course[23] were ascertained from six class exams. The M-demand of each question was calculated using the following criteria as suggested by Case[25] :

1. The first step was to identify the goal of the task to be performed.

2. The second step is to map out a series of steps by which a successful individual might reach this goal. One technique that was useful in doing this was to execute the criterion task oneself and to list the sequence of operations one went through in order to reach the goal.

3. Having mapped out a hypothetical series of steps that should lead to the correct answer, the next step was to compare this hypothesised series of steps to the performance individuals actually exhibit.

4. Having checked out the hypothesised series of steps against the individual's actual performance, one may wish to modify the series of steps one has hypothesised and to recycle through steps 1 to 3.

A task analysis of the of 23 questions from the general chemistry course[23] was undertaken using the above criteria. Example 2.1 shows the method used in the study[23] to establish the M-demand of the questions. Table 2.2 shows how student's performance was affected by increasing the M-demand of the questions.

<u>**Example 2.1**</u>

Calculate the number of gram-equivalents of H_3PO_4 in 200 ml of a 0.25 M solution of H_3PO_4. (M-demand = 4)

1. Hypothesise: 1 mol of H_3PO_4 = 3 equivalents of H_3PO_4

∴ 1 M H_3PO_4 = 3 N H_3PO_4

2. Calculate 0.25 M H_3PO_4 = 0.75 N H_3PO_4

3. Remember: normality = no. of gram-equivalents/V (litres).

4. Calculate: no. of gram-equivalents of H_3PO_4.

<u>Table 2.2</u>

Relation between M-Space and Student success in Items of Different M-Demand in a Program of General Chemistry

Mean score (%) In Items of Different M-Demand

M-Space	N	M=4	M=5	M=6	M=7
7	24	65.8	50.3	56.1	55.2
6	24	54.7	46.3	42.5	40.9
5	7	44.2	28.8	25.2	18.9

(Adapted from Niaz[23])

The findings suggested that M-capacity was not a significant factor in student exam performance with chemistry questions of relatively low M-demand ie 4 or 5. This happened because there was no discrimination at low M-demand, keeping all of the tasks within the capacity of each student taking part in the experiment. However, when the M-demand of questions was raised to levels of 6 and 7, then only individuals with large enough M-space were capable of finding appropriate solutions.

In another study, Niaz[26] investigated the relationship that existed between the M-demand of chemical questions and the functional M-capacity (M_f), which was the amount of M-space actually used by the learner. This idea came from Pascual-Leone[17] who pointed out that some individuals used a high functional M-capacity that was close to their full or structural M-capacity (M_s). Whilst others were considered to be "low processors" and were only capable of utilising a limited amount of their structural M-capacity.

A sample of one hundred students were tested in this research[26] to establish four cognitive predictor variables, namely: formal operational reasoning (Lawson[27]), disembedding ability (Witken et al.[24]), general intelligence level (Raven[28]) and functional M-capacity (Pascual-Leone and Burtis[29]). The M-demand of the questions was calculated using the guidelines applied in the previous study[23]. The students were was calculated using the guidelines applied in the previous study[23]. The students were presented with four chemistry questions, each of increasing M-demand. A score of 0-5 marks could be gained for each solution, depending on the quality of the answer given. Therefore, a maximum of 20 points was available to candidates who responded well to all of the chemistry items involved.

Table 2.3 shows the mean scores of students with different M-capacity (M_f) in solving chemistry problems of increasing M-demand. In general, it seemed that the mean score for the four problems increased along with the students functional M-capacity. Similarly, the experiment implied that functional M-capacity increased with performance in the different cognitive predictor variables assessed.

Table 2.3

Performance of subjects with different functional M-capacity (M_f) in solving problems of chemical solutions of increasing M-demand

	Mf=	2	3	4	5	6	7
Problem	M-Demand	(N=6)	(N=7)	(N=8)	(N=20)	(N=50)	(N=9)
SOL 1	4	1.71	2.57	2.88	2.9	3.34	4
SOL 2	5	2.14	1.29	3	2.45	3.04	3.33
SOL 3	6	1.14	0.86	1.13	0.95	1.26	1.22
SOL 4	7	0.71	0.29	1	1.5	1.4	1.78
Total Sol		5.7	5.01	8.01	7.8	9.04	10.33

(Adapted from,Niaz[26])

The study[26] also demonstrated the important influence information processing demand had on individual performance in chemistry examinations. Niaz[26] recommended that teachers should take cognizance of this factor when designing curriculum. The findings indicated that students would benefit if topics with the same logical structure and different M-demand, were introduced with items of low M-demand first and gradually progressed towards tasks of greater demand.

2.3 Human Memory

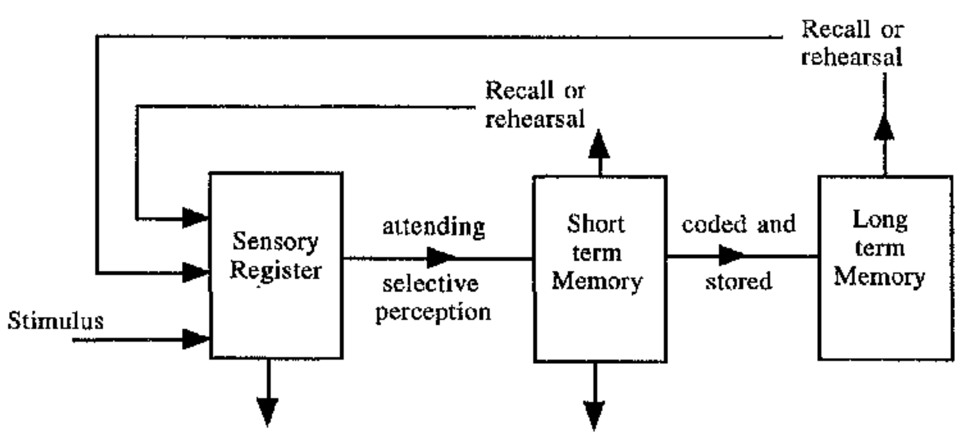
The term memory is used by psychologists to describe our mental capacity to acquire, store and retrieve information. The concept that memory is not a single system but consists of a number of sub-systems has been put forward by a number of theorists. Over the years researchers have made many attempts to define and establish the nature of these cognitive structures. This has led to a large number of hypotheses regarding the nature of human memory. An effort has been made to examine a few of these ideas in the rest of this chapter.

2.3.1 Components of memory

Klatzky[30] suggested that the human memory could be divided into three principal storage structures namely: the sensory memory, the short-term memory and the long-term memory. Another researcher, Child[31], has shown hypothetical storage structures of an information processing model of memory. This can be seen in figure 2.1.

Figure 2.1

Hypothetical structures of the information-processing model of memory.



(from Child[31])

2.3.2 Sensory memory

The sensory memory[30] is thought to involve a register that is linked to the five senses, namely: sight, hearing, touch, smell and taste. Psychologists, however, have been mostly interested in the effects that auditory (echoic) and visual (iconic) stimulis have on this kind of memory. The function of the sensory register is to hold information until it is processed into some more enduring form, before being sent further into the system. The sensory memory is only capable of storing data for a very short period of time (a few hundred milliseconds), as anything held at this point is subject to rapid decay. This type of memory is distinguished from others by: its sensory content, the large amount of material it can retain temporarily and its very short span.

2.3.3 Short term memory

The short term memory, Child[31], is capable of storing information for only a few seconds after the stimulus is removed. If, however, the material is constantly updated, then no decay should occur. The information we are actually dealing with is held in short term memory whilst it is organised into some manageable form. Generally, new data is then either committed to long term memory or completely forgotten. Miller's[32] suggestion that short term memory capacity is around 7± 2 chunks of information, has been widely accepted by theorists. The process known as chunking helps the learner remember by arranging items into groups of data, for example, sentences or telephone numbers. Nonetheless, some researchers believe that most subjects seldom utilise all of their available working memory capacity. This might be one of the challenges open to people working in the field of education. More details about the function of this kind of memory will be explained in section 2.4.

2.3.4 Long term memory

The long term memory[31] has an enormous capacity for storing information and is not prone to the same process of decay characteristic of the other two memory structures. There are theorists[33] who believe that the material held in long term memory never decays but only becomes less accessible through time. Conversely, there are those[31] who think that metabolic changes cause gradual decay until all memory traces disappear into the nervous system. The transfer of information from short to long term memory requires a considerable amount of concentration. Material is returned to the short term memory (working memory) in order to be utilised through the process known as retrieval. It is also assumed that data can be retrieved more quickly than it was stored in long term memory.

2.4 Working Memory and Overload

Johnstone and Wham[34] suggested that practical work in laboratories did not produce effective learning when the individual's 'working memory' was overloaded with new information. Baddeley[35], described the function of the working memory whilst investigating the relationship that existed between short term and working memory:

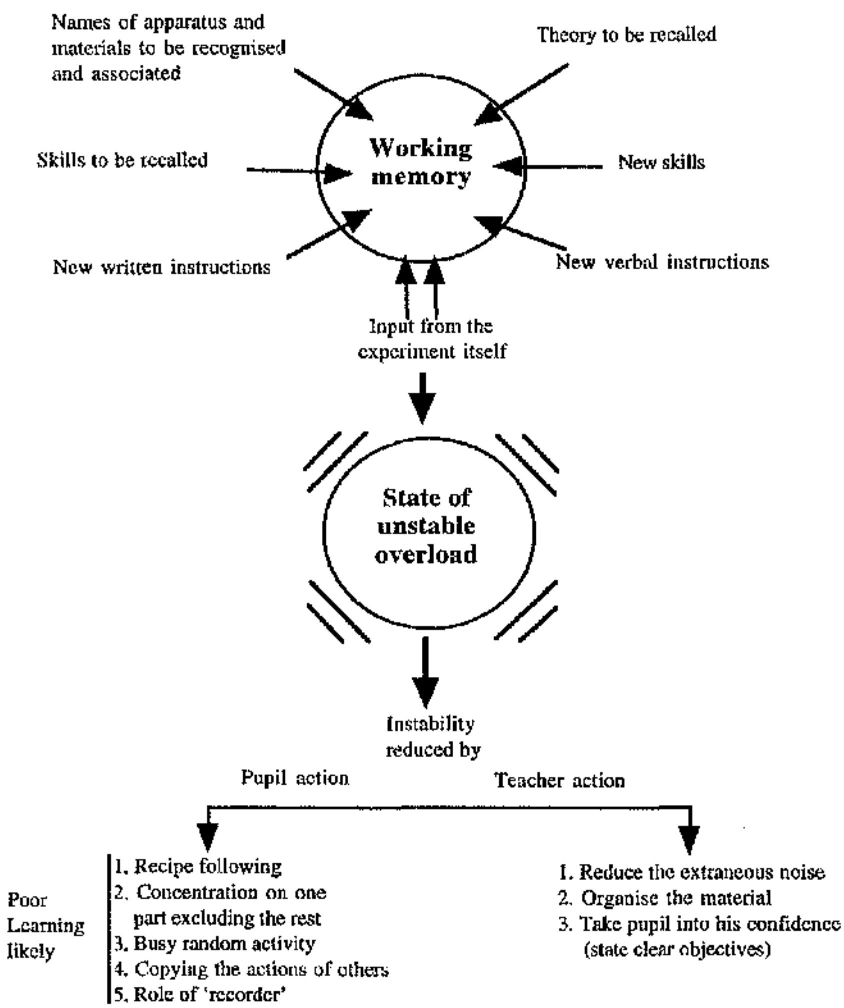
> "The term working memory implies a system for the temporary holding and manipulation of information during the performance of a range of cognitive tasks such as comprehension, learning and reasoning". (Baddeley, 1986[35])

During a laboratory experiment[34], the learner usually deals with a whole range of unfamiliar instructions, observations and deductions etc. Many facts and figures have to be collated, rearranged into some coherent form and hopefully understood by the end of the experiment. Sometimes students become completely overwhelmed with the sheer quantity of new material, before any real understanding of its purpose has taken place. When the amount of data exceeds the individual's working memory capacity, they may pursue some less demanding course of action, such as recipe following or copying from others. Although this, or similar tactics may seem logical during the experiment, the exercise is generally ineffective as very little meaningful learning can occur under these conditions.

Johnstone and Wham[34] attempted to show that when the quantity of information being presented to students in the laboratory was beyond their working memory capacity, then they eventually lost concentration and reached what was described as a 'state of unstable overload'. This dilemma was represented diagrammatically by these researchers in figure 2.2 overleaf.

Figure. 2.2

The effects of overloading working memory capacity in practical work



(From, Johnstone & Wham[34])

2.4.1 Signal and noise

The term 'noise' was used to describe the material that was extraneous to the laboratory experiment and 'signal' to represent the useful information that the teacher was transmitting. It appeares that this unwelcomed noise could have a significant effect in overloading the learner's working memory during a lesson. According to this work[34], it was possible to reduce the noise and enhance the signal in the laboratory through more carefully designed experiments. The researchers[34] believed that the likelihood of effective learning increased, if a 'common sense' approach was taken by teachers whilst organising the student's investigation. For example, redesigning experiments that have gathered moss over the years, giving clear statements of the learning outcomes involved in the work or teaching essential skills before they are actually required.

Although much effort has gone into finding ways to remove noise from the laboratory environment, its presence is also regarded as potentially valuable in some circumstances. When a degree of competence has been gained, the student's grasp of the theory might be enhanced through exposure to more demanding work which involved a certain amount of noise. The process of distinguishing signal from noise, seems to reinforce the experienced individual's knowledge and understanding of the experiment.

2.5 Capacities, Demands and the Information Processing Hypothesis

Using information supplied by the Scottish Examination Board (SEB), in a study originally involving some 20000 secondary school pupils, Johnstone and El-banna[36] attempted to show that failure occurred in chemistry tests, when the demand of the questions exceeded the candidate's working memory capacity. Each question was analysed and the load or demand (Z) was taken as the maximum number of thought steps required by the least able pupil to reach a solution. This is similar to the approach taken by Niaz[23] when assessing the M-demand of chemistry questions, in research discussed earlier in this chapter. Example 2.2 shows the approach taken by Johnstone and El-banna[36] to determine the Z-demand of questions from the SEB chemistry tests:

Example 2.2

'What volume of 1.0M hydrochloric acid would react exactly with 10.0g of chalk?':

1. Chalk is calcium carbonate (recall).
2. Calcium carbonate is $CaCO_3$ (recall).
3. Formula mass = 100 g mol^{-1} (calculate and recall).
4. Therefore 10 g is 1/10 mole.

5. Write equation for reaction (recall products and use formula).
6. Balance (recalled skill).
7. Deduce mole relationship.
8. Therefore 1/10 mole $CaCO_3$ = 1/5 mole HCl.
9. 1/5 mole HCl is 200 ml of 1.0M HCl.

It was then suggested that a chemistry teacher might employ a less exhaustive strategy to solve the same problem:

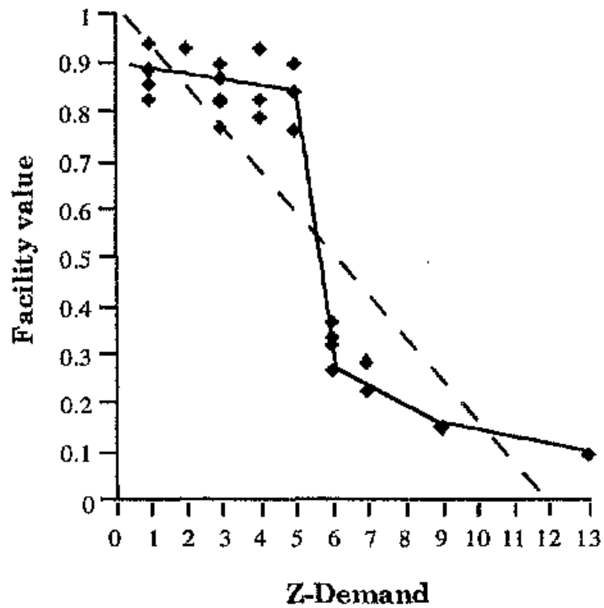
1. 10g chalk is 1/10 mole $CaCO_3$ (recall from frequent use).
2. Mole ratio of HCl to $CaCO_3$ is 2:1 (experience).
3. 1/5 mole of 1.0M HCl is 200 ml.

This approach was much less cumbersome as the experienced individual has probably mastered the technique of grouping the sequence of steps into manageable[32] chunks. This implied that they only needed to use a certain amount of their available working memory capacity to perform the calculations. The pupils, on the other hand, may have found that the demand of the question was beyond their mental capacity. Therefore, they were unable to hold the information whilst organising it into an order that assured a solution.

Johnstone and El-Banna[36] used the SEB data to plot the facility value, that is the fraction of pupils who solved the problems, against the complexity or demand of each question. A negative correlation was obtained giving an S shaped curve similar to that shown in figure 2.3 overleaf. Interestingly, a dramatic change in pupil performance occurred between 5 and 6 on the question complexity axis. This phenomenon was extremely close to Miller's hypothesis[32] and could be interpreted as thought steps (demands) exceeding working/thinking space. Although a sudden drop appeared on the graph, it did not actually reach zero beyond 6 on the Z-demand axis. In fact, the curve gradually descended at that point from a facility value of 0.35 to 0.10. This implied that subjects were capable of employing 'strategies' that permited them to solve problems of Z-demand, greater than their mental capacity.

Figure 2.3

Correlation between facility value (FV) and question Complexity (Z)



(Adapted from, Johnstone and El-Banna[36])

The 20000 pupils used in the study[36] probably had a range of working memory capacities which varied from low to high. The researchers had to find a method of ascertaining the thinking/working space of individuals before continuing their work. Each pupil's performance in the chemistry tests could then be assessed against the separate categories of thinking space.

2.5.1 Measurement of thinking/holding space

The researchers[36] used 206 school pupils of age 15+ and 271 university undergraduates in their subsequent work. Two tests which are designed to measure the thinking or holding space were chosen for this experiment viz: the digits backwards test (DBT) and a figure intersection test (FIT). In the DBT, a set of digits were read out to individuals who had to then recall them in reverse order, i.e. 2453 becomes 3542. The number of digits was gradually increased until the candidates began to make errors. The highest number of digits successfully recalled by each student was taken as a measure of their thinking space or capacity (X) as it was called. With the FIT, students were asked to look at a number of shapes and then on a separate sheet, shade in the common area of overlap in a diagram constructed from a selection of these shapes. As the number of shapes was increased, so did the level of difficulty of the task. Again the upper limit achieved by each candidate was used to determine their X-capacity. There was a 75% agreement on the scores from both of these tests.

2.5.2 A model for information processing

The information processing hypothesis[36] reflects the manner in which the memory encodes, stores and retrieves information. The ability of an individual to manipulate data depends upon the size of their working memory space. Ideas are both held and thought about simultaneously in the human mind. However, a number of other aspects must also be considered when looking at they ways information is handled mentally. In an exam situation, for example, the magnitude of the tasks and the students previous experience, will play important roles in whether or not they are successful in passing. It was suggested that three important factors should be considered when analysing the information processing hypothesis:

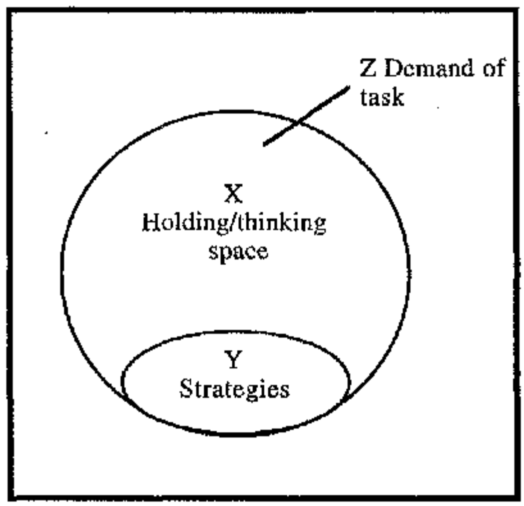
- X - the individual's working memory capacity;
- Y- the mental strategy that is applied by the individual to help solve the problem (techniques, tricks and previous knowledge etc);
- Z - the demand the problem places on the individual's mental capacity

This theory[36] then implies that the Z-demand represents the load that is applied to an individual's working memory space X when they are given a problem to solve. Ideas are then held in the working memory whilst the overall situation is considered. Y strategies such as techniques, tricks and previous knowledge are used at the same time to try to find a solution to the problem. Apparently, these strategies account for an individual being able to go beyond their working memory capacity in a problem solving situation.

To allow hypotheses to be raised the experimenters[36] summarised their thinking in the simplified information processing model seen in figure 2.4.

Figure 2.4

Simplified information processing model



(From, Johnstone and El-Banna[36])

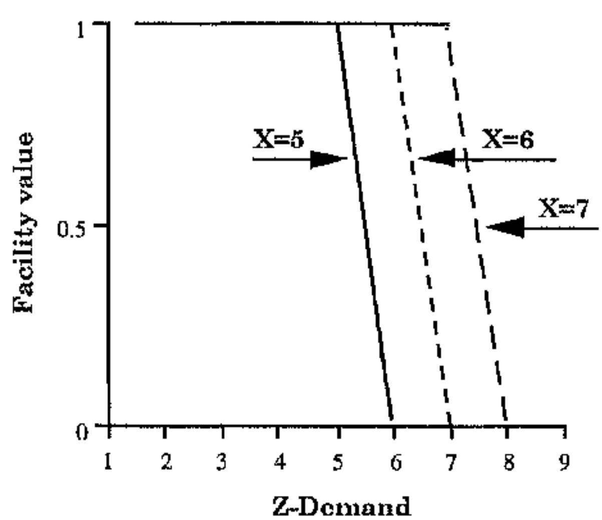
2.5.3 Hypothesis against chemistry tests results

It was thought that the S shape plotted in figure 2.3 might be a composite of curves generated by candidates of varying X-capacity. This idea was tested by comparing the X values established in the digit span test, to the corresponding scores in the chemistry questions. Johnstone and El-Banna[36] believed that subjects with a mental capacity of X = 5 could solve problems of Z-demand 5 or less. Similarly, a pupil of X = 6 should be successful with questions of Z-demand 6 or less and a pupil of X = 7 should solve tasks of Z-demand 7 or less. Here an assumption was made that no Y strategies came into operation, as the chemistry questions were unfamiliar to all of the candidates in the sample.

The set of curves, seen in figure 2.5 overleaf, which was based on the predictions of the information processing model, showing the facility value versus Z-demand, was generated by these researchers[36]. When the results of the school chemistry tests were compared with these curves there were strong similarities. Pupils of capacity X = 7 held a facility value greater than 0.7 for questions of Z-demand 7 or less and dropped suddenly to values of less than 0.1 beyond that point. The other categories followed the predicted trends with only pupils of X = 5 making a slight recovery at Z = 7. Further analysis revealed that some of the X = 5 pupils in the sample performed like X = 7 candidates in exams. The most likely reason for this was that these subjects have developed Y strategies to help cope with the extra demand.

<u>**Figure 2.5**</u>

Expected performance of pupils with given values of X



(Adapted from, Johnstone and El-banna[36])

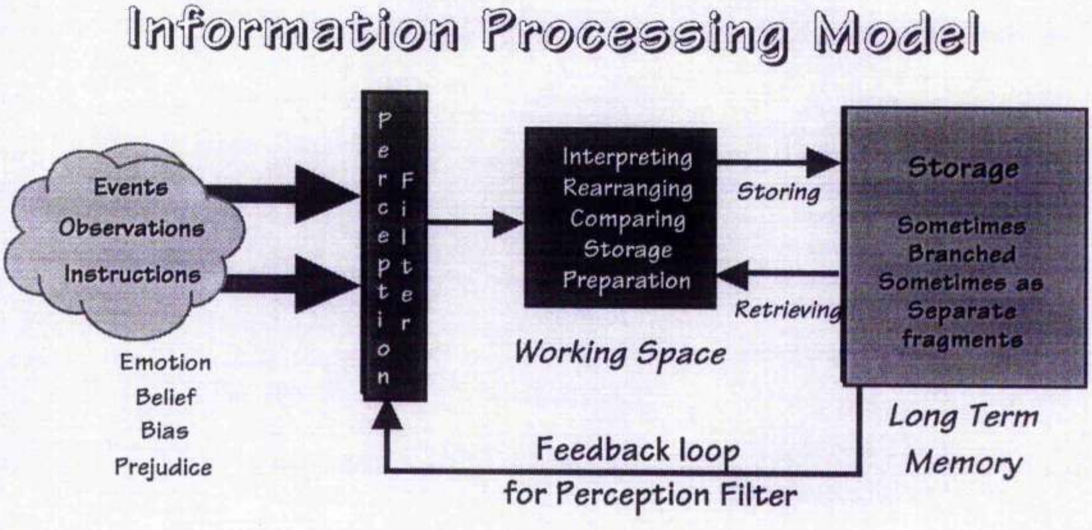
Graphs obtained from the results of a conventional class exam taken by the group of undergraduates also showed remarkable similarities to the trends exhibited in the idealised curves, figure 2.5. It appears from this[36] work, that a relationship did exit between the information processing demand of chemistry questions and the mental capacity or X space, of the subjects involved in the study.

2.6 Further development to the Information Processing Model

Johnstone et al.[37] used an information processing model to help redesign the laboratory work in a first year inorganic chemistry course that involved some 500 undergraduates. A great deal of time, money and effort had gone into the original planning and delivery of the experiments for this course. Nonetheless, many students resorted to the tactics associated with 'unstable overload' [34], such as recipe following or copying from others. This raised questions regarding the quality of the learning that occured in relation to the expenditure, in this type of training. The information processing model was used to help develop strategies that would make the laboratory experiments a more effective learning experience for students, figure 2.6.

Figure 2.6

Information processing model of learning



(From Johnstone[37])

Three main sections of the model concerning the brain were analysed[37] to focus attention and to help develop a greater understanding of the apparent shortcomings in the laboratory work, namely: the perception filter, the working memory space and the long term memory. The perception filter is used by the learner to select what is considered to be important, interesting or exciting, out of an environment that generates vast quantities of stimuli. Of course, this means that the filtration system allows the individual to ignore any material thought to be incidental or irrelevant. If much of what is attended to depends on prior knowledge, then students may be confused when dealing with new information. In other words, differentiating between 'signal' and 'noise' can cause the first time learner some difficulties. On the other hand, an experienced person knows what to look for because relevant information is already held in the long term memory.

The working memory or working space is the area in the mind where information from the environment interacts with what is retrieved from the long term memory. This in turn produces knowledge that is immediately utilised, stored or forgotten. As discussed earlier in the chapter, this space can become overloaded when the data presented exceeds the subject's working memory capacity. The researchers[37] suggested that the long term memory is a 'large store' that informs the filter system, whilst providing information for the working memory.

After analysis of the first year chemistry course, a number of changes aimed at improving learning efficiency were introduced, including: pre-labs to prepare students for new information, revised manuals that reduced extraneous noise and mini-projects to reinforce the new knowledge. Results showed that these measures did bring about changes in student 'attitude and outlook' that were conducive to more effective learning.

Johnstone[38], explained in a paper how the model had assisted researchers in understanding the way that the process of filtration happened in an individual's mind. The whole system appears to be controlled by what was already stored in the long term memory. Material is picked up by the senses, selected in the perception filter, processed in the working space and stored in the long term memory. All of this occurs whilst information is being retrieved from the long term memory to assist with the processing that went on in the working space. Furthermore, the model has been useful in exposing the limitations of the working memory when handling large amounts of data. It also helped experimenters focus attention on the links that exist between the long and short term memory.

2.7 Summary

Amongst other things, the information processing model appears to offer a useful aid to educators, by providing a starting point for curriculum development and for assessing the effectiveness of existing courses. The knowledge and understanding gained from such analysis could be used to improve and consolidate the individual's learning. If pupils fail exams in school, they are sometimes accused of having poor motivation or even lacking intelligence. Although these are areas to be considered, it is still possible that the main problems lie within the existing course structures. This presents a great challenge to psychologists, curriculum designers, teachers and indeed every person involved in the provision of education. The following chapters give an account of the researcher's attempts to apply the information processing model to assess and improve the effectiveness of a secondary school technology course.

Chapter Three

Technological Education at secondary school level in conjunction with some **Psychological Factors** affecting pupil attainment

3.1 Introduction to Technology

In this chapter, the researcher proposes to review some aspects concerning the teaching and learning of technology at Scottish schools. It was considered beneficial to discuss certain recommendations from a number of important documents regarding: general aims, course content and attainment in technology at primary and secondary levels of education. Furthermore, it is intended to look at one short course from the S2 technology syllabus on mechanisms and to present the results of a test taken by pupils from St. Stephen's High School in Port Glasgow, who took part in that course during the academic year 1996/97. Some psychological factors thought to affect the level of pupil attainment in the mechanisms test are also addressed.

3.2 Technology Education a view for the future

A large number of disciplines within the secondary school curriculum deal with technology in various ways. For example, science, computing studies and technical education allow pupils to consider technology from different positions. In 1996, the Scottish Consultative Council on the Curriculum (SCCC) published a paper[39] expressing their opinions and concerns, about what they saw as the 'perspectives and principles', which should underpin future developments in technology education:

> "The overall purpose of technology education should be to develop technological capability in young people. Technological capability encompasses understanding of appropriate concepts and processes; the ability to apply knowledge and skills by thinking and acting confidently, imaginatively, creatively and with sensitivity; the ability to evaluate technological activities, artifacts and systems critically and constructively". (SCCC[39])

3.3 Environmental Studies and the role of Technology

The Secretary of State for Scotland issued the guidelines[40] for 'Environmental Studies' to Scottish schools in March 1993. This document dealt with five main curriculum areas, namely: science, social subjects, technology, health education and information technology. Detailed advice was given to both primary and secondary school teachers to assist in establishing progressive, comprehensive and coherent programmes of study for pupils in the 5-14 age group. The guidelines were based on the 'existing good practices' that had been witnessed by a review and development group (RDG), during a study of educational provision for environmental studies in Scottish schools:

> "The scope of Environmental Studies
>
> The environment as it is reflected in these guidelines encompasses all the social, physical and cultural conditions which influence, or have influenced, the lives of the individual in the community; and which shape, or have been shaped by, the actions, artifacts and institutions of successive generations. At a more immediate level, this definition includes everyday curricular experiences through which pupils' knowledge of the environment develops". (SOED[40])

3.3.1 Attainment outcomes and key features

The five curriculum areas addressed in Environmental Studies[40] contained a number of 'attainment outcomes' which identified the main kinds of learning that pupils should have experienced, from the first year of primary school (S1) until the end of second year (S2) at secondary school. Two such attainment outcomes were set out for the technology curriculum, namely:

- understanding and using technology in society;
- understanding and using the design process.

The attainment outcomes[40] for technology were thought to reflect the various forms of knowledge and different ways of thinking that existed within technical education. They were introduced by a statement of their 'key features' which encompassed a range of 'contexts and content' that could be used to enhance experience of the environment, from a technological perspective. The key features offered a convenient method of organising a substantial part of what pupils should be able to do as a result of their learning in this curriculum area. It was believed that through participation in the activities suggested under these attainment outcomes[40], knowledge and understanding of technology as it related to the environment would be increased.

3.3.2 Strands

The 5-14 guidelines[40] employed a specific set of 'strands' within the attainment outcomes for: science, social subjects and technology. Their purpose was to assist in identifying the important aspects of learning for these three curriculum areas:

- Knowledge and understanding;
- Planning;
- Collecting Evidence;
- Recording and Presenting (Science and Social Subjects only);
- Applying Skills and Presenting Solutions (Technology only);
- Interpreting and Evaluating;
- Developing Informed Attitudes.

Strands could be used along with the attainment outcomes to help plan and assess programs of work in environmental studies. For example, when designing an artifact in technology: planning is carried out first, information is then collected, possible designs are presented either graphically or in three dimensional models, the best solution is then manufactured and finally the new product is evaluated. From this, pupils should gain knowledge and understanding of: the design process, materials, tools and manufacturing techniques. New skills and informed attitudes about various aspects of the environment are thought to develop through involvement in this type learning of activity.

3.3.3 Attainment targets

Specific 'attainment targets' were used to chart the pupil's progress in each of the attainment outcomes from primary one (P1) until the end of secondary two (S2). The attainment targets[40] were grouped at the following five levels of progression:

Level A: should be attainable in the course of P1-P3 by almost all pupils.

Level B: should be attainable by some pupils in P3 or even earlier, but certainly by most in P4.

Level C: should be attainable in the course of P4-P6 by most pupils.

Level D: should be attainable by some pupils in P5-P6 or even earlier, but certainly by most in P7.

Level E: should be attainable by some pupils in P7-S1, but certainly by most in S2.

3.4 The scope of Technological Studies in secondary schools

The researcher was chiefly concerned with the curriculum taught by secondary school Technical Departments and in particular a relatively new course called 'technological studies' as it was presented to the lower school (S1/S2). The term technology is commonly used by technical teachers to distinguish technological studies from two other subjects taught by them, namely: 'craft and design' and 'graphic communication'. The Scottish Examination Board (SEB) offered the arrangements[41] for Standard Grade 'technological studies' to Scottish secondary schools in 1987. Four main curriculum areas were addressed in the syllabus, namely: electronics, pneumatics, mechanisms and manufacturing systems. This new subject was introduced in attempt to raise awareness of the ways that technology is applied in industry and commerce. Since 1987 a lot of time and effort has gone into developing good teaching materials for technological studies at Standard Grade and to provide introductory courses (units) for children in first and second year classes. Pupil achievement in one of these introductory courses was the main focus of attention for the researcher in this study.

3.5 Mechanisms - S2 Course in Technological Studies

Technological education encompasses a wide and varied range of topics during the early years of secondary school. In this study the researcher aimed at one particular short course from the technology syllabus that dealt with simple mechanical control systems. The course which was presented to a group of seventy one secondary school pupils during the third term of S2, looked primarily at the operation of gear and belt driven mechanisms. An example of the coursework booklet that was used in the S2 technology course on mechanisms can be found in appendix A.

Although mechanisms could be addressed under a number of key features from the 5-14 guidelines for environmental studies, it is highlighted specifically under the attainment outcome[40], understanding and using the design process:

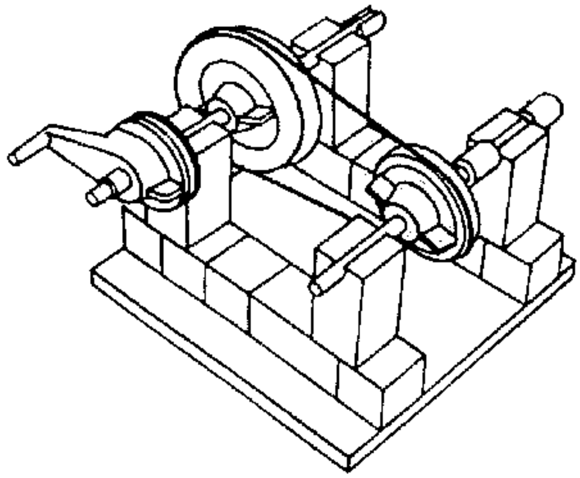
> **"Devices and tools associated with control and their application**
>
> • the effective and efficient use of control technology in design tasks, *eg.*
>
> *burglar alarms, lifting mechanisms for car park levels, cranes, level crossing barriers, warning systems."* (SOED[40])

3.5.1 Teaching approach to S2 course in mechanism

The mechanisms course was taught over four 55 minute periods and involved a range of teaching approaches and materials. Pupils worked mainly in pairs when undertaking the practical sections of the course. Fishertechnik construction kits, which consist of sophisticated engineering modelling equipment, were used to build models of the gear and belt driven systems. An example of the type of materials used in these experiments can be seen in appendix B. Figures 3.1 and 3.2 overleaf, show two of the models that were constructed by the pupils during the practical work. After constructing the belt driven system in figure 3.1 each pulley was marked with a piece of chalk to give a reference point. One group member then turned the handle on the input pulley clockwise whilst counting a set number of turns. The other group member counted the number of turns made by the output pulley and noted the direction in which it turned. Finally, the results of the experiment were noted and discussed by the pupils and teacher.

Figure 3.1

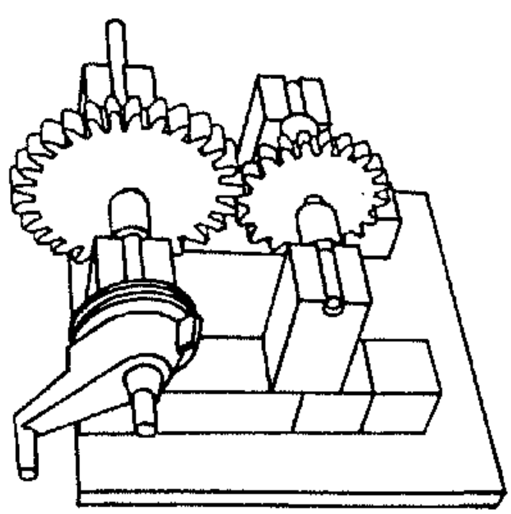
A typical belt driven system from the S2 mechanisms course.



As with the belt driven system in figure 3.1, a reference point was marked with a piece of chalk on each gear in figure 3.2. One pupil then turned the handle on the input gear clockwise and counted a set number of turns. At the same time another pupil noted the direction of the output gear and the number of turns it made. The results of the experiment were then noted and discussed by pupils and teacher.

Figure 3.2

A typical gear driven system from the S2 mechanisms course.



Although lessons were delivered to the class as a whole, when introducing new concepts and when recapitulation was deemed necessary, the majority of teaching time available for the mechanisms course was taken up with group activities.

3.5.2 Analysis of the mechanisms questions into Demands (Z) according to the information processing hypothesis

At the end of the short technology course on mechanisms each pupil was given a test to ascertain their knowledge and understanding of the ways that the speed and direction of gears and pulleys could be controlled in simple mechanical systems. As the pupils progressed through the assessment they were presented with questions that increased in level of difficulty. A sample of the test on mechanisms that was used for the technology course can be seen in appendix C. Not surprisingly, a number of children began to fail as the questions became more difficult. Nonetheless, eleven pupils from the sample of seventy one were able to answer all of the questions correctly.

According to Johnstone and El-Banna[36] failure occurred in chemistry tests when the demand of the questions (tasks) exceeded the students working memory X-capacity (X-space). This is to say that the working memory had reached what was described[34] as a 'state of unstable overload'. These researchers[36] defined the demand (Z) of a question as: 'the maximum number of thought steps required by the least able pupil to reach a solution'. It was believed that this phenomenon of overloading of the working memory capacity might explain the poor results achieved by some of the children who undertook the mechanisms test.

The maximum number of thought steps (Z-demand) of the questions from the mechanism test was determined using the criteria suggested by Case[25] in chapter two. Considering the qualitative nature of the process, it was thought that the analysis of these questions might be subject to a certain amount of interpretation. Therefore, a number of experienced individuals were asked for their opinions regarding the possible strategies that pupils might adopt in solving these problems. They agreed that it was reasonable to assume that a novice learner might use the number of thought steps designated by the researcher, when finding solutions to the questions from the S2 mechanisms test. Some of the children involved in the course were also asked to describe their thought processes as they worked towards a solution to these problems.

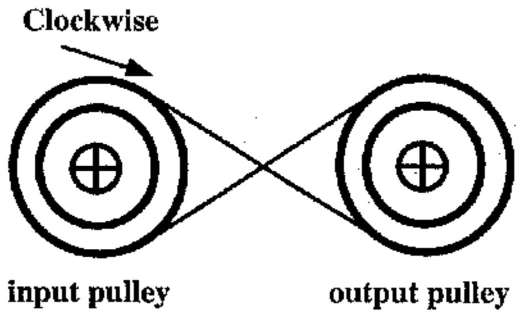
The mechanisms test comprised of a total of 12 questions that involved various combinations of gear and belt driven systems. The questions were analysed into thought steps which suggested a Z-demand that ranged from 3 for the easiest to 8 for the most difficult. Questions 4, 8 and 9a from the mechanisms test have been illustrated in figures 3.3, 3.4 and 3.5 respectively, to demonstrate the procedure used to determine the number of thought steps in each task.

Question 4 (figure 3.3) was viewed by the researcher as a single task rather than a question with two distinct parts, for the purpose of establishing its Z-demand. It was thought that the pupil might read through the whole question before arriving at a conclusion about the speed and direction of the output pulley. A full description of the method used to establish the number of thought steps contained in the rest of the questions from the mechanisms test can be seen in appendix D.

<u>**Figure 3.3**</u>

Question 4 from the mechanisms tests which was believed to contain five thought steps.

Q.4



What is the direction of the **output** pulley? ____________________

Does the **output** pulley turn: **faster, slower** or at the **same speed** as the input pulley?

____

Approach taken by the researcher to determine the maximum number of thought steps required by the novice learner to solve question 4 from the mechanisms test is set out below:

1. Look at the system and note the direction and size of the input pulley.
2. Realise that the pulleys follow the direction of the belt as it goes round them.
3. Follow the belt and consider the effect of it crossing over in the middle.
4. Continue to follow the belt around the output pulley and see by comparison that it is turning in the opposite direction to the input pulley, i.e. anticlockwise.
5. Consider the size of the pulleys, ie the same, therefore they must be going round at the same speed.

It was thought that an experienced technology teacher, for example, might employ a much less exhaustive approach in reaching a solution to the same problem:

1. Look at the system and note the direction and size of the input pulley.
2. Remember that a belt crossing over in the middle means that the pulleys must turn in the opposite direction, therefore the output will turn anticlockwise.
3. Recall that pulleys of the same size in this type of belt driven system must turn at the same speed.

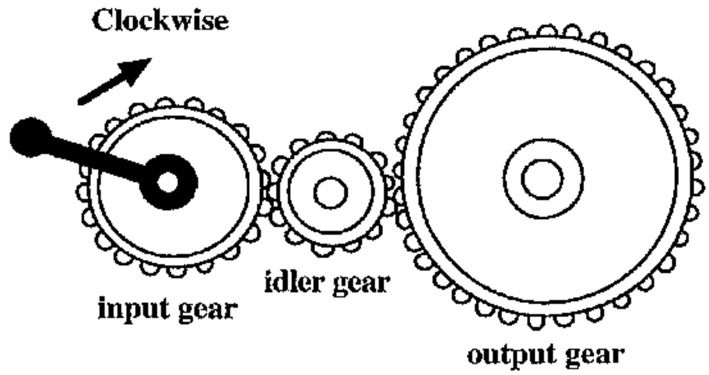
The second approach is much less cumbersome because the experienced individual has probably mastered the technique of grouping the steps into more manageable [32] chunks. It could also be that the question is so familiar that hardly any thought is given to it at all and the answer is simply remembered.

Question 8 from the mechanisms test, shown in figure 3.4 overleaf, involved a gear driven system and was considered to have a Z-demand equal to 6. Like the previous example (figure 3.3) this question has been viewed as a single task, for the purpose of analysis into thought steps.

Figure 3.4

Question 8 from the mechanisms tests which was believed to contain six thought steps.

Q.8



What is the direction of the **output** gear? ________________________

Does the **output** gear turn: **faster**, **slower** or at the **same speed** as the input gear?

____

Approach taken to determine the maximum number of thought steps required by the least able pupil to solve question 8 (figure 3.4) from the mechanisms test is set out below:

1. Look at the system and note the direction and size of the input gear.
2. See that the teeth on the input gear must push down on the idler gear turning it anticlockwise.
3. Consider that the idler gear must be pushing up on the output gear turning it clockwise.
4. Think about the speed of the output gear in relation to the whole system.
5. Remember that idler gear cannot change the speed of the gear train.
6. Compare the size of the output gear to the size of the input gear, i.e. larger, so it must turn slower.

As with the previous problem (figure 3.3) it was thought that an experienced individual might use a much less demanding strategy in solving the above question (figure 3.4):

1. Look at the system and note the direction and size of the input gear.
2. Remember that the idler gear makes the output gear turn in the same direction as the input gear, i.e. clockwise.
3. See that the output gear is bigger than the input gear therefore it will turn slower.

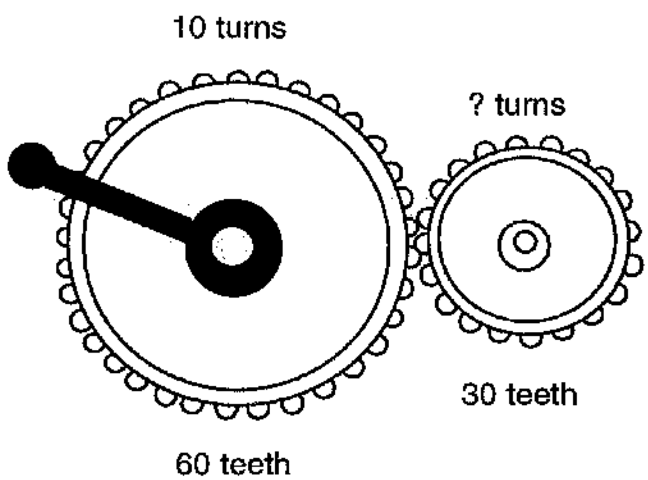
Question 9a from the mechanisms test, shown in figure 3.5, involved a gear driven system and was considered to have a Z-demand equal to 7. In this question pupils were required to carry out a number of mathematical calculations.

Figure 3.5

Question 9a from the mechanisms tests which was believed to contain 7 thought steps.

Q.9a

For the gearing system shown below find the missing number.



Approach taken to determine the maximum number of thought steps required by the least able pupil to solve question 9a (figure 3.5) from the mechanisms test is set out below:

1. Look at the gear system and note that the output number of turns is missing.

2. Consider the number of turns made by the input gear and relate this to the output gear.

3. Compare the number of teeth on each gear and consider the effect of the big gear turning the small gear.

4. Recall the method for calculating a missing number in this type of system namely; the number of teeth on the input gear (big gear) multiplied by the number of turns it makes; equals the number of teeth on the output gear (small gear) multiplied by the number of turns it makes:

Teeth x Turns (input) = Teeth x Turns (output).

5. => 60 x 10 = 600

6. => 30 x ?T = 600

7. ∴ 600/30 = **20 Turns**

It is possible that a more advanced pupil, for example, might use a previously learned technique that involved fewer mathematical calculations, thus reducing the steps to solve this problem (figure 3.5):

1. Look at the gear system, see that it is the output number of turns that is missing and relate this to the input number of turns, i.e. 10.

2. Compare each gear and see that there are double the number of teeth on the big gear, giving a ratio of 2:1.

3. Through mental arithmetic, calculate that the output gear will turn twice as many times as the input gear, i.e. 20 turns.

3.6 A Limiting factor in the Mechanisms Test

If the working memory capacity was a limiting factor in answering the questions from mechanisms test, then some form of independent measurement had to be found to establish a category for each pupil, before any comparison of results could be made. Johnstone and El-Banna[36] used the digits backwards test (DBT) and figure intersection test (FIT) to divide their sample into three distinct groups i.e. X=5, X=6 and X=7, where X was the number of chunks of information that could be handled at any given time. The digits backwards test was a modified version of the digit span test (DST) which has been around[42] since the late nineteenth century. As discussed earlier, this test involved a set of digits being read out to students who had to recall them in reverse order. The number of digits was gradually increased until the candidates began to make mistakes. The highest number of digits successfully recalled by each student was taken as a measure of their working memory space.

Originally, it was intended that the digits backwards test should be used in the case of the secondary school pupils who undertook the mechanisms test. Nonetheless, the researcher discovered that this kind of test was very difficult to apply to these children and generally only produced authentic results when administered on a one to one basis. The figure intersection test had already proved to be very labour intensive and was considered unsuitable because of the time constraints involved in this current study. Therefore, a modified version of the digit span test that involved dates written in words was used instead of the digits backward and figure intersection tests.

3.6.1 A new test for working memory capacity using 'Dates'

Over the years the Centre for Science Education at the University of Glasgow has carried out a great deal of research in the area or working memory capacity. The test that was used to measure the X-space of the children studied in the S2 technology course was developed by Johnstone at the Centre and was briefly discussed[38] in the 1996 Brasted Lecture. Here, a date printed in words on a transparency was shown to pupils by means of an overhead projector (OHP) for a limited period of time. The date had to be converted from words into numbers then rearranged in ascending numerical order. When the OHP was switched off the pupils wrote their answers on a sheet of paper that was designed for the purpose.

The experiment began by giving the pupils two separate attempts at dates that contained three digits. These were replaced with dates that had four digits, then five and so on until finally eight digits was reached. One second was allowed for each digit contained in the date plus two extra seconds. For example, the OHP was on for a total of five seconds for a three digit date. The two extra seconds were given because the pupils had to continually look up and down at the OHP screen. Many of the children also experienced difficulty working out the numbers that corresponded to each month. Furthermore, although the answers were required to be written down immediately after the OHP was switched off, some pupils took a little longer than others in writing. To overcome this problem the dates were displayed quite quickly, one after the other, forcing the class to move onto the next set of digits.

If a candidate failed on both attempts at one of the dates they were considered to have a working memory capacity of the same magnitude as the previously correct answer. For example, a pupil who got both of the six digits wrong, but had at least one correct answer up to that point, was deemed to have an X-space equal to 5. An example of the dates test that was used to determine the working memory space of the pupils is shown in table 3.1. The full version of the this test can be seen in appendix E.

Table 3.1

Extract from the 'Dates test' that was applied to pupils on the S2 technology course

THE THIRD OF DECEMBER	123
THE TWENTY SIXTH OF NOVEMBER	1126
MARCH NINETEEN EIGHT FOUR	13489
THE SIXTH OF MAY FIFTEEN THIRTY TWO	123556
THE FOURTEENTH OF MARCH SIXTEEN FORTY THREE	1133446
THE TWENTY FOURTH OF DECEMBER NINETEEN SEVENTY FIVE	11224579

3.6.2 Arranging the sample into X-capacity categories

From the results of the dates test the sample of seventy one secondary school pupils were divided into three distinct categories, namely: low, intermediate and high with corresponding X-values of 5, 6 and 7. This was in keeping with similar studies[36,43,44] that have been carried out in this field at the Centre for Science Education. The pupil's performance in the dates test is shown in table 3.2 overleaf.

Table 3.2

Working space groups for pupils from St. Stephen's High involved in mechanisms test

Groups (X Space)	Number of pupils
X = 5	43
X = 6	12
X = 7	16
Total (N)	71

3.6.3 Comparison of Results

A comparison was made between the pupil's performance in the questions from the mechanisms test and the psychological test for working memory capacity. The Z-demand of these questions was distributed from 3 to 8 with some being of equal magnitude, see appendix D. The facility value (F.V.), which represents the number of pupils who answered a question of a particular Z-demand correctly, divided by the total number attempting that question, was calculated for the individual groups. Table 3.3 was constructed from these figures for the purpose of comparison.

Table 3.3

The facility value (F.V) for the questions of different Z-demand in the mechanisms test related to the pupils from St. Stephen's High X-capacities (N=71)

Z-demand	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8
X=5	0.93	0.79	0.8	0.67	0.33	0.14
X=6	1	0.96	0.97	0.92	0.53	0.5
X=7	0.97	1	0.96	0.8	0.56	0.4
Questions	Q. 1,5	Q. 2,7	Q. 3,4,6	Q. 8	Q. 9a,9b,10b.	Q. 10a.

Although the table suggested an improvement between the pupils of X=5 and X=7, those of capacity X=6 have done slightly better than the X=7 group in some of the questions. It was difficult to draw any conclusions from this because of the small sample involved in the study. If even one pupil from either the X=6 or X=7 group performed poorly or was in the wrong category of working memory capacity, then this might have affected test results. Nonetheless, there appeared to be a general trend which supported the hypothesis that failure occurred when the demand of a question went beyond the individual's working space.

3.6.4 Mechanisms test and the Information Processing Hypothesis

According to Johnstone and El-Banna[36] a pupil with a mental capacity of X=5 should be able to solve problems that had a Z-demand of 5. Similarly, children with an X-capacity of 6 should be successful with questions of Z-demand 6, whilst a pupil of X-capacity 7 should be capable of solving problems of that same value. The results that were obtained from the mechanisms test did not conform exactly to the idealised curves (fig. 2.5) shown in chapter two. Nonetheless, there were distinct similarities, with facility values falling considerably as the demand of the questions increased beyond 5 in the X=5 group and 6 in the other two categories. Figures 3.6, 3.7 and 3.8 show how the facility values varied with Z-demand for each X-capacity group of pupils.

Figure 3.6

The performance of pupils from St. Stephen's High of X=5 in the mechanisms test

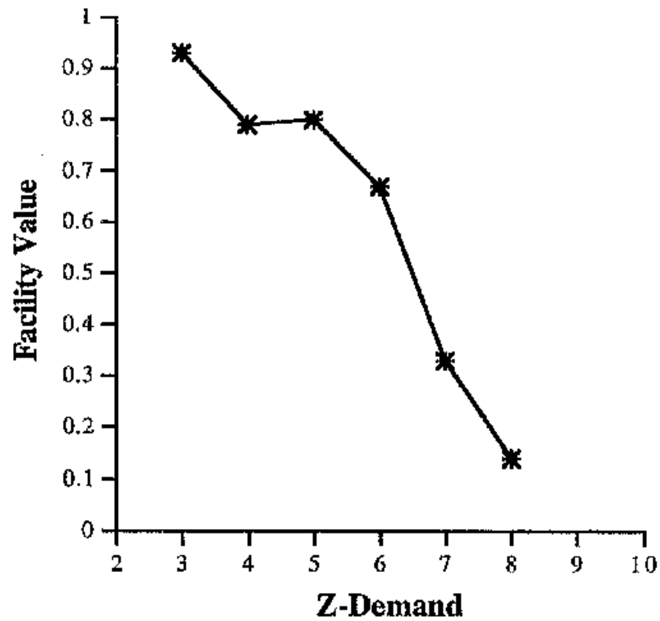


Figure 3.7

The performance of pupils from St. Stephen's High of X=6 in the mechanisms test

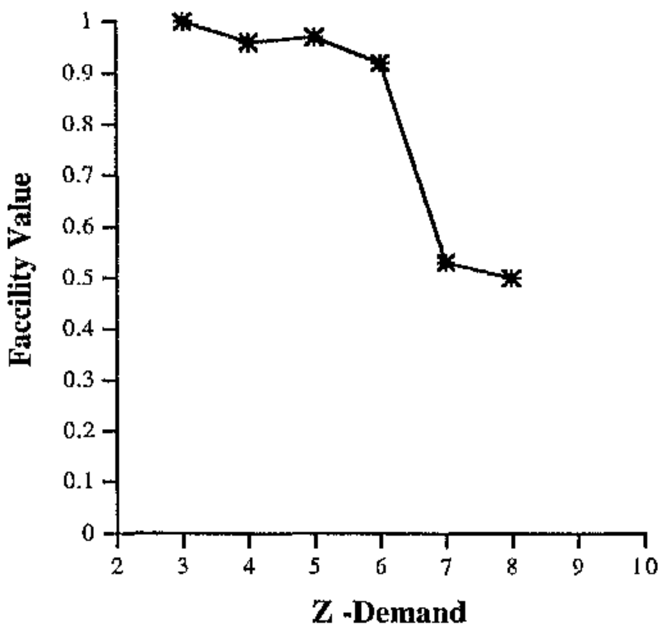
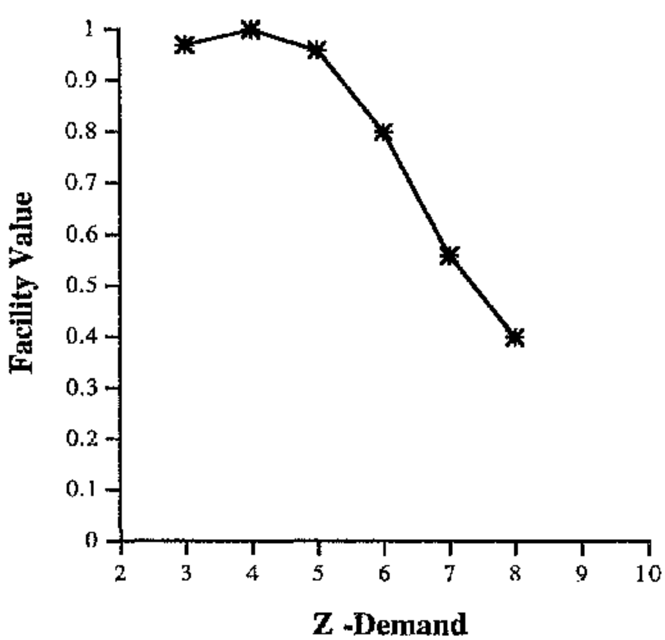


Figure 3.8

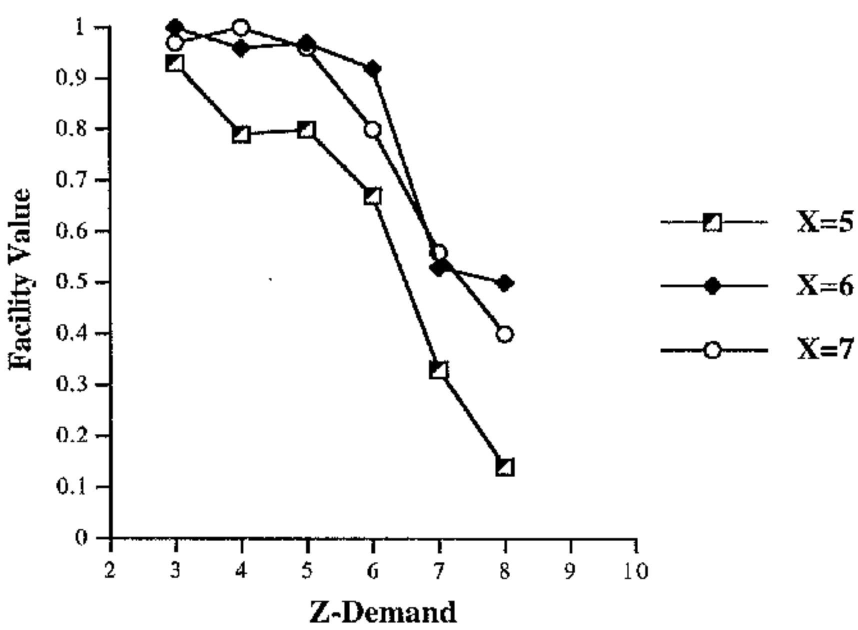
The performance of pupils from St. Stephen's High of X=7 in the mechanisms test



From the graphs, figures 3.7 and 3.8 it appeared that the pupils in the X=6 category have performed slightly better than those of X=7. It is also clear that some members in each group were capable of answering question of Z-demand beyond their working memory capacity. This is probably because they have developed strategies (Y) that reduced the number of thought steps in the questions of higher demand[43]. Figure 3.9 shows the overall pattern in a composite of the three curves.

Figure 3.9

Comparison of the performance of pupils from St. Stephen's High for all three categories of X-space in the mechanisms test



3.7 Summary

The composite of curves (figure 3.9) seemed to indicate that the demand of the questions in the mechanisms test was a limiting factor in the pupils performance. Nonetheless, the X=6 group did better than the X=7 pupils, which raised questions about the different factors, both practical and psychological that might be involved. If the Y-strategies had a significant effect in the results, then how might the technology course be improved. Furthermore, what other abilities did the children possess that separated them in the mechanisms test. The researcher will attempt to answer some of these questions in the chapters that follow.

Chapter Four

Application of an **Information Processing Model** for Learning to the S2 **Technology** course and pupil performance in relation to **X-Capacity**

4.1 The New Sample

Here, the researcher describes some of the changes that were made to the S2 technology course on mechanisms by applying Johnstone's[37] information processing model for learning. Furthermore, the results of a new test on gear and belt driven systems that was taken by pupils from St. Columba's High School in Clydebank during the academic year 1997/98 are analysed. Working memory capacity is also considered, in relation to the demand of the questions from the new test on mechanisms.

4.2 Applying the Information Processing Model

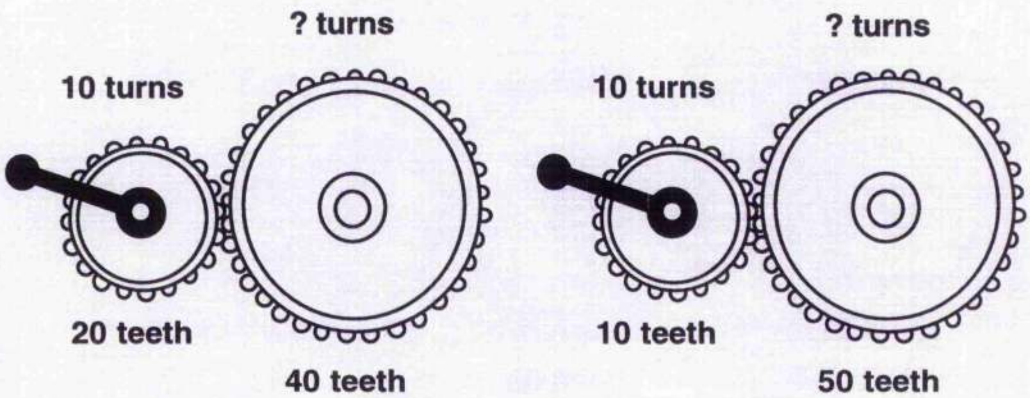
The information processing model shown in figure 2.6 was used to highlight some of the areas in the original mechanisms course thought to be causing confusion and to inform the development of a new course. The three sections of the model used to help improve understanding of the pupils learning difficulties were: the perception filter, the working space and the long term memory.

4.2.1 Perception filter

It was believed[37] that individuals applied the perception filter to select what was thought to be important or interesting from information presented to them. Therefore, it was necessary to remove anything considered irrelevant or confusing from the instruction booklet (see appendix A) and other materials used in the mechanisms course. It had to be said that the original booklet did give directions that were quite easily understood by an experienced individual. Nonetheless, pupils encountered problems in separating the tasks because of the amount of information presented on each page. Further confusion was created as the number of teeth on the illustrated gears did not correspond to the actual gears available in the Fischertechnik kits (see appendix B). Gears that appeared to be of the same size were distinguished by assigning a different number of teeth when calculations were required. This problem is demonstrated in figure 4.1 overleaf.

Figure 4.1

An example of the gear systems illustrated on page 4 of the original mechanisms booklet



4.2.2 Working space

The working space is the cognitive area where information from external sources interacts with that held in long term memory to produce further knowledge and understanding. It is used for holding and manipulating simultaneously and as discussed in previous chapters, is of limited capacity. It has been shown[34] that it was possible to overload this area of the mind by presenting large quantities of information, thus producing tasks that went beyond the learner's mental capacity. When this situation has been established no further learning takes place and only confusion follows. One section of the original booklet (appendix A5) attempted to describe a method of solving the most demanding of the questions in the mechanisms test (appendix C) by cramming the whole explanation onto a single sheet. Therefore, it was thought necessary to reduce the amount of material being presented to pupils on each page. The researcher believed that the demand of the tasks would decrease by reorganising any instructions and presenting them in smaller chunks.

4.2.3 Long term memory

The long term memory interacts with the other parts of the model by informing the perception filter whilst providing information for the working memory. It is also the area in the mind where a large bank of facts are held and new concepts are developed. It is generally accepted[5] that the basis of meaningful learning is the quality and organisation of what the individual already knows. Therefore, it was important that pupils were able to access related facts and concepts during the mechanisms course. This is to say that their existing knowledge should allow them to interpret what was happening whilst involved in tasks. The booklet started by mentioning household goods such as washing machines and video recorders that had moving parts. The majority of children in the study had never seen inside any of these machines before. The blank looks and discussion that followed indicated that this approach had only provided more extraneous information (noise) to deal with. The pupils were not familiar with the Fischertechnik kits that were used in the original course either.

4.3 The New Mechanisms Course

A considerable number of problem areas were identified in the original mechanisms course by applying the information processing model. Nonetheless, some of the ideas it contained were considered to be quite good. For example, pupils were successful in solving the questions of lower demand in the mechanisms test. However, the poor performance when mathematical calculations were required was a major cause for concern. Furthermore, there were no such calculations that involved belt driven systems. The course could have been better used in addressing other aspects from Environmental Studies 5-14[40] that were related to the topic. For example, the ways in which energy is converted in electrically powered machines.

Clearly the original course on mechanisms required a substantial number of adjustments to rectify the areas thought to be causing difficulties for the pupils. The researcher decided to concentrate on three principal strategies to affect these changes and in doing so hoped to enhance the teaching and learning in the course, viz:

- develop a new and more comprehensive booklet (unit);
- review the equipment (Fischertechnik kits) used in the experiments;
- make the course more comprehensive by introducing more sophisticated power driven systems to demonstrate the capability of machines.

4.3.1 The new booklet

The study revealed that a large number of changes were required in the original booklet for the mechanisms course. Therefore, it was decided that it should be replaced with an entirely new version. Nonetheless, the basic content of gear and belt driven mechanisms remained the same. The original method for finding the direction and number of turns in these systems manually was also kept, as pupils seemed to understand this approach quite well. A copy of the new booklet is shown in appendix F. The following points were introduced in the new version of the booklet for the course on mechanisms:

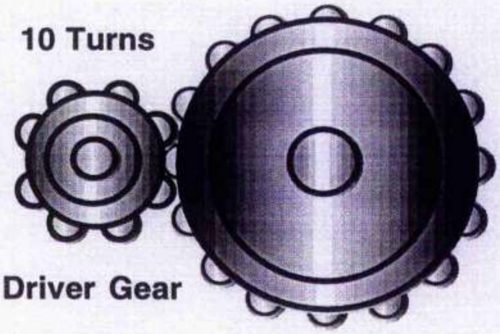
- tasks were numbered, set out in a standard format to provide familiarity and separated by borders;
- the amount of information was reduced on each page and important points were set in **bold** letters;
- illustrations corresponded to the equipment being used where feasible, i.e. pulleys had the same diameters and gears had the same number of teeth;
- pupil's attention was drawn to important points by using symbols (icons), i.e. arrows, balloons, etc;
- the overall appearance was improved by desk top publishing techniques;
- more examples involving mathematical calculations (including belt drives) were given;
- a whole new section showing coloured illustrations of power driven mechanisms that had to be constructed was introduced.

4.3.2 Problems involving mathematical calculations

Pupil's performance in questions of higher demand involving mathematical calculations was poor in all categories of X-space; therefore, this area was given particular attention whilst revising the mechanisms course. In the new booklet the topic on gears began by asking pupils to find the output number of turns in several two gear systems by counting, as in the previous course. However, after doing this they were introduced to a method of solving the same problems mathematically. Four different examples of these calculations were given on separate pages in the new booklet. In the old mechanisms booklet three examples were crammed together on a single sheet. The method used for finding solutions to the problems of higher demand was more or less the same as in the original course. Nonetheless, the steps involved were separated into smaller chunks of information. Numbers considered to be easier for pupils to handle were also used in the first example that had to be calculated mathematically. Figure 4.2 demonstrates the approach taken to explain the relationship that exists between two gears in the kind of systems used in the tasks from the mechanisms course.

Figure 4.2

Approach taken in the New Mechanisms Booklet for calculations involving gears



Firstly, multiply the number of **Teeth** on the **Driver** Gear by the number of turns it made.

Teeth x Turns

8 x 10 = ?

Secondly, multiply the number of **Teeth** on the **Driven** Gear by the number of turns it made.

Teeth x Turns

16 x 5 = ?

The teacher then explained that the relationship could be written in one chunk:

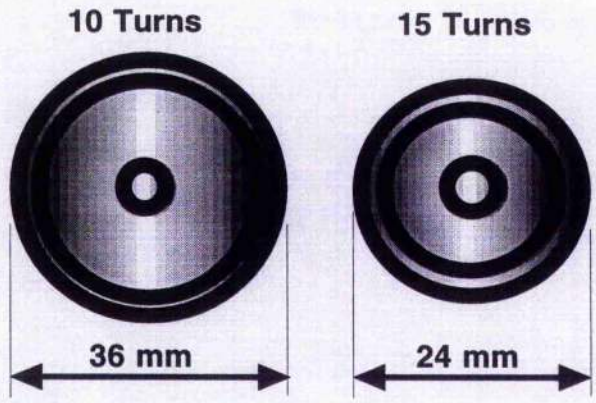
Teeth x Turns (Driver) = Teeth x Turns (Driven)

4.3.3 The Introduction of New Concepts

It was believed that the old mechanisms course had missed out on an ideal opportunity to discuss the energy changes that take place in gear and belt driven systems. Therefore, it was considered necessary to discuss these issues in the new booklet and try to show their effects during the tasks that the pupils were involved in. The original booklet had not demonstrated a method of determining the pulley diameters and number of revolutions mathematically either. This concept was introduced in the new booklet by showing the calculations after the tasks had been carried out manually as in the gears. An example of the approach taken to demonstrate this procedure is shown in figure 4.3.

Figure 4.3

Mathematical calculations involving pulleys in the New Mechanisms Booklet



Firstly, multiply the **diameter** of the **large pulley** by the number of **turns** it made:

$$36 \times 10 = 360$$

Secondly, multiply the **diameter** of the **small pulley** by the number of **turns** it made:

$$24 \times 15 = 360$$

The teacher then explained that the relationship could be written in one chunk:

Diameter x Turns (Driver) = Diameter x Turns (Driven)

4.3.4 The new equipment

The 'Fischertechnik' construction kits (appendix B) used originally, allowed the pupils to build good engineering models for the tasks involved in the mechanisms course. Nonetheless, it was discovered that most of the children taking part in this work had already used similar materials that were supplied by 'LEGO dacta' in primary school. Therefore, the Fischertechnik kits were replaced with LEGO as this was readily available in the school. It was thought that using familiar equipment might reduce the demand of the tasks. Figures 4.4 and 4.5 demonstrate the way this new equipment was set up for pupils to count the number of revolutions in the gear and pulley systems. The LEGO dacta kits that were used in the new mechanisms course can be seen in appendix G.

Figure 4.5

A typical gear system from the new mechanisms course

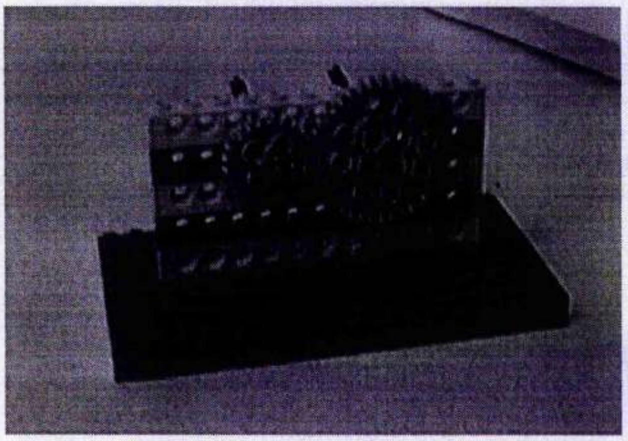
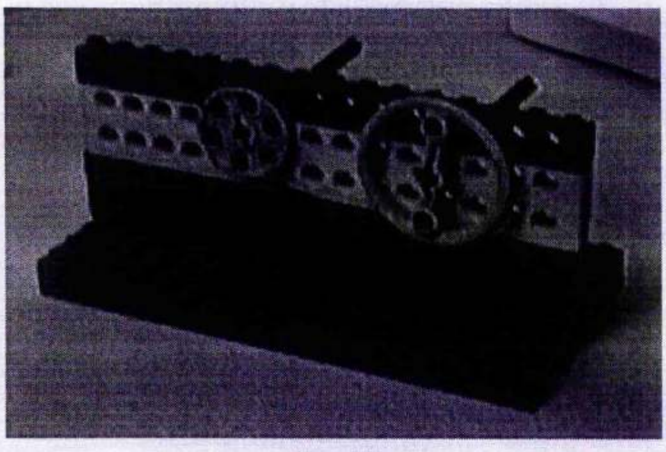


Figure 4.4

A typical pulley system from the new mechanisms course



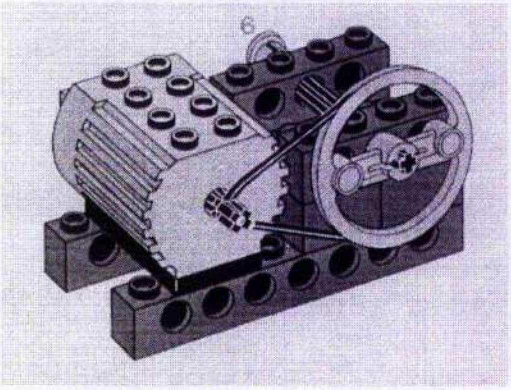
In the original course the number of teeth on the gears in the Fischertechnik kits did not match those illustrated in the booklets. The new booklet showed pulleys of the same diameter and gears with the same number of teeth as those in the LEGO kits. However, the smaller gears had to be magnified so that the teeth could be clearly seen for counting (figure 4.2). This point was explained to the pupils at the beginning of the course.

4.3.5 Introducing power driven mechanisms

The new course involved pupils in the construction of a number of power driven mechanisms. It was thought that they would enjoy this aspect of the work whilst developing a better understanding of the use of gears and pulleys in machines. This also provided the opportunity to discuss the idea of energy changes. Figure 4.6 shows the kind of model that was built during one of the tasks from new course.

<u>**Figure 4.6**</u>

A power driven mechanism from the new course



4.4 Teaching the New Course on Mechanisms

The new course on mechanisms was presented to 105 secondary school pupils from St Columba's High School during the third term of second year (S2). It was taught over six or seven 55 minute periods. Most of the time was spent by pupils working in pairs whilst carrying out the tasks. The final period was used for reinforcement of the concepts covered during the course. This involved the teacher going over a number of examples on the board. The following week pupils were given a test that consisted of questions on gear and belt driven systems.

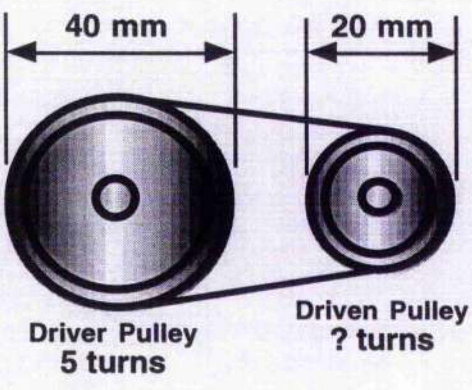
4.4.1 The new test on mechanisms

The new mechanisms test, shown in appendix H, comprised of 16 questions that involved various combinations of gear and belt driven systems. The questions were analysed into thought steps which suggested a Z-demand that ranged from 3 for the easiest to 8 for the most difficult. Questions 12 and 15 from the new mechanisms test have been illustrated in figures 4.7 and 4.8 respectively, to demonstrate the procedure used to determine the number of thought steps in each case. A complete analysis of the questions from the new mechanisms test can be seen in appendix I.

<u>Figure 4.7</u>

Question 12 from the New Mechanisms test considered to contain 6 thought steps

Q.12



How many times will the **Driven** pulley turn?

The approach taken by the researcher to determine the maximum number of thought steps required by the least able pupil to solve question 12 from the new mechanisms test is set out below:

Q.12 6 thought steps

1. Assess the system and note the number of turns made by the driver pulley.

2. Consider the diameter of each pulley.

3. Recall method of calculation: Dia x Turns (driver) = Dia x Turns (driven).

4. Dia x Turns (driver) = 40 x 5 = 200.

5. Dia x Turns (driven) = 20 x ? = 200

6. Driven pulley = **200/20 = 10 turns**

It is possible that a more advanced pupil might use a previously learned technique that involved fewer mathematical calculations, thus reducing the steps to solve this problem:

1. Assess the system and note the number of turns made by the driver pulley.
2. Compare the diameters and see that the driver pulley is twice the size of the driven pulley giving a ratio of 2:1.
3. Through mental arithmetic, calculate that the driven pulley must turn twice as many times as the driver pulley, i.e. **10 turns**.

The second approach is much less demanding because, as mentioned in chapter three, the experienced pupil has probably mastered the technique of grouping the steps into smaller[32] chunks of information. This, of course, makes the problem much easier to work with because they do not have to apply their full X-capacity to reach the solution.

Another method used to solve this problem was to write an algorithm that gave the answer in a single step. Here, it was possible that pupils were employing Y-strategies[36] that were developed in mathematics or science, as this approach was not shown in the technology class. For example, one girl wrote the following statement beside her calculations for question 12:

> *"I found my answer by multiplying the diameter of the driver pulley by the number of turns it made, then dividing by the diameter of the driven pulley"*

Diameter x Turns(driver)/ Diameter(driven) = Turns(driven)

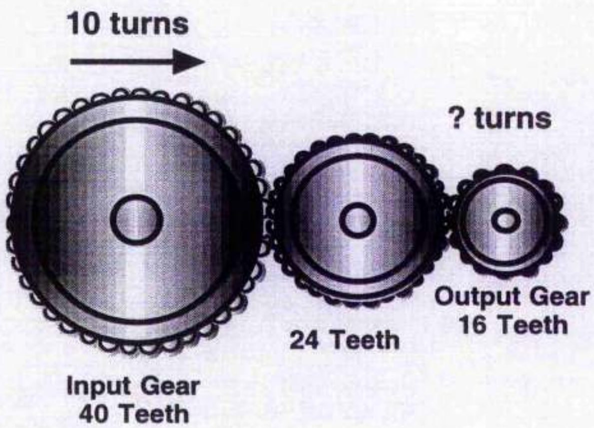
(40 x 5)20 = 10 turns

Question 15 from the new mechanisms test, shown in figure 4.8, involved a three gear system that was considered to have a Z-demand equal to 8.

Figure 4.8

Question 15 from the New Mechanisms test considered to contain 8 thought steps

Q.15



How many times will the **Output** gear turn?

The approach taken by the researcher to determine the maximum number of thought steps required by the least able pupil to solve question 15 from the new mechanisms test is set out below:

Q.15 8 thought steps

1. Assess the system and note the number of turns made by the input gear.
2. Consider the affect the middle (idler) gear has on the speed of the output gear.
3. Remember that the idler gear does change the speed in the system.
4. Compare the number of teeth on the input and output gears.
5. Recall the method of calculation: Teeth x Turns (input) = Teeth x Turns (output)
6. Teeth x Turns (input) = 40 x 10 = 400
7. Teeth x Turns (output) = 16 x ? = 400.
8. Output gear = **400/16 = 25 turns.**

As with the previous problem (figure 4.7) it was thought that an experienced individual might use a much less demanding strategy in solving the above question (figure 4.8):

1. Assess the system and note the number of turns made by the input gear.
2. Remember that the idler gear can be ignored when calculating the speed of the output gear.
3. Compare the number of teeth on the input and output gears.
4. Recall method of calculating: Teeth x Turns (input) = Teeth x Turns (output)
5. Transpose equation: Teeth x Turns (input)/Teeth(output) = Turns (output)
6. **(40 x 10)/16 = 25 Turns**

4.5 X-Capacity versus Pupil Performance in the New Mechanisms Test

The digit span test involving dates (table 3.1) was applied to the new sample of 105 pupils from St. Columba's High School to ascertain their working memory capacities. This was then compared with their performances in the new mechanisms test to try to determine whether or not any relationship existed between the two scores. It was hoped that all categories of X-space would achieve better results than the pupils from St. Stephen's High School in the questions of greater Z-demand. A comparison between the two schools performance in the mechanisms tests might allow the researcher to assess the effectiveness of the new course in improving the learning in this curriculum area.

4.5.1 Arranging the new sample into X-capacity categories

The method applied in the previous chapter (table 3.2) was used to divide the new sample into three distinct categories of working memory capacity, viz: low, intermediate and high. Pupils who scored 5 and below were considered to be of low X-capacity. Those who scored 6 were thought to be of intermediate X-capacity and pupils who scored 7 or above were thought to be of high X-capacity. Table 4.1 overleaf shows the working space groups that were established from the new sample's performance in the dates test.

Table 4.1

The working space groups for pupils from St. Columba's High School

Groups (X Space)	Number of pupils
X = 5	79
X = 6	13
X = 7	13
Total (N)	105

4.5.2 Comparison of results

A comparison was made between the pupil's performance in the new mechanisms test and the psychological test for X-capacity by determining the facility values for the individual groups. These results are shown in table 4.2 below.

Table 4.2

The facility values (F.V) for the questions of different Z-demand in the New mechanisms test related to the pupils from S.t Columba's High X-capacities

Z-demand	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8
X=5	0.93	0.82	0.73	0.74	0.59	0.46
X=6	0.92	0.92	0.92	0.92	0.79	0.77
X=7	0.92	0.88	0.82	0.94	0.95	0.92
Questions	Q.1a,1b.2a,2b.	Q.3,4,5,6.	Q.7,8a,8b.	Q.9,11,12,16.	Q.10,13,14.	Q. 15

Table 4.2 suggested that pupils of capacity X=7 had performed better in questions of higher Z-demand (Z>5) than those of X=5 and 6. It also showed that pupils of capacity X=5 had not done as well as those of X=6 in the questions of greater complexity. Although there appeared to be a general downwards trend for pupils of capacity X=5, that was in keeping with the information processing hypothesis[36], they had still maintained a facility value of 0.74 for questions of Z=6. The other two groups had facility values

greater than 0.7 for question 15 (figure 4.8) that had a Z-demand of 8. It is possible that pupils have correctly answered questions with a Z-demand greater than their working memory capacities because they have employed Y-strategies developed during the mechanisms course or in maths or science classes. However, as with the previous sample (table 3.2) it was difficult to draw any conclusions from these results because of the small numbers of pupils who were thought to be of X-capacities 6 and 7. Figures 4.9, 4.10 and 4.11 show how the facility values varied with Z-demand for each category of X-space.

Figure 4.9

The performance of pupils from St. Columba's High of X=5 in the New mechanisms test

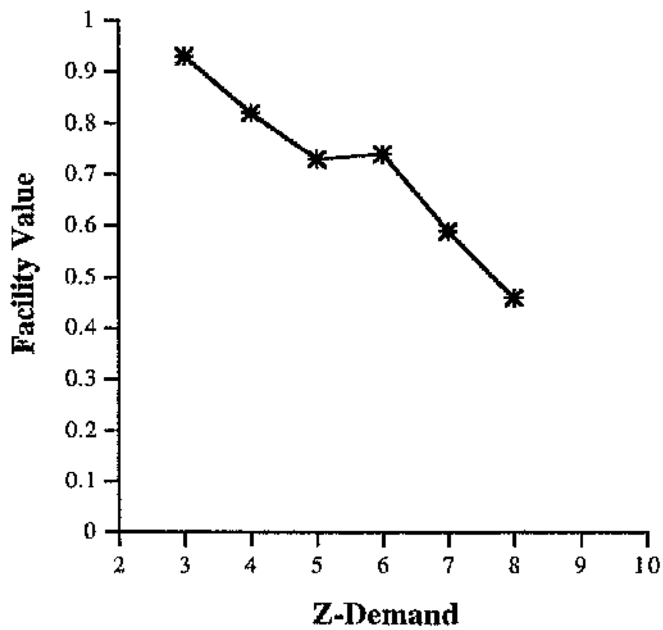


Figure 4.9 demonstrates a steady fall in facility value until questions of Z=5 was reached, then quite a sharp fall beyond Z=6. Although the information processing hypothesis[36] predicts that individuals of X=5 would fail suddenly beyond a Z-demand of 5, this is still fairly close the expected curve. Furthermore, pupils of low working memory capacity appeared to be performing reasonably well with the questions of greater complexity. The poor achievement of the X=5 group from St. Stephen's High School (table 3.3) in the more demanding questions from the original mechanisms test had caused some concern.

Figure 4.10

The performance of pupils from St. Columba's High of X=6 in the New mechanisms test

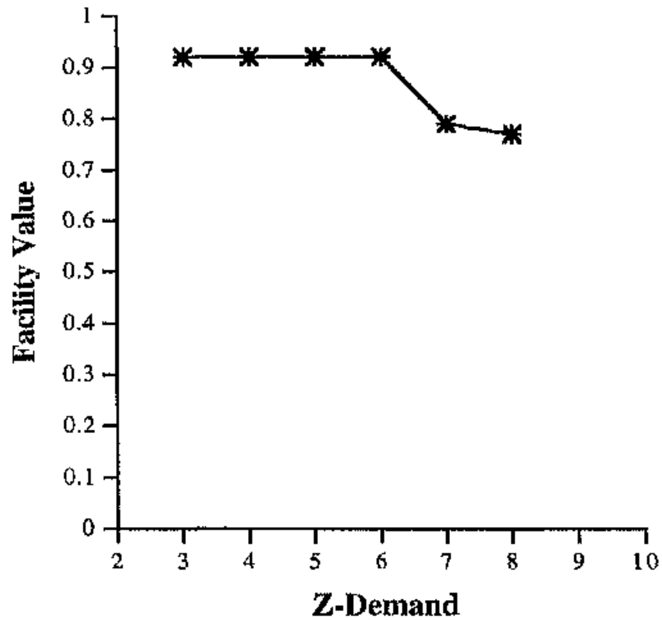
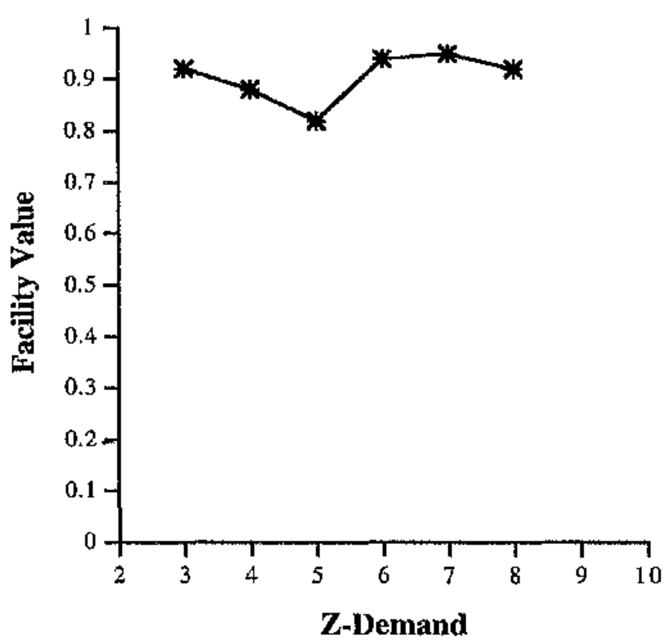


Figure 4.11

The performance of pupils from St. Columba's High of X=7 in the New mechanisms test

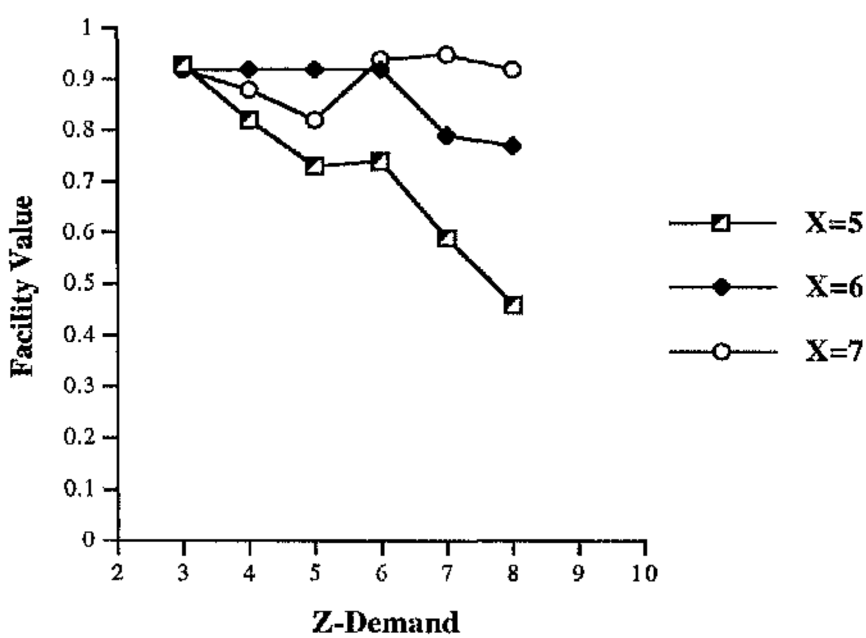


Although figure 4.10 shows a straight line until Z=6 is reached, the curve does drop characteristically at that point. Nonetheless, unlike the idealised graph (figure 2.5) it does not descend rapidly to zero, but only goes down to a facility value of 0.77. The pupils of high working memory capacity have coped extremely well in the new mechanisms test with only a slight dip at questions of Z=5. It is possible that there may have been some discrepancy in the way that one of these questions was analyses for its thought steps.

The overall performance of pupils in the new mechanisms test is perhaps made clearer by considering the composite of the three curves shown in figure 4.12 below.

<u>Figure 4.12</u>

Comparison of the performance of pupils from St. Columba's High for all three categories of X-space in the New mechanisms test



4.6 The Pupils Results from Both Samples

The pupils performance in each of the different categories of X-space from both samples were compared by considering the graphs of facility value against Z-demand separately. These plots can be seen in figures 4.13, 4.14 and 4.15 overleaf.

Figure 4.13

Comparison of the performance of pupils from both samples for X=5 against the Z-demand of the questions from the mechanisms tests

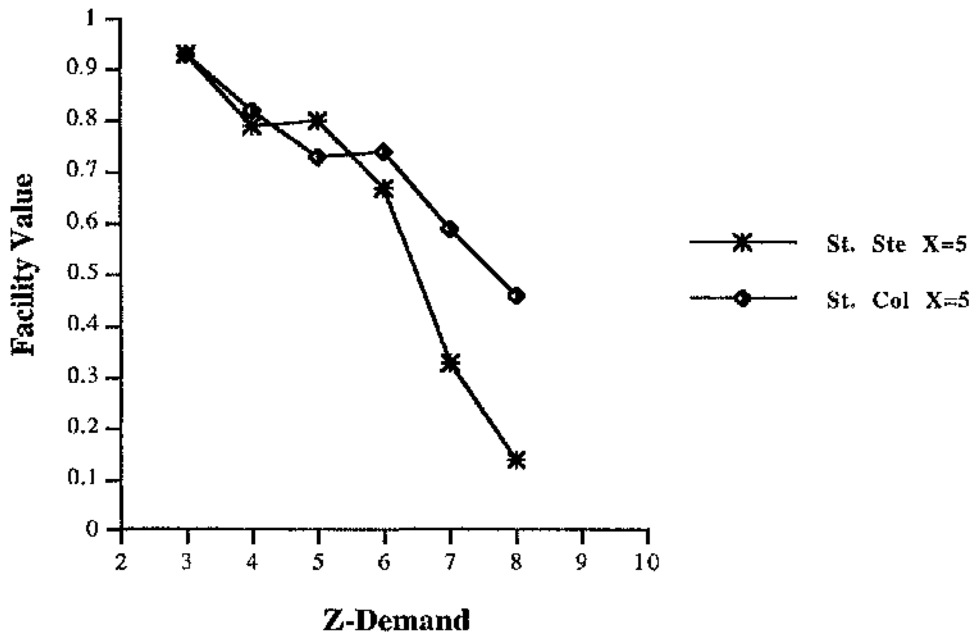


Figure 4.14

Comparison of the performance of pupils from both samples for X=6 against the Z-demand of the questions from the mechanisms tests

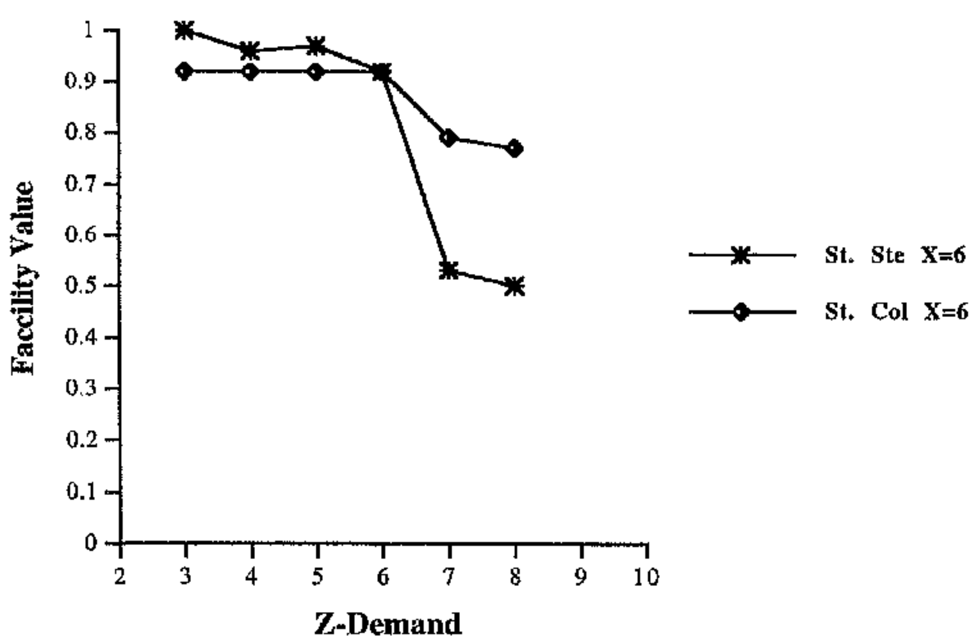
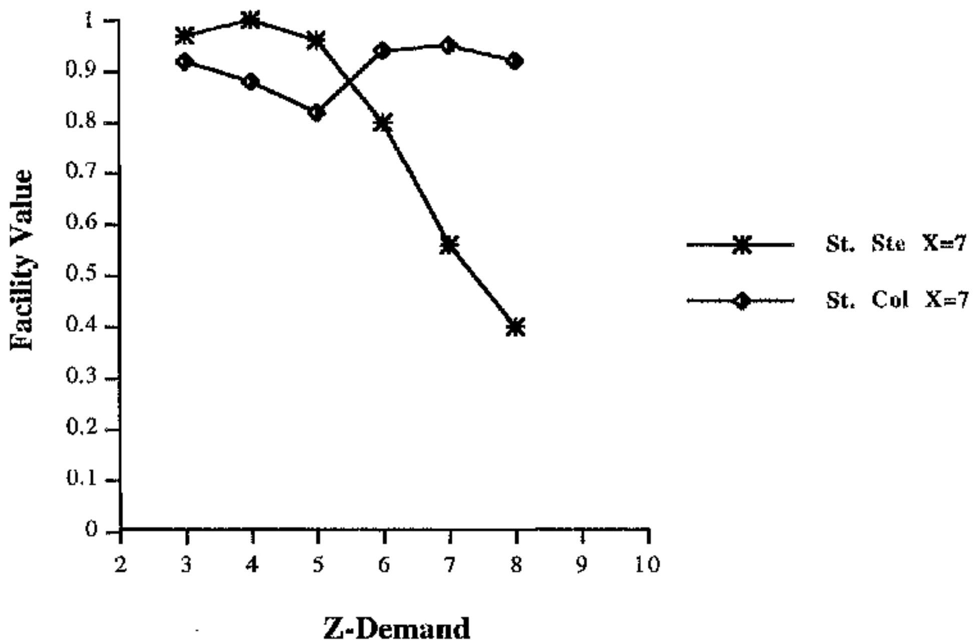


Figure 4.15

Comparison of the performance of pupils from both samples of X=7 against the Z-demand of the questions from the mechanisms tests



These plots showed that the pupils from St. Columba's High had achieved better results in the questions of greater Z-demand that those from St. Stephen's High in all three categories of X-space. Although there were many difference in the circumstances involved during the teaching of these courses; in each case the types of questions being asked were of a similar nature and the approach taken to determine the Z-demand was more or less the same. Therefore, it is possible that the improvements made to the original course may account for the difference in pupil performance.

4.7 Summary

The application of the information processing model[37] appeared to have helped in improving the learning in the mechanisms course. It is also possible that pupils had developed Y-strategies that reduced the Z-demand of the questions in the test on gear and belt drives. Nonetheless, other psychological factors such as the ability to attend to important information and disregard the irrelevant could also affect pupil performance. Therefore, these aspects will be addressed in the following chapter.

Chapter Five

The application of **Field-Dependence/Field-Independence** and **Mental Capacity** in relation to pupil performance in **Technology**

5.1 The Nature of Field-Dependent/Field-Independent Cognitive Styles

The theory on field-dependent and field-independent cognitive styles originated from Witkin's[45] laboratory investigations that involved a study of human personality and perception. Perceptual processes were thought to be central in determining an individual's designated cognitive style. Perception was defined as:

> "a response of living organisms to their environments by way of focussed or integrative recognition of what the environment offers." (Witkin[45])

Witkin developed an interest in human perception during the years of World War II when he carried out a large number of experiments in this area. His early work involved several projects related to the individual's capacity to establish the vertical from a tilted chair or a sloping room. The first tests attempted to ascertain the mental factors responsible for the maintenance of correct orientation toward the upright in space. However, in those days of war the idea of looking for distinctions within perceptual processes, tended to focus on determining the ability to detect camouflage or to evaluate a difficult terrain, on which an aircraft might make a safe landing. Nonetheless, the wider issues concerned with personality in relation to the integrative processes of making contact with the environment through perception, have been vigorously investigated by many theorists over the years since Witkin's initial studies.

5.1.1 Psychological differentiation

An important step in the development of the work of Witkin et al[19] was the formulation of the theory of psychological differentiation. Here, differentiation refers to the complexity of structure of the psychological system in which an organism has to function. One particular aspect of the differentiation theory is the idea of segregation of self from the outside world. This is where boundaries are set up between the person and their immediate environment i.e. people, places and things. Each individual was thought to posses a level of psychological differentiation that related directly to the degree of 'self-nonself' segregation they exhibited. Therefore, it might be concluded that a greater self-nonself segregation went along with greater psychological segregation. It seemed that the self-nonself segregation aspect of differentiation was the main factor in determining field-dependent and field-independent cognitive styles.

5.1.2 Definition of field-dependence/independence

Witkin[19] suggested, that field-dependent individuals were more likely to rely on external frames of reference when handling information, than those considered to be field-independent. Field-independent responses tended to be governed by internal frames of reference and were not generally affected by social cues. Apparently, field-dependents took greater account of other people's opinions when forming views, than field-independents. This implied that field-dependent individuals had attributes that might be useful with respect to interpersonal skills, i.e. building good human relationships.

When internal referents were not available field-dependent people were inclined to respond to the dominant properties of a field presented to them. On the other hand, the field-independent person was capable of 'restructuring' a field by breaking it up into separate parts or organising a field that lacked inherent structure. This operation was called restructuring because it required the field-independent person to make a number of changes to the field or to 'go beyond the information given' - rather than religiously following it, as it stood. Witkin[19] attempted to define the main characteristics of the field-dependent/independent individual as:

> "An individual who can easily 'break up' an organised perceptual field and separate readily an item from its context, is a field-independent individual, whereas the individual who can insufficiently separate an item from its context and who readily accepts the dominating field or context would be defined as a field-dependent individual." (Witkin[19]).

It has been demonstrated[19] that field-independent individuals were more inclined to use cognitive restructuring strategies in problem solving situations than their field-dependent counterparts. For example, the field-independent individual was thought to be more competent with tasks that required some important item to be taken out of the context in which it was presented, then restructuring the task so that the item was used in a different context to reach a solution. One of the restructuring dimensions associated with field-independence was known as 'disembedding ability' or 'flexibility of closure'. Witkin used what he called 'the embedded figure test' to establish this cognitive phenomenon. Here, the individual was required to locate a previously seen simple geometric shape hidden within a larger more complex figure. It was thought that the relationship which existed between an individual's success in the tests for perception of the upright and disembedding ability could be associated with competence in cognitive restructuring.

Since Witkin's early work[45] a number of psychologists have undertaken studies concerned with field-dependence/independence in relation to other cognitive factors such as intelligence, learning and memory. It was thought that field-dependence/independence had affected individual performance in tasks of high information processing demand and that these tasks could be used to stress the differences that existed between certain cognitive styles. Nonetheless, it was important to realise that the designation of field-dependence/independence did not imply that two distinct categories of human beings existed, but reflected a continuum from one class of perception to the other.

5.2 Field-Dependence/Independence and Intellectual Functioning

Goodenough and Karp[46] attempted to explain why field-dependent learners might achieve poorer IQ scores on the Wechsler Intelligence Scale for Children (WISC) than field-independent learners. In this research, 55 boys and 25 girls aged between 9 and 12 years were involved a number of tests for field-dependence/independence and intelligence. The results supported the hypotheses that some intellectual and perceptual tests had a common requirement for overcoming an embedding contexts. Furthermore, that the relationship found between measures of field-dependence/independence and standard intelligence tests were based on this common factor.

In a study of literature, Goodenough asserted[47] that the field-dependent individual had a relatively 'global' cognitive style that meant a prevailing field governed their learning experience. Being dominated by the most salient aspects of the stimulus, these types were forced to accept the organisation of a field as it was presented to them. Conversely, the field-independent individual possessed an 'analytical' cognitive style that allowed the restructuring of a field where necessary.

It appeared that field-independent people were inclined to adopt a 'participant' role whilst engaged in the learning process. This was taken as another indication of their greater cognitive restructuring ability. On the other hand, field-dependent people tended to take on the role of 'spectator' during learning experiences. For example, hypothesis testing was considered to be more characteristic of field-independent than field-dependent individuals.

Goodenough[47] concluded that many theorists had suggested that field-dependent and field-independent individuals differed more in the way learning or memory occurred, than in how effective these processes were. This theory was disputed by a number of psychologists.

5.3 Field-Dependence/Independence - Learning and Memory

Davis and Frank demonstrated[48] that field-dependence/independence had a number of implications for learning and memory. The results of a study involving combinatorial tasks suggested that field-independent students performed more efficiently in testing hypothesis than field-dependent students. It was thought that memory processes accounted to some extent for the differences in performance. The researchers believed that the field-independent students were using either a different or 'more effective' encoding strategy when solving problems.

The paper[48] discussed the hypothesis that the performance of field-dependent students might be poorer than field-independent students when the demand of tasks increased the amount of information being processed in working memory. This idea was based on

Pascual-Leone's theory[17] that field-dependent individuals were unable to use their full M-space. The hypothesis was consistent with the researchers findings involving students in concept learning tasks that placed a high demand on working memory capacity. It was believed that these tasks had emphasised differences in the performance of field-dependent and field-independent students.

It was shown[48] that field-independent students were more effective than field-dependent students in recalling information from short term memory when the information load was high or if interference was present. However, when the task demand was low and no interference existed there was no apparent difference in performance. The researchers believed that the likely explanation for this phenomenon was that the field-independent learner had more efficient memory processes than the field-dependent learner. Therefore, Goodenough's hypothesis[47] that the difference between the two categories was more in the way learning or memory took place than in the effectiveness of the processes, was not accepted as it stood. The theorists[48] concluded that field-dependent and field-independent individuals differed not only in the cognitive strategies they applied to tasks, but also in the efficiency of their memory processes.

It was suggested, in another study[49] involving 180 undergraduates in tests on disembedding ability and memory, that field-dependent students processed information more rigidly than field-independent students. Apparently, this resulted in inefficient use of cues to trigger the recall of previous information. Frank believed that the cognitive restructuring capabilities of field-independent students gave an indication of their greater information processing flexibility. The results of the study seemed to confirm the hypothesis.

5.4 Field-Dependency a Limiting Factor in Processing Information

El-Banna[50] demonstrated that an overload of the student's working memory capacity resulted in poor performance in chemistry questions. It was believed that one of the factors causing this situation was the student's inability to separate 'signal' from 'noise' which made the memory processes inefficient. In effect, this meant that irrelevant data took up needed holding space in the field-dependent individual's already limited working memory capacity. Under such conditions, failure generally occurred when the Z-demand of the chemistry questions was close to the student's full X-space.

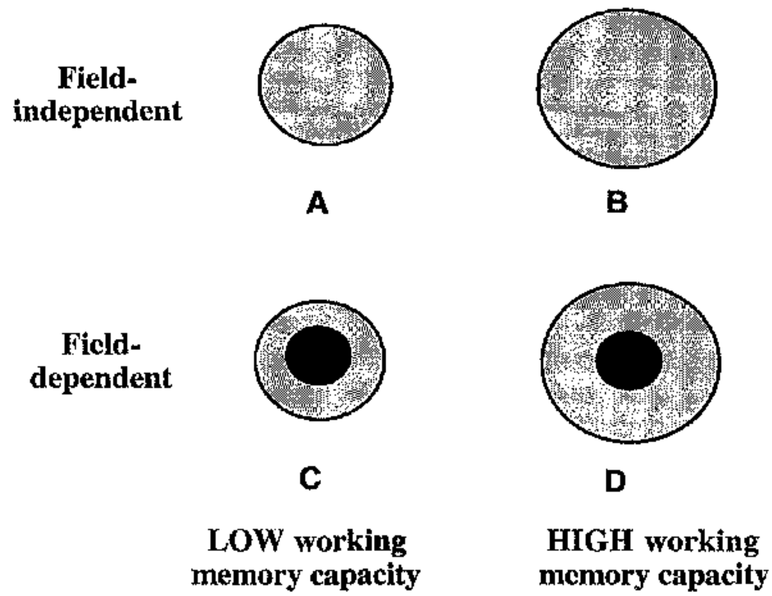
Al-Naeme[51] also considered the interaction of working memory capacity and field-dependence/independence against student performance in chemistry tests. It was thought that individuals who experienced difficulty in selecting relevant information from complicated stimuli would not be as successful in solving problems as those who could be selective. The results of this work showed that a relationship existed between working memory capacity, field-dependence/independence and performance in the chemistry tests. Apparently, students of low working space were more inclined to be field-dependent than those of high working space and performed less effectively in the chemistry questions of greater Z-demand. This was explained as low X-capacity field-dependent students could not afford to waste any of their limited working memory space on extraneous noise. Therefore, failure occurred even before the Z-demand of the tasks reached their full X-capacity.

The researcher[51] believed that high X-space field-dependent students possessed spare capacity to deal with irrelevant information when the Z-demand of the tasks was within their working memory space. This accounted for their superior performance in the chemistry tests compared to the low capacity field-dependent students. The study implied that low capacity field-independent students could perform as effectively as the high capacity field-dependent students in the chemistry tests. This was considered to be a consequence of their more efficient memory processes. It was also shown that when the demand of the questions was low no difference was present between the various categories of students undertaking the chemistry tests.

The relationships that were thought to exist between efficiency of performance in working memory and degree of field-dependence/independence was illustrated diagrammatically by Al-Naeme[51] and is represented in figure 5.1 overleaf.

Figure 5.1

The effects of 'noise' on X-capacity and field-dependence/independence



 Working memory space available for information processing.

 Working memory space taken up by 'noise' and therefore not available for information processing.

(From, Al-Naeme[51])

As can be seen from figure 5.1 the amount of working memory space available for processing information was thought to be reduced considerably by extraneous noise with field-dependent individuals (C and D). The X-space accessible to field-independent low X-capacity students (A) was almost the same as the field-dependent high X-capacity students (D). The high X-capacity field-independent individuals (B) were thought to be the most efficient information processors of all the categories.

5.5 Measurement of Field-Dependence/Independence

The Centre for Science Education at the University of Glasgow developed a new[50] version of Witkin's[24] group embedded figure test to determine an individual's degree of field-dependence/independence. The hidden figure test (H.F.T), as it was called, comprised of 20 complex figures, plus 2 additional introductory items that were included as examples. A selection of simple geometric target shapes were presented at the back of a booklet that was designed for the H.F.T. This was a group administered test that required individuals to identify one of the target shapes which was embedded within each of the complex patterns, by tracing its outline with a pen or pencil. A maximum score of twenty points was available for the test; with one point being given for each correctly identified target shape. A sample of the H.F.T booklet, along with solutions, can be seen in appendix J.

The conditions for carrying out the H.F.T were as follows:

- a total of 20 minutes were allowed for the test;
- tasks should be addressed in the order in which they appeared in the H.F.T booklet;
- the target shapes must be traced in the same size, proportions and configuration as they appeared in the booklet;
- only the required target shape should be traced, ignoring any of the other shapes in each complex pattern;
- no rulers, or any other measuring device should be used to help identify the target shapes;
- the page showing the selection of target shapes could be consulted as often as necessary during the test.

5.6 The H.F.T Applied to the Pupils from St. Stephen's High School

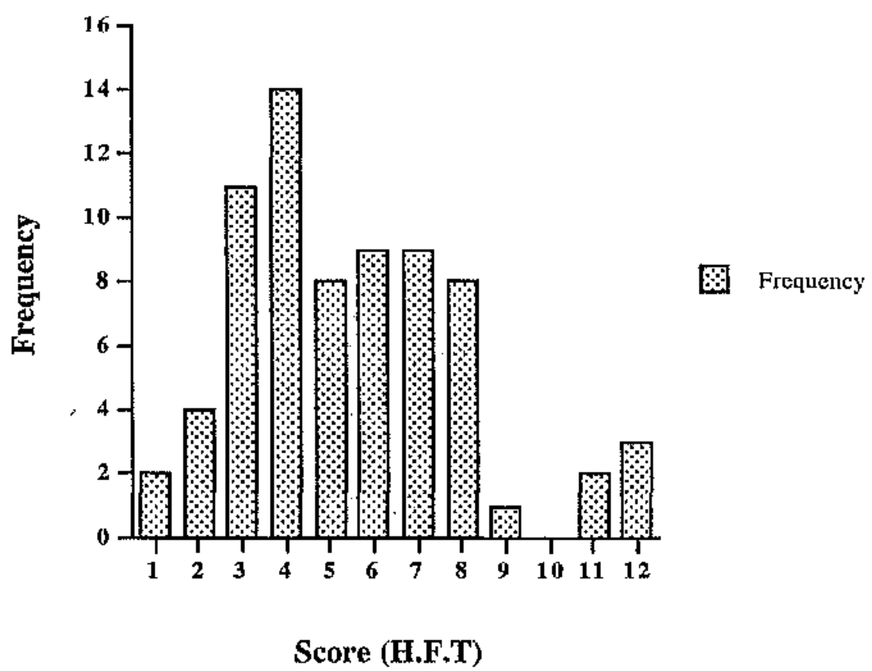
The hidden figure test was applied to the sample of 71 pupils from St. Stephen's High School. The criterion used by a number of researchers[51,52,53] who studied at the Centre for Science Education was used to create the categories of field-dependence/independence. Pupils who scored less than a half standard deviation (S.D) below the mean (m) were considered to be field-dependent (F.D<m-0.5S.D). Those scoring more than one half standard deviation above the mean were classed as field-

independent (F.IND>m+0.5S.D). The pupils whose scores fell within plus or minus one standard deviation of the mean were labelled as field-intermediate (F.INT=m± 0.5 S.D). A graph was plotted to demonstrate the distribution of the hidden figure test total scores, see figure 5.2 below.

Figure 5.2

The distribution of the H.F.T total scores for pupils from St. Stephen's High School N=71

(Mean = 5.5, S.D = 2.6)



5.6.1 Classification of sample from St. Stephen's High

From the distribution of the hidden figure test total scores the sample from St.Stephen's High School were divided into three distinct categories, viz: field-dependent (F.D), field-intermediate (F.INT) and field-independent (F.IND). Table 5.1 overleaf shows how the pupils were separated into the different groups.

Table 5.1

The Classification of the pupils from St. Stephen's High into F.D/F.IND Learning Style Categories

GROUP	NUMBER OF PUPILS
Field-Dependent	31
Field-Intermediate	17
Field-Independent	23
Total	71

5.6.2 F.D/F.IND against X-capacity for St. Stephen's High sample

The researcher sub-divided the sample from St. Stephen's High according to the pupil's previously obtained X-capacity groupings and field-dependent/independent learning styles. This has been represented in table 5.2 for the purpose of making comparisons.

Table 5.2

The pupils from St. Stephen's High F.D./F.IND Learning Styles versus their X-Space (N=71)

GROUP	F.D	Fraction of Group	F.INT	Fraction of Group	F.IND	Fraction of Group	TOTAL
X=5	23	0.53	9	0.21	11	0.26	43
X=6	5	0.42	5	0.42	2	0.16	12
X=7	3	0.19	3	0.19	10	0.62	16

Table 5.2 implied that the majority of X=5 pupils were field-dependent and those of X=7 were mainly field-independent. The X=6 group were chiefly distributed between the field-dependent and field-intermediate categories. The results suggested that pupils of high working memory capacity were inclined to be field-independent and those of low working memory capacity were likely to be field-dependent.

5.7 Comparison of F.D/F.IND, X-Space and the Mechanisms Test

It was thought that the field-independent pupils of high working memory capacity were more likely to achieve better marks in the mechanisms test than those who were field-dependent with low working memory capacity. Therefore, a comparison of these three variables was illustrated in Table 5.3.

Table 5.3

The F.D/F.IND Learning Styles and X-space classifications versus the mean scores(%) in the Original Mechanisms test for the St. Stephen's High pupils

GROUP	F.D	Mean Score(%)	F.INT	Mean Score(%)	F.IND	Mean Score(%)	TOTAL
X=5	23	44	9	48	11	70	43
X=6	5	58	5	78	2	86	12
X=7	3	63	3	64	10	74	16

Table 5.3 suggested that a relationship existed between F.D/F.IND, X-space and the mean scores in the mechanisms test. There appeared to be a steady improvement in the pupil's marks as they moved across the table from field-dependence to field-independence in all X-space groups. The X=7 field-independent mean scores were higher than the X=5 field-dependent groups. The X=6 field-intermediate and field-independent pupils achieved better results than their X=7 counterparts, which was not as expected. However, the sample numbers in these two groups were quite low which means that one or two poor scores could affect the results considerably. Interestingly, the X=5 field-independent pupil's mean scores were very close the X=7 field-dependents. This was in keeping with Al-Naeme's[51] suggestion that these two groups would perform similarly in exams, because of the space taken up by noise in the X=7 field-dependent pupil's working memory.

Scatter diagrams for the three variables: F.D/F.IND, X-space and mechanisms test were plotted in addition to calculating the Pearson correlation coefficient (r) between the scores. These graphs have been exhibited in figures 5.3, 5.4 and 5.5 overleaf.

Figure 5.3

H.F.T scores versus X-capacity for pupils from St. Stephen's High (N=71]

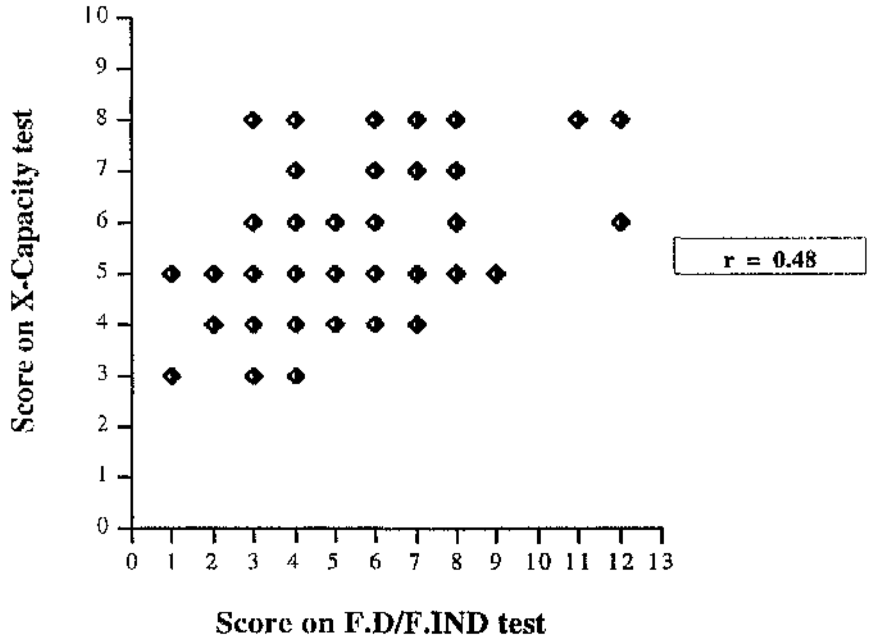


Figure 5.4

H.F.T versus Mechanisms test scores for pupils from St. Stephen's High (N=71)

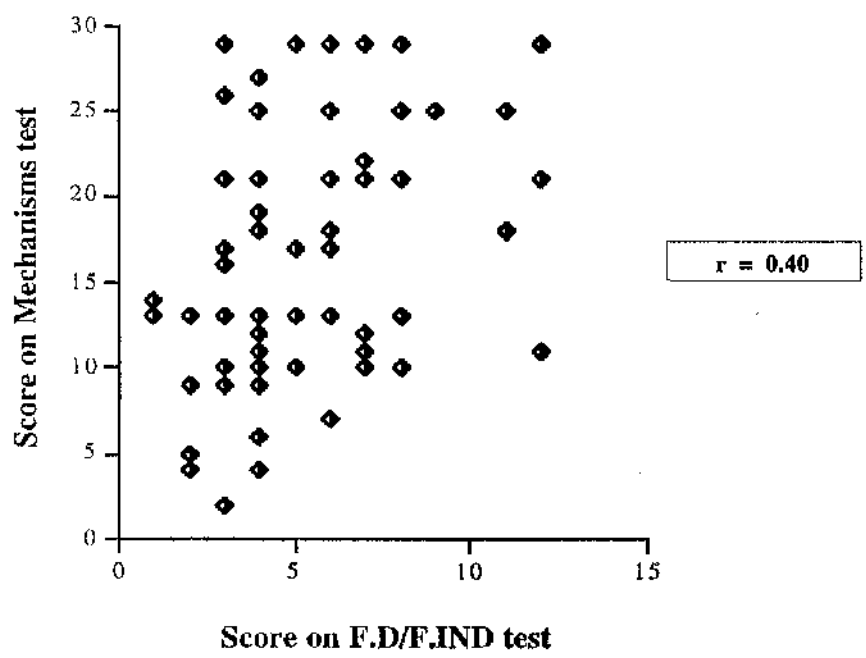
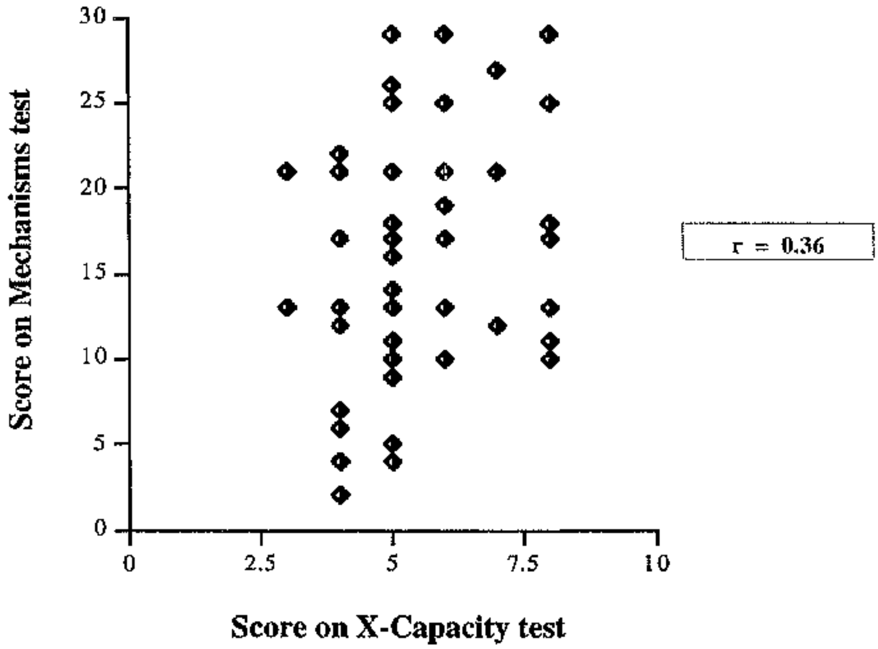


Figure 5.5

X-capacity versus Mechanisms test scores for pupils from St. Stephen's High (N=71)



There was a positive correlation between F.D/F.IND and X-space (r=0.48) that was significant at the 0.1% level. The scores on the mechanisms test also correlated with F.D/F.IND (r=0.40) and X-capacity (r=0.36) at the 0.1% level of significance.

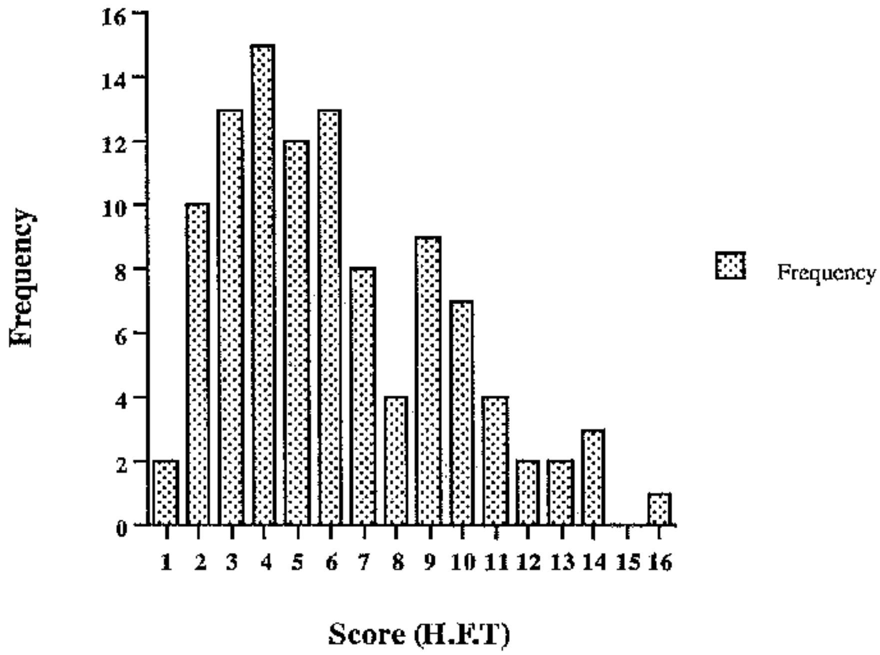
5.8 The H.F.T Applied to Pupils from St.Columba's High School

The hidden figure test was applied to the sample of 105 pupils from St.Columba's High School. The previously described criterion[51,52,53] was used to create the categories of field-dependent/independent learning styles. The distribution of the H.F.T total scores for the sample from St.Columba's High School is shown in a histogram in figure 5.6 overleaf.

Figure 5.6

The distribution of the H.F.T total scores for pupils from St. Columba's High N=105

(mean=6.2, S.D=3.4)



5.8.1 Classification of sample from St. Columba's High

As described above (table 5.1), the sample from St. Columba's High were divided into three categories of field-dependent, field-intermediate and field-independent. Table 5.4 shows how the pupils were separated into the different groups.

Table 5.4

The Classification of the pupils from St. Columba's High into F.D/F.IND Learning Style Categories

GROUP	NUMBER OF PUPILS
Field-Dependent	40
Field-Intermediate	33
Field-Independent	32
Total	105

5.8.2 F.D/F.IND versus X-Space for the St. Columba's High pupils

The researcher sub-divided the pupils from St. Columba's High according to the pupil's previously obtained X-capacity groupings and field-dependent/independent learning styles as in the previous sample. This is shown in table 5.5 below.

Table 5.5

St. Columba's High pupil's F.D/F.IND Learning Styles versus their X-Space

GROUP	F.D	Fraction of Group	F.INT	Fraction of Group	F.IND	Fraction of Group	TOTAL
X=5	35	0.44	23	0.29	21	0.27	79
X=6	2	0.15	8	0.62	3	0.23	13
X=7	3	0.23	2	0.15	8	0.62	13

Table 5.5 suggested that X=5 pupils were more likely to fall into the field-dependent category. Nonetheless, quite a considerable number were thought to be either field-intermediate or field-independent. The X=6 group were chiefly in the field-intermediate category and the X=7 group were mainly field-independent. The results implied that pupils of high working memory capacity were inclined to be field-independent and those of low working memory capacity were likely to be field-dependent.

5.9 Comparison of F.D/F.IND, X-space and the New Mechanisms Test

A table was constructed, as in the previous sample, for comparison of the three variables: F.D/F.IND, X-capacity and scores in the new mechanisms test for the pupils from St. Columba's High School. Once again it was thought that the field-independent pupils of high X-capacity would achieve better marks in the new mechanisms test than those who were field-dependent with low X-capacity. Nonetheless, a general overall improvement in pupil attainment was anticipated in view of the changes that had been made to the mechanisms course. These results have been illustrated in table 5.6 overleaf.

Table 5.6

The F.D/F.IND Learning Styles and X-space classifications versus the mean scores(%) in the New Mechanisms test for the St. Columba's High pupils

GROUP	F.D	Mean Score%	F.INT	Mean Score%	F.IND	Mean Score%	TOTAL
X=5	35	62	23	70	21	78	79
X=6	2	92	8	85	3	91	13
X=7	3	97	2	86	8	90	13

Table 5.6 demonstrated that the X=5 pupils had not achieved as well in the new mechanisms test as those considered to be X=6 or X=7. However, there was a steady improvement in attainment in the X=5 group as they moved from field-dependence to field-independence. The X=7 field-independent pupils had performed better than the other two groups in nearly all categories of field-dependence/independence. Nonetheless, there was only a negligible difference between the X=6 and X=7 pupils with each group scoring very high throughout the new mechanisms test. The overall achievement of the sample appeared to have improved compared to the pupils from St. Stephen's High School (table 5.3). Therefore, it was possible that the changes made to the original mechanisms course made the difference.

Scatter diagrams for the three variables: F.D/F.IND, X-space and the new mechanisms test were plotted and the Pearson correlation coefficient (r) between the scores was determined. As with the sample from St. Stephen's High there was a positive correlation between F.D/F.IND and X-space (r=0.34) that was significant at the 0.1% level. The scores on the new mechanisms test also correlated with X-capacity (r=0.41) and F.D/F.IND (r=0.32) at the 0.1% level of significance. The graphs are shown in figures 5.7, 5.8 and 5.9 overleaf.

Figure 5.7

H.F.T scores versus X-capacity for pupils from St. Columba's High (N=105)

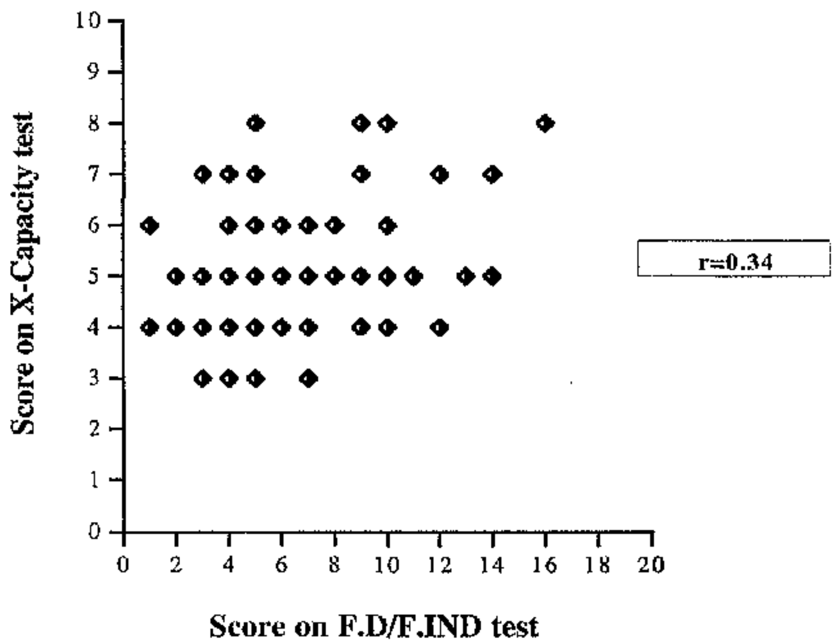


Figure 5.8

H.F.T versus Mechanisms test scores for pupils from St. Columba's High N=105

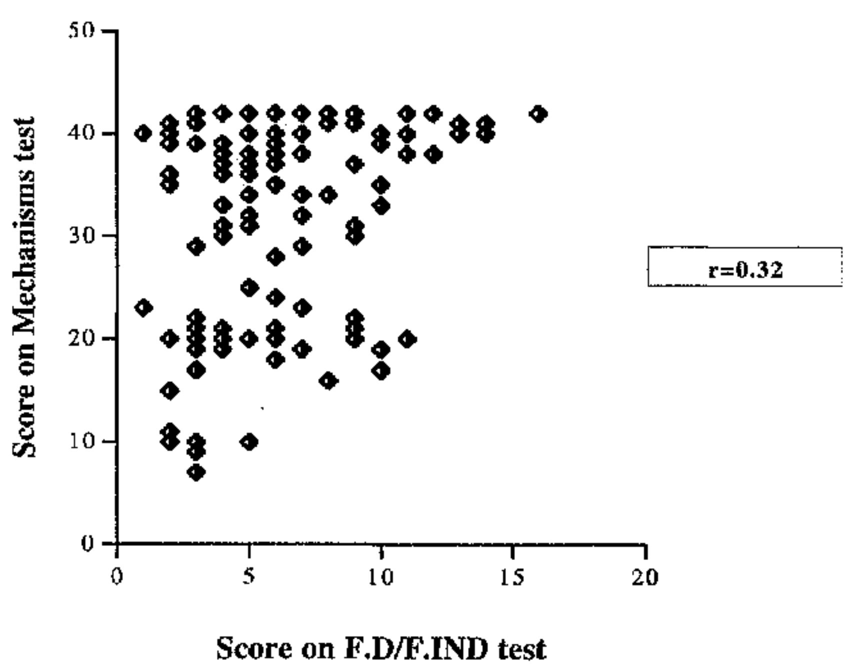
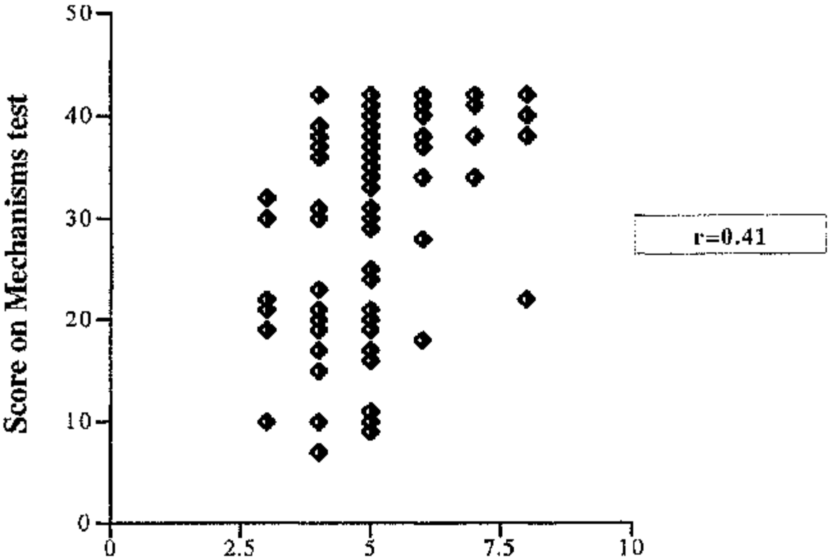


Figure 5.9

X-capacity versus Mechanisms test for pupils from St. Columba's High N=105



5.10 Summary

The results from both St.Stephen's and St.Columba's High Schools suggested that field-dependence/independence was a limiting factor in pupil attainment in the mechanisms tests. The performance of those thought to be field-dependent and of low working memory capacity was the poorest of all the categories. Generally, the pupils who were field-independent and of high working memory capacity did better in the mechanisms questions of greater Z-demand than those of low working memory capacity who were considered to be field-dependent. The study was in agreement with Al-Naeme's hypothesis[51] that pupils of high X-capacity were inclined to be field-independent and those of low X-capacity were more likely to be field-dependent. Furthermore, that pupils who were X=5 field-independent would perform similarly to the X=7 field-dependents because of the space taken up with noise.

The overall performance of the pupils from St.Columba's High was better than St. Stephen's High in the mechanisms tests. It was possible that the changes made to the original technology course; by way of Johnstone's[37] information processing model, brought about the improvement in exam marks. This would perhaps support the ideas of El-Banna[50] in as much as the changes had removed the noise and enhanced the signal in the course. These and a number of other factors will be addressed more fully in the final chapter of this study that follows.

Chapter Six

Review, Conclusions, Discussion and **Recommendations** for **Further Work** in **Technology** at Secondary Schools

6.1 Review of Present Work

During the present study the researcher attempted to apply an information processing model[37] to assess and improve the effectiveness of the teaching and learning in a Secondary School technology course involving gear and belt driven mechanisms. Two psychological factors thought to have an important influence on pupil attainment in technology were also measured, namely: field-dependence/independence and working memory capacity. The instruments that were used for this purpose had been designed at the Centre for Science Education in Glasgow University. The pupil's performance in the technology tests were analysed along with the two cognitive factors. These results were used in conjunction with the information processing model to help identify areas thought to have caused problems for the learners.

The researcher endeavoured to test the following hypotheses during this study:

- failure occurred in technology questions when the Z-demand went beyond the learner's working memory capacity;
- there was a direct relationship between working memory capacity and field-dependence/independence;
- field-dependence/independence was a limiting factor in pupil performance in technology questions;
- teaching and learning in technology could be improved through the application of an information processing model.

6.2 Approach to the Study

In the first instance, a technology course on mechanisms (appendix A) was presented to a sample of 71 pupils aged between 13 and 14 years from St. Stephen's High School in

Port Glasgow. After completing the course, they were given a test (appendix C) that involved questions on gear and belt driven systems. These questions were assessed individually for the level of difficulty (Z-demand) they placed on the pupils mental capacity (appendix D). The working memory space (X-space) and degree of field-dependence/independence (F.D/F.IND) of the sample were determined using a new version of the digit span test (appendix E) and the hidden figure test (appendix J) respectively. The pupil's performance in the mechanisms test was then analysed along with the two psychological measures.

The information processing model[37] was applied to the original mechanisms course so that any areas which may have caused problems for the learner could be identified and eradicated. It was discovered that a substantial number of changes were needed to improve the general quality of the course and to remove the material thought to have presented difficulties (noise) for the pupils. Considering the amount of modifications required, it was decided that a completely **new mechanisms course** (appendix F) had to be developed. The new course, not only covered the original content of gear and belt driven systems, but included power driven mechanisms; providing the chance to discuss control technology and energy utilisation. These new topics were added because it was thought that the original course had missed ideal opportunities to address a number of points from the 5-14 Guidelines for Environmental Studies[40]. Nonetheless, the test questions were limited to aspects related to simple gear and belt driven systems.

The new mechanisms course was presented to 105 pupils from St. Columba's High School in Clydebank who were in the same age group as the first sample. At the end of the course a new test (appendix G) involving questions on gear and belt driven systems was given to the pupils. The information processing model was used to advise the planning of the new mechanisms test in an attempt to reduce the Z-demand of the questions (appendix I). For example, being more specific about the wording so that pupils knew immediately what they were being asked to find. The working memory capacity and field-dependence/independence of the new sample was ascertained and analysed along with the performance in the new mechanisms test. From this, the effectiveness of the new technology course was considered.

6.3 Findings and Conclusions

A number points were raised from the application of the psychological tests and pupil performance in the mechanisms questions form both samples. It appeared that there was a definite relationship of some description between working memory capacity, field-dependence/independence and achievement in the mechanisms tests. Furthermore, the application of the information processing model seemed to have helped in improving pupil attainment in the technology course.

The tests that were carried out on the pupils from St. Stephen's High School will be considered before making a comparison between the two schools. An analysis of the results suggested that:

- although failure occurred in the mechanisms questions when the Z-demand was quite close to the pupil's designated working memory capacity (figure 3.9), the facility values did not reach zero;
- high and intermediate X-capacity pupils performed better in the mechanisms questions of greater Z-demand than low X-capacity pupils;
- the majority of pupils classed as field-dependent seemed more likely to be of low X-capacity and those considered to be field-independent were mainly of high X-capacity (table 5.2);
- high X-capacity field-independent pupils scored better in the mechanisms test than those thought to be field-dependent and of low X-capacity (table 5.3);
- performance in the mechanisms test appeared to improve as the pupils went from being field-dependent to field-independent.

The following conclusions were drawn from the results of the tests that were carried out on the sample from St. Columba's High School who participated in the new course:

- pupils of low working memory capacity experienced a sudden drop in performance close to the predicted Z-demand of questions from the new mechanisms test, but the facility value did not fall to zero (figure 4.9);

- the high and intermediate X-capacity pupils performed similarly in the new mechanisms test;
- although the pupils classed as field-dependent seemed more likely to be of low X-capacity; there was a substantial number in the field-intermediate and field-independent categories (table 5.5);
- pupils considered to be field-independent were mainly of high X-capacity;
- high X-capacity field-independent pupils scored better in the new mechanisms test than those thought to be field-dependent and of low X-capacity
- performance in the new mechanisms test appeared to improve as the pupils of low working memory capacity went from being field-dependent to field-independent;
- the performance of the pupils form St. Columba's High seemed to be better than those from St. Stephen's High in the technology questions of greater Z-demand.

The overall facility values of the pupils from St. Stephen's High and St. Columba's High has been illustrated in table 6.1 and figure 6.1 for the purpose of comparing the difference in performance in the technology questions. Clearly, the pupils who took part in the new mechanisms course have achieved better results in the questions of greater Z-demand than those involved in the original course.

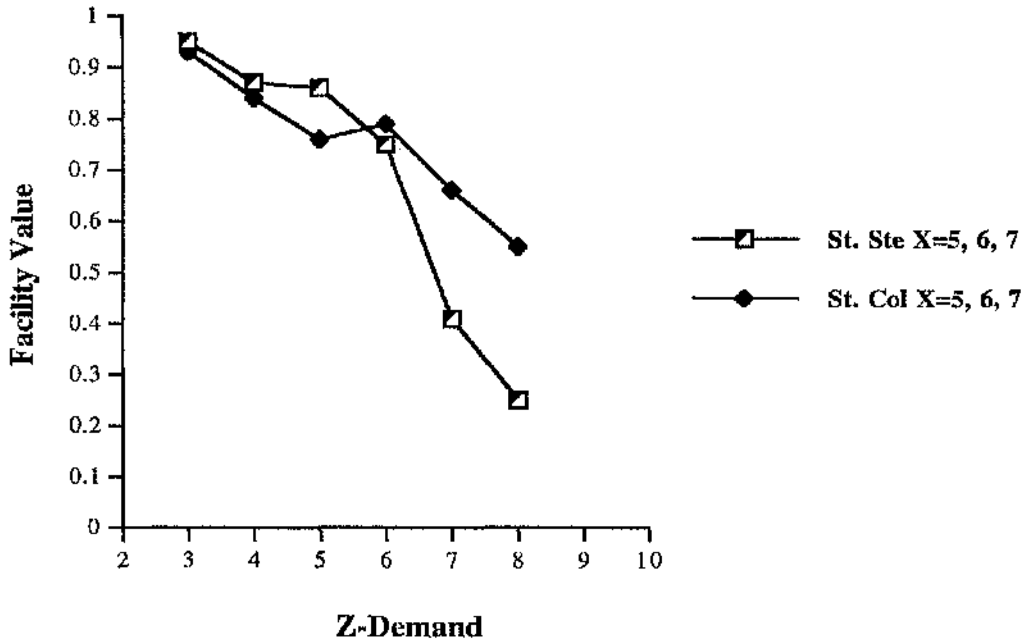
Table 6.1

A comparison of the facility values (F.V) for the questions of different Z-demand in the technology tests for the pupils from St. Stephen's and St. Columba's High

Z-demand	Z=3	Z=4	Z=5	Z=6	Z=7	Z=8
St. Stephen's	0.95	0.87	0.86	0.75	0.41	0.25
St. Columba's	0.93	0.84	0.76	0.79	0.66	0.55

Figure 6.1

Comparison of both samples overall performance in the Technology questions



6.4 Discussion

Although it appeared that the application of the information processing model had improved achievement in the technology tests; there were many differences in the circumstances involved during the teaching apart from the two courses. For example, some of the teachers, the sample and background of the school were not the same. Nonetheless, the content of the mechanisms tests were of a similar nature and the approach taken to determine the Z-demand of the questions was more or less the same. If anything, the new test was thought to be more comprehensive than the original one, because it included questions that required the diameters and number of turns in pulley systems to be calculated mathematically.

The results from the work implied that questions had been answered with an assessed Z-demand that went beyond the working memory capacity of some pupils from each of the schools (figures: 4.13, 4.14 and 4.15). It is possible that these children had developed strategies (Y) during the course; or in other subjects such as mathematics or science, that allowed them to chunk[32] the information presented to them. However, there was a good deal of similarity in the types of questions being asked which could have made the tests easier for the pupils as they progressed through them. It must also be said that the idea of determining the number of thought steps in a question to find its Z-demand is open to much criticism, because of the arbitrary nature of the processes involved. Nonetheless, the criteria suggested by a number of educators[23, 25] was very painstakingly employed during the study in an effort to limit the amount of error in determining the Z-demand of the technology questions.

6.4.1 Problems with the distribution of the sample

The findings from the study seemed to support the hypotheses concerned with the relationships that existed between field-dependence/independence, working memory capacity and performance in technology questions. However, the number of pupils considered to be field-independent with high X-capacity was pretty small in comparison to those believed to be field-dependent with low X-capacity. Nonetheless, the findings were quite convincing, with significant correlations being calculated for all the combinations of: field-dependence/independence, X-capacity and performance in the mechanisms tests.

It was believed that the inordinate number of pupils in the low X-capacity groups (tables 3.2 and 4.1) could be related in some way to Pascual-Leone's model[17] which implied that M-space (working memory capacity) increased with age. This explanation was thought possible because the pupils taking part in the research might not have reached the Piagetian[1] substage of so called formal thinking. Furthermore, recent work[54] on the development of reasoning chains supported the idea that working memory capacity increased gradually with age. Nonetheless, the presence of pupils who were thought to be of high X-capacity, might support the criticism[5] that the ages which Piaget's[1] children moved from one developmental stage to the next were too narrowly defined.

6.5 Recommendations for Further Work

As a result of this research a substantial number of questions have arisen regarding teaching and learning in technology. The study revealed several aspects that could be looked at more closely by future researchers in this curriculum area. Pupil attainment in the subject might be improved by further investigations into:

- the effectiveness of the different approaches to teaching and learning in the technology;
- the limitations of working memory capacity and field-dependence/independence in Standard Grade and Higher Grade technology courses;
- the Z-demand of technology tasks and methods used to determine this factor;
- the suitability of the different materials available to teachers as aids to learning;

It appeared that there were other cognitive factors which influenced pupil's achievement in technology and should be considered when designing curriculum. For example, motivation, self esteem and convergent/divergent styles of thinking. Gender issues such as the attitude of girls to technical education might be addressed. The performance of males and females in technology tests could also be compared.

Finally, it seems that educators must surely take cognizance of the learner's ability to select and manipulate information whilst developing new material. Therefore, it might be appropriate to write courses that are aimed at the pupil who is field-dependent, with low working memory capacity, whilst providing scope for the more able candidates. Not only does the information processing model offer an excellent instrument for curriculum design, but also heightens the awareness of educators to their own shortcomings and to the limitations of the individuals they are attempting to teach.

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