Cognitive Acceleration across the primary-second level transition

by

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own work, that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Acknowledgements

It's not the destination that's important.
It's the journey that takes you there.

I am grateful to all the people who made my journey a most enjoyable one. I would like to thank my supervisors Dr. Odilla Finlayson and Dr. Thomas McCloughlin for their endless support, advice and encouragement. I would also like to thank each and every teacher, pupil and student that I had the privilege of working with over the course of this study. Thanks are also due to the Irish Research Council for Science, Engineering and Technology for their support. Finally, I would like to thank all my family and friends, and everyone who helped me along the way.

Glossary

Notation	Meaning
ARTS	Arts, Reasoning and Thinking Skills
BLOT	Bond's Logical Operations Test
C	Non-intervention group
CA	Cognitive Acceleration
CAME	Cognitive Acceleration in Maths Education
CASE	Cognitive Acceleration through Science Education
CAT	Curriculum Analysis Taxonomy
CATE	Cognitive Acceleration through Technology Education
CSMS	Concepts in Secondary Mathematics and Science
E	Intervention group
ESRI	Economic and Social Research Institute
GCSE	General Certificate of Secondary Education
IE	Instrumental Enrichment
ILEA	Inner London Education Authority
INSET	In-service Education for Teachers
KS	Key Stage
LASSI	Learning and Study Strategies Inventory
M	Mean
MSCE	Malawi School Certificate Examination
N	Sample number
OECD	Organisation for Economic Co-operation and Development
OFSTED	Office for Standards in Education

Glossary continued

Notation	Meaning
PD	Professional Development
PISA	Programme for International Student Assessment
RGS	Residual Gain Score
rJCSS	revised Junior Certificate Science Syllabus
SAT	Standard Assessment Tests
SE	Standard Error
SESE	Social, Environmental and Scientific Education
SPSS	Statistical Package for the Social Sciences
SRT	Science Reasoning Task
STEP	Scientific Thinking Enhancement Project
STS	Science, Technology and Society
TS1	Thinking Science 1
TS2	Thinking Science 2
UK	United Kingdom
USA	United States of America

Contents

Abstract

Cognitive Acceleration across the primary-second level transition

In an Irish context, the cognitive level profile of primary (pre-transfer) and second level (post-transfer) students was obtained. This profile showed that virtually no 6th class primary school pupils (age 12.3 years), and little less than 10 percent of 1st year second level students (age 12.8 years) in this study, were at levels capable of formal operational thought. This type of thought, formal operations, is believed to develop in children between the ages of 11 and 15 years and it is necessary for meaningful engagement and understanding of many scientific and mathematical concepts.

In response to the low numbers of students capable of formal operational thought, and in an attempt to address the lack of pedagogical linkage across the primary-second level transition in Ireland, the Cognitive Acceleration through Science Education (CASE) programme was adapted for use in the final year of primary school and in the first year at second level. Students' cognitive development levels were measured using *Science Reasoning Tasks* (developed by the Concepts in Secondary Maths and Science team in the 1970's) before and after the respective interventions, and compared with non-intervention groups to assess the effectiveness of the programmes. Statistically significant cognitive gains were found for the intervention groups at primary level (0.51 σ (standard deviation)) and second level (0.52 σ). When the *Learning And Study Strategies Inventory (High School)* was used to determine if there was a correlation between the 1st year students' motivation and the effect of the intervention programme on their cognitive development, no correlation was found.

In an attempt to increase the sustainability of CASE in second level classrooms, a series of lessons, based on the CASE methodology, were developed in the context of six Junior Certificate science topics. These lessons were implemented in the second year and analysis of cognitive change showed a large effect size (1.74 σ). There was also a significant difference between the performance of students in the intervention group, compared with the non-intervention group, on tests assessing conceptual understanding. Again no significant correlation was found between the effects of the intervention on students' cognitive development and their motivation, implying that the CASE methodology contributed to the enhanced cognitive development.

This work has shown an equal increase in cognitive development whether implemented in 6th class of primary school or in 1st year at second level. The effect size on students who were taught through both programmes was double that of those who completed only one programme. Implementation of the CASE methodology in 2nd year had an even greater effect on students' cognitive development.

Introduction to the study

One of the most important roles of education is to stimulate the mental growth of children, in order for them to make sense of the world around them. Problem solving, logical reasoning and creative thinking are all fundamental skills required for life. During the primary and secondary school years, the most pertinent years of a person's cognitive development, these thinking skills should be developed.

The development of children's thinking was a main feature of Jean Piaget's work. He believed that the process of mental development was hierarchical and linked to age. He proposed several clearly defined stages through which children's thinking passes through, from sensori-motor (0 to 2 years) to formal operational thought (11 to 15 years). In light of Piaget's contribution, studies [1, 2] highlighted the low number of students at the more developed stages of thought, and hence not portraying higher order thinking skills. Furthermore, when the contents of the science and mathematics curricula were matched with their respective Piagetian levels, alarming findings were evident [3]. The majority of students were at levels which were lagging behind those necessary for true engagement and understanding of scientific concepts. In an attempt to address this mismatch, the Cognitive Acceleration through Science Education (CASE) programme [4] was developed by Adey, Shayer and Yates with the aim of accelerating the cognitive development of students. It has been implied that Piaget predicted that no such process was possible [5] but the results of CASE very much contradicted this, with several studies recording increased student cognitive levels, as well as improved performance in science, mathematics and English examinations [6, 7].

In Ireland to date there have been relatively few reports on the cognitive developmental profile of children. However, international research shows that Irish students are not unique when it comes to finding science difficult. Results from *The Relevance of Science Education in Ireland* study reported that about 50 percent of students regard Junior Certificate science as a demanding and difficult subject [8]. The responses from students to the statement 'School science is easy for me' are shown in Figure 1 [8]. Irish students' responses, as well as students in other industrialized countries, show low disagreement with the statement. Students in less-industrialized countries responded more positively and in general showed more agreement with the statement.

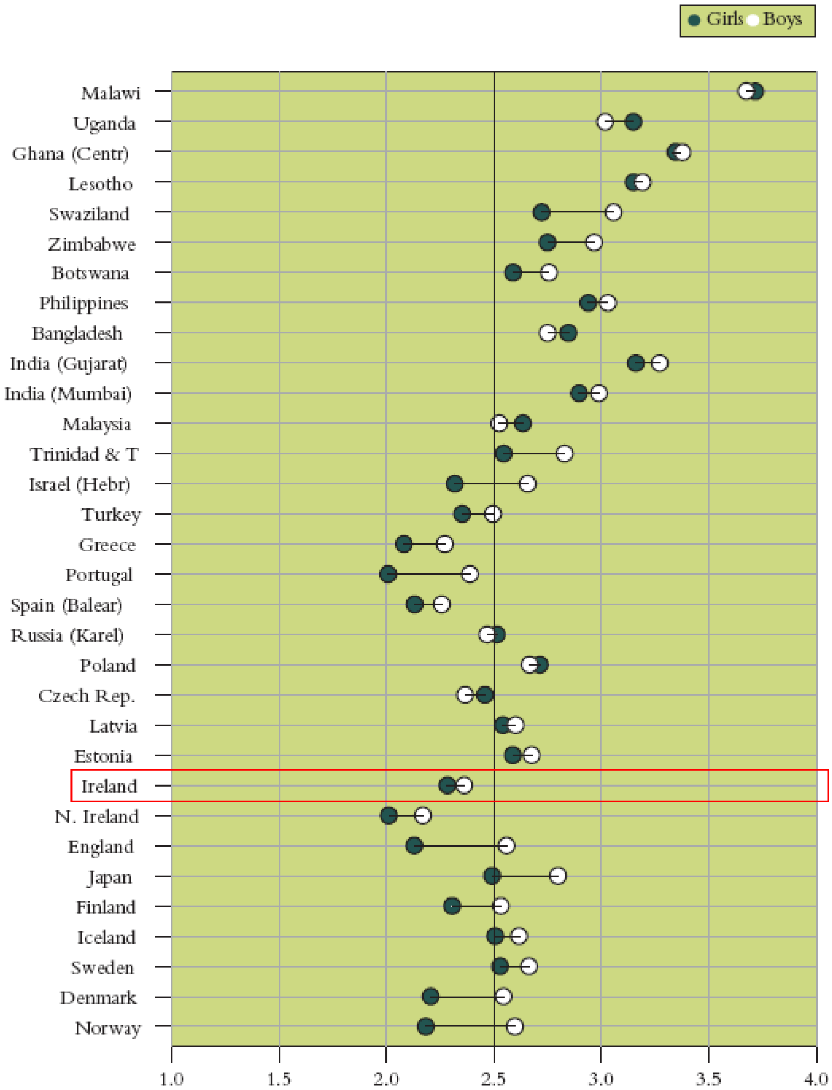


Figure 1: **Responses from ROSE project to the statement 'School science is easy for me' 1=disagree, 2=low disagree, 3=low agree, 4=agree** (taken and adapted from [8])

In the context of the Irish findings, on the difficulty of science, this evidence has repercussions in terms of the perception of science and the numbers of students that choose to do science subjects for the Leaving Certificate programme and pursue science as a career. But perhaps more worryingly is that a large cohort of students have not developed the capacity to think in a higher order, formal operational manner, necessary for everyday life.

The first question of this thesis was to determine the Piagetian developmental profile of Irish primary (pre-transfer) and second level (post-transfer) students, and to compare the findings to elsewhere.

The second question of this thesis was to find out if the cognitive levels of pre- and post-transfer students could be increased, through the implementation of the CASE programme. This study was a longitudinal one, designed to track the development of students across the transfer from primary to second level, a transfer which boasts of little continuity or pedagogical linkage in the Irish context. An additional question was to assess if motivation was a underlying factor in the effects of CASE on students' cognitive development.

Arising from the implementation of the CASE programme, there were certain aspects of the programme that required adjustment, in order for its sustainable use in the Irish second level system. As opposed to single activities, the CASE methodology was adapted to serve as a teaching methodology for entire topics on the Junior Certificate science curriculum. The Curriculum Analysis Taxonomy, a tool developed to analyse the difficulty of science activities, was used to match some of the contents on the Junior Certificate science syllabus with their required Piagetian level. In compliance with British findings, many of the demands of the curriculum exceeded the majority of second year students' capabilities. This provided the scope for the third major question, to explore if the cognitive development of students could be enhanced through the teaching of entire science topics through the CASE methodology. In addition, the effect of this type of intervention on student examination performance, in both traditional recall questions and questions that require conceptual understanding, was assessed.

This thesis has four chapters. In the first chapter, the literature surrounding the area of cognitive development and methods of cognitive acceleration are reviewed, as well as the transition between primary and second levels of education, particularly in the area of science. The second chapter reports how the original CASE materials were adapted to make them suitable for use in the Irish primary and second level systems, how the programme was implemented and the effects of the programme on pupils' and students' cognitive development, at both levels. Arising from issues in the implementation of the CASE programme in the first year at second level, a new set of lessons linked to the Junior Certificate syllabus, based on the CASE methodology, were designed and trialled in second year at second level. The process of development of these lessons and their implementation is described in Chapter 3 and the results of their effect on students' cognitive development are presented in Chapter 4. Following this, the overall conclusions and implications are presented. The bibliography and appendices are located at the end of the thesis.

In this thesis the term pupil is used to describe a child in primary level education, while the term student is used to describe those in the second and third levels of education.

Chapter 1

A Review of Theories and Research on Cognitive Development and the Transition between Primary and Second Level Education

Introduction

This chapter is divided into two sections. The first section reviews literature in the area of cognitive acceleration methodologies and the second reviews the transition between primary and second level education. The influence that both Piaget and Vygotsky had in the area of cognitive development is discussed and how their contribution lead to the development of programmes which aimed to enhance and promote cognitive development. Some of these programmes and their main findings are discussed also. The CASE programme and its effects are discussed in particular detail, including some of the applications of the methodology in other contexts and settings. Finally, the issues surrounding the transition from primary to second level are discussed, in order to put the study into context.

1.1 Cognitive development

1.1.1 Piaget's and Vygotsky's influence on learning

In the teaching of any subject, be it in science or any other discipline, it is vital to take into account the prior knowledge that learners have about the content being taught, in order for the lesson to be productive and fruitful. Identifying this existing knowledge is not a superficial task. As the term 'individualised knowledge' implies, each pupil's experiences, attitudes and methods for constructing knowledge are unique [9]. There have been several theories describing how learners construct this individualised knowledge and also what constitutes knowledge. Two of these theories have been particularly influential in the evolving art of teaching and instruction, namely cognitive developmental theory and social constructivist theory born of the psychologists Piaget [10, 11, 12, 13] and Vygotsky [14, 15], respectively. The former theory, cognitive developmental theory, suggests that an individual's active exploration of the world generates their knowledge about it and their thinking becomes more sophisticated with maturity. The latter, social constructivism, implies that learners construct their knowledge and develop theories they hold through experiences and interactions with others. Each of these theories are elaborated in the following sections.

Piaget's theory of cognitive development

Piaget linked maturation to cognitive growth and development, and his in-depth analysis into this is called stage theory. Fundamental to this theory is the premise that all children pass through distinct stages of cognitive development. These are called; (i) the sensori-motor, (ii) pre-operational and (iii) operational stages. Piaget described three major stages that all children go through in the development of their cognitive skills. The behaviour and thinking abilities displayed by all children within each stage is similar, both between different contexts and different children. The general age/ stage picture, presented by Piaget is shown in Figure 1.1.

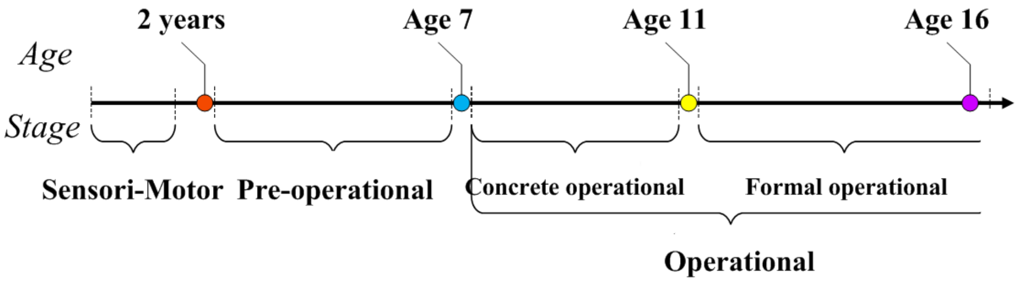


Figure 1.1: **Time-line of Piagetian stages of cognitive development**

In the sensori-motor stage, the child's intelligence is informed by the sensory information that he or she can gain about the outside world from his or her actions. Children apply the skills and abilities (e.g. looking, grasping, sucking) that they were born with to learn more about their environment. Upon completing the development of the sensori-motor period, the child has reached a point of conceptual development that is necessary for the development of language and other cognitive skills in the next major period of cognitive development; the pre-operational period.

In the pre-operational stage, there is a qualitative shift from the previous stage. The child becomes increasingly able to internally represent events, i.e., think, and they become less dependent on their sensori-motor actions for direction of behaviour. In addition, during this stage there are some dramatic attainments. Language is acquired between the ages of 2 and 4 years. Behaviour in the early part of this stage is mostly egocentric and non-social, but towards the end of this period the child becomes largely communicative and social. One of the limitations of this stage is the inability to reverse operations. For example, a pre-operational child is shown two equal-length rows of 8 coins each. He agrees that each row has the same number of coins. However, when one of the rows is lengthened (to make it look longer) the child no longer agrees that there is the same number of coins in each row. The child cannot reverse the act of lengthening. Also, the pre-operational child cannot follow transformations. An example of this would be if a child is presented with two containers of equal size and shape, and asked to compare the amount of liquid (equivalent) in the two containers. Following this, the liquid from one of the containers is poured into a taller, thinner container and the child yet again is asked to compare the quantity of liquid in the two containers. As well as not attending to the concept of conservation, the pre-operational child typically does not attend to all aspects of transformation that he sees. The child only considers the perceptual aspects of the problem. Also in the pre-operational stage the child's thoughts and actions are mostly egocentric. For these reasons, thought at this stage can be characterised as restrictive and tactile.

The stage central to the development of concepts necessary for science and mathematics is that of the operational stage, the most pertinent stage in this study. This stage is divided into two; concrete and formal operational thought. During concrete operations, between the ages of 7 to 11 years, the child's reasoning processes become logical. Concepts such as space, time, causality and speed evolve. One of the key features of this stage is the attainment of reversibility. In addition, the ability to solve conservation problems emerges. The conservation of number problems are solved around 6 or 7 years, conservation of area and mass problems are solved by 7 or 8 years and the conservation of volume problems around 11 or 12 years. For example, a child who has attained concrete operations can appreciate that when a liquid is poured from one container into another of a different shape, the quantity of liquid stays the same. As the term 'concrete' suggests, the child's thinking in this stage is based on their experiences of real or concrete objects or events. The limitations of this period include the solving of hypothetical problems, problems that are entirely verbal and some problems that require complex operations. Shayer [16] advises that in the first two years at second level students need much work to consolidate this stage.

The most sophisticated of all the stages is that of the formal operational stage. According to Piaget, the child's cognitive structures reach maturity during this period. Schemata in general reach the maximum qualitative development, by about the age of 15 years. The child can think logically about problems and is no longer restricted to concrete objects or events. Attainment of this period usually means the child is better able to organise data, reason scientifically and generate hypotheses. Problems which were deemed impossible to solve at the concrete operational stage such as those involving combinatorial thought, complex verbal problems, hypothetical problems, proportions and conservation of movement are now possible at the formal operational stage. Formal operational thinking is characterized by the ability to deal with abstract ideas and at that point, children become able to grasp ideas such as those involved in the setting up and testing of hypotheses, the control of variables, ratio and proportion.

All the periods of cognitive development and their characteristics are summarised in Table 1.1.

Table 1.1: **Summary of the three main stages of cognitive development, according to Piaget**

Stage	**Typical age** (Years)	**Characteristics of the stage**	**Significant change of the period**
Sensori-motor	0-2	Internal representation	Development proceeds from reflex activity to representation and sensori-motor solutions to problems
Pre-operational	2-7	Problems solved through representation- language development, Egocentric thought and language, Cannot solve conservation problems	Development proceeds from sensori-motor representation to pre-logical thought and solutions to problems
Concrete operational	7-11	Can handle reversibility, Can solve conservation problems- logical operations developed and apply them to concrete problems, Cannot solve complex verbal problems	Development proceeds from pre-logical thought to logical solutions to concrete problems
Formal operational	11-15	Logically solves all types of problems, Has the ability to solve complex verbal problems, Mature cognitive structures	Development proceeds from logical solutions to concrete problems to logical solutions to all classes of problems

As Piaget's chronological framework highlights, maturation is an essential factor in the development of children's thinking abilities [17]. In the case of normal development and schooling, as children get older their cognitive processes increase with sophistication. Piaget specified three other factors that influenced a child's cognitive development. These are discussed briefly;

- **A child's daily activities and experiences**

  Piaget recognised the potential value of the 'right' experience at the 'right' time. He believed that experiential and social situations could be structured so the developing child can interact with others and act upon things and situations that he/ she finds themselves in. One of the key applications of

Piaget's theory is the necessity for children to interact physically with the environment for the stimulation of cognitive development. Piaget said:

> *It is absolutely necessary that learners have at their disposal concrete material experiences (and not merely pictures), and that they form their own hypotheses and verify them (or not verify them) themselves through their own active manipulations. The observed activities of others, including those of the teacher, are not formative of new organizations in the child* [18].

- **Social interaction**

  This does not become an effective variable in cognitive development until after the pre-operational period, when egocentrism is less prevalent. After 6-7 years, interactions have 'social' value when the child can assimilate the views of others, even those that don't necessarily comply with their own. At this age, most children become able to accommodate the views of others and peer interactions become valuable settings that stimulate cognitive conflict and lead to such accommodation. Role-playing, games, play and group activities are all situations that stimulate valuable peer interactions.

- **Equilibration**

  Assimilation and accommodation were two processes in learning central to Piaget's stage theory ([17] (page 24)). Assimilation, in brief, is the interpretation of new learning experiences within existing cognitive structures. Accommodation is the modification of existing thinking/cognitive structures to take account of new learning experiences. The balance between these two processes, termed equilibration, was deemed as a key element of learning by Piaget. Cognitive development is the progressive increase in equilibrium. When a new idea or concept emerges from the world, the subject loses his or her equilibrium and accommodation must occur for them to re-establish the equilibrium. If the new idea can be assimilated into the old equilibrium, then no development occurs. But if it cannot be assimilated, it must be accommodated and a new and better equilibrium will occur. In essence, too much assimilation leads to no new learning, but too much accommodation causes confusion in thinking.

According to Piaget, the interaction of all four factors (maturation, experience, social interaction and equilibration) lay out the course for development. Both maturation and equilibration are immune to any type of external control. The other two variables, experience and social interaction, are for the most part determined by external events.

The impact of Piaget's work - Curriculum sequencing

Piaget proposed that schemata develop in a uniform sequence for all children. Schemata, put simply are intellectual structures that organise events, as they are perceived by the individual, into groups according to common characteristics. Although the ages at which children attain these particular structures may vary, due to factors such as intelligence and social environment, the sequence is the same. Curriculum sequences should be designed with children's cognitive status in mind. Four specific messages are clear from Piaget in terms of curriculum sequencing;

1. Teachers should not try to teach children material that is beyond their present stage of cognitive development. One example of this is the teaching of arithmetic. All the basic concepts of arithmetic- number conservation- are achievements of the concrete-operational stage yet in most cases this instruction begins in early primary schooling, with children at a range of stages from pre-operational to concrete operational. Piagetian theory would suggest that only the last group is 'ready' to begin assimilating the relevant information on arithmetic.

2. Teachers should avoid trying to speed up their pupils' progress through subject material. Piaget advises that thorough mastery of a subject is a much better criterion of learning than the speed at which the material is covered.

3. Children should be taught new concepts in the same order that the concepts emerge during spontaneous cognitive development. Such a curriculum is referred to as a developmentally based curriculum. Much of Piaget's work at the pre-operational and concrete operational stages provide extensive information about the order of spontaneous concept development.

4. In a Piagetian curriculum, teaching is always a two-step process, beginning with diagnosis and followed by instruction. In terms of diagnosis, Piaget refers to the critical identification of each child's present cognitive level in each area in which the child will receive instruction. Upon this judgement the teacher can organise instructional material and the teaching processes accordingly.

Critisms of Piaget

There is an extensive body of literature criticizing the work and techniques of Piaget [19, 20, 21]. Most of the criticisms focus on the extent to which it is possible to identify general stages of development and the age at which certain levels of thinking are demonstrated. Nagy and Griffiths [22] document many views on the critisms of Piaget's theory in particular on the nature of the evidence of stages. Many disagree with the model of cognitive growth that Piaget proposes.

> *Intellectual growth is systematic, but the stage descriptions Piaget offers as evidence of the system seem less than adequate* [19].

Some of the other main critiques are summarised as follows;

- Work done on the development of thinking with pre-school children suggests that young children are capable of much more sophisticated thinking than Piaget's theory proposed [23]. It has been suggested that performance on tasks by subjects in Piaget's study could have been underestimated due to language and interpretation difficulties.
- The development of general cognitive structures was questioned by Novak [17] in light of evidence from a number of studies which indicate that individuals can operate at different developmental levels depending on the context in which they are working.

In response to his critics, Piaget proposed the idea of 'décalage'. This suggested that children could be at one stage of cognitive development in one activity and at another stage in some other activity. This apparent inconsistency and lack of synchrony was investigated by Longeot [24]. His study confirmed that for instance, some children advance first on spatial relation tasks while others first develop superior performance on verbal tasks, such as classification and seriation [25]. He proposed the idea of nodes in the developmental process through which all children pass in order and which act as preconditions for further development in any schema. Data from studies of children from 5 to 10 years of age in a range of countries [26] confirmed that there were indeed nodes through which children pass. When a child reaches a node he or she can nearly always carry out tasks that precede the node, but the development of cognitive ability between the nodes was not the same for each task. It appears to be the case that children need to successfully master all the tasks in one node before they can manage the tasks in the next node. Adey and Shayer [25] propose that this provides evidence for a central processing unit, which is a premise of Piaget's theory.

> *Children need integrated success on all parts of the psychological spectrum before the central processor makes a qualitative jump allowing the next phase of development to commence* [25].

Vygotsky's social constructivist theory

When Kozulin analysed Piaget and Vygotsky's theories side-by-side he describes their;

> *common denominators as a child centered approach, an emphasis on action in the formation of thought, and a systematic understanding of psychological functioning* [27].

Their biggest difference, according to Kozulin, is their understanding of psychological activity [27]. Vygotsky's perception is that psychological activity has socio-cultural characteristics and concepts can be formulated from a range of different stimuli, implying a problem-solving role for students and a facilitator role for the teacher.

Vygotsky's work on cognition arose partially due to his criticism of the use of psychometric tests to predict children's ability for progression in learning, especially in reading. Vygotsky was convinced that what children can achieve assisted by an adult tells more about their capacity to learn in the future than tests they undertake in isolation. Vygotsky and his co-workers pioneered *dynamic* testing where the child's potential may be realised through dialogue between a child and psychologist, in the context of an individual interview. By comparing the child's unassisted responses -where discussion is limited to explaining the meaning of a question or vocabulary- to the final response obtained following dialogue of strategies needed for the test-items, the psychologist can obtain a measure of the child's potential to learn. Quantitatively, Vygotsky [15] showed that the information obtained from this type of testing was a better predictor of children's progress in school learning over the following two years than static test scores. The measure gives a more helpful clue to the dynamics of intellectual progress, compared with an estimation of mental age [28].

The testing has the following format. The child is first given a standard intelligence test and their mental age estimated from the score. The psychologist then takes the child through some of the easier items on which they failed, giving various hints and/or discussing the problems with the child. With this assistance the child can then solve more of the items, and hence a new mental age can be calculated relating to the limit of the child's success with the mediation of the psychologist. The difference between the two scores represents the *Zone of Proximal Development* (ZPD) of the child which is described in Vygotsky's words below.

> *It is the distance between his actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers* [15].

ZPD describes what dynamic testing tries to achieve and also the dynamics of mental growth:

> *learning which is oriented toward developmental levels that have already been reached is ineffective from the viewpoint of a child's overall development. It does not aim for a new stage of the developmental process but rather lags behind this process* [15].

Vygotsky [15] proposed that a chief feature of learning is that it seeks to minimise this ZPD and so quality learning evokes a variety of developmental processes that operate when the child is interacting with people in his or her environment and in union with their peers.

ZPD should not be viewed as a merely internal function of the child, according to a quote from Vygotsky [29];

> *Any function in the child's cultural development appears twice, or in two planes. First it appears on the social plane, and then on the psychological plane. First it appears between people as an interpersonal category, and then within the child as an intra-psychological category* [29].

According to Vygotsky, the ZPD lies as much outside the individual, in the skills, concepts and strategies located in the social space which he and his peers inhabit, as it does in his own mind. The child internalizes as a personal skill, what he has approved and observed in his peers' practice. Three main themes provide the foundation for learning, according to Vygotsky. They include the central role of language, the importance of culture and the means by which intellectual development takes place. Vygotsky's advice to teachers is to remain in tune with children's level of mental development. He warns;

> *Practical experience also shows that direct teaching of concepts is impossible and fruitless. A teacher who tries this usually accomplishes nothing but empty verbalism, a parrot-like repetition of words by the child, simulating a knowledge of the corresponding concepts but actually covering up a vacuum* [28].

Vygotsky [15] emphasizes the necessity to optimise learning through instruction;

> *the only 'good learning' is that which is in advance of development* [15].

In other words, learning tasks that are well within the child's capabilities do not provide the challenge that stimulates cognitive growth. The emphasis is on student's own construction of higher-level modes of thinking. The teacher can most surely provide appropriate experiences and lead the students constructively but they cannot put higher-level thinking capability directly into the student's mind. This is something that the student must construct for themselves.

According to Vygotsky, development is a non-linear process and rather uneven;

> *development of different functions, metamorphosis or qualitative transformation of one form into another, intertwining of external and internal factors, and adaptive processes* [15].

In contrast to Piaget's concentration on the individual, Vygotsky's premise was the social processes of learning [30]. However, work by Les Smith [31] shows that Piaget and Vygotsky occupied similar territory with respect to the social origins of thinking, at least at an abstract level.

Further developments

Piaget and Vygotsky's contribution to the area of cognition and development lay the groundwork for many research studies and developments in the area of teaching and learning psychology. Some of the most influential research was by Adey and Shayer. Their work fell into three main categories;

- the development of tools to measure pupils' levels of cognitive development;
- the analysis of curriculum materials in terms of their cognitive demand;
- methods to accelerate cognitive development.

Each of these categories will be discussed in detail in the following sections.

1.1.2 The Development of Science Reasoning Tasks (SRTs)

In 1970, Shayer highlighted the need for two things for the successful planning of science courses; (i) knowledge on the sequence of conceptual development in children and, (ii) statistics on the proportion of children that reach particular developmental levels at different ages [16]. The first was made available by Piaget by that time, the latter was not.

In 1973, the Concepts in Secondary Mathematics and Science (CSMS) programme was initiated with three core needs in mind. Up to this time, population norms for the Piagetian levels of cognitive development had not been determined anywhere in the world. In addition, Piaget's research had not been validated with the use of objective testing methods. This testing of the Piagetian stages in populations could potentially have provided valuable information for curriculum designers, researchers and teachers. In order to meet any of these needs, tests would have needed to be carried out with thousands of children, which was impractical with the traditional Piagetian method of assessing children's level of thinking by individual interview. The most practical solution to this laborious and expensive method was to develop practical tasks that could be given to whole class groups at one time. The CSMS team were aware that they would have to implement the essential features of the Piagetian technique while transposing the clinical method into a class task. These techniques included;

- the use of apparatus that provides feedback to children's suggestions and predictions;
- the ability to question the subject on the reasoning underlying his/her responses;
- observation of the child's reaction to counter-arguments or proposals of alternative explanations;
- some allowance for flexibility in questioning following the child's responses.

The CSMS team developed a series of class tasks, which were published and became known as Science Reasoning Tasks (SRTs) [32]. The function of the SRTs was to assess the ability of children or adults to use concrete and formal reasoning strategies, as described by Piagetian stage theory. In each of the tasks, demonstration skills are employed as a focal point for the questions. This technique allows for the feedback of experimental results during the test and so, giving the pupil the maximum chance of using all the structures of thinking that he/she possesses. Each test starts with an original Piagetian task (i.e., the Pendulum, spatial relations) and items to assess the child's grasp of each task are accompanied.

Their development was part of a major research programme conducted over six years. After the CSMS team trialled up to eight different versions, each on a suitable class of the appropriate age/ability, they arrived at a final version. This version was given to a sample of over 200 pupils and their responses were used to arrive at scoring-rules. Shayer [33] checked that there was no systematic difference between the SRT estimate of Piagetian level, and the estimate made on the same children by individual interview. Another advantageous feature of the SRT is that as well as providing an overall Piagetian level of performance, the particular successes of each person on items of all aspects of a task are recorded. The overall estimate is based on a technique of item-analysis, which focuses on each sub-stage at a time and the decision as to whether the subject possesses the competence of a stage is made independently for each sub-stage. For example, however many correct concrete operational responses a subject may give, they cannot eventually add up to a score which denotes the formal operational level. In this way a hierarchy of development is not being imposed on the data by the scoring system. Each of the stages of cognitive development were divided into late and early stages and Adey and Shayer [1] use the notation shown in Table 1.2 to indicate stages and sub-stages of the cognitive development scale.

Table 1.2: **Stages of development and corresponding notation (compiled from [1] and [25])**

Piagetian Level	**Notation**
Pre-operational	1
Early concrete operational	2A
Mid concrete operational	2A/2B
Late concrete operational	2B
Transitional	2B/3A
Early formal operational	3A
Formal generalisation	3B

A new method of ascribing a level of cognitive development to an individual has been achieved. This re-analysis, using Rasch scaling, asserts that the probability of a correct response is a function of the difference between the individual's ability and the difficulty of an item. The appropriateness of applying this Rasch model to Piagetian measures of stages of thinking has been endorsed by Hautamåki [34]. Table 1.3 shows the level of thinking on this scale. The standard error on any task is greater near the end of each task's range, i.e., out of a 14 item task, pupils scoring 1, 2, 13 or 14 will not be as reliably assessed as those scoring in the 3 to 12 range [35].

Table 1.3: **Age/stage picture and Rasch scale**

Piagetian level	**Symbol**	**Scale Number**
Early concrete	2A	3
Mid concrete	2A/2B	4
Late concrete	2B	5
Concrete generalisation	2B*	6
Early formal	3A	7
Late formal	3A/3B	8
Formal generalisation	3B	9

The SRTs

In total there were seven tasks developed and designed to assess a range of sub-levels from pre-operational to late formal operational thinking. Each task was designed to be administered to approximately thirty pupils at a time. The administrator, who need not have any professional training in Piagetian studies, demonstrates the task and gives oral instruction to the pupils. Pupils respond in writing on designated worksheets. The tasks are not content specific and each task can assess a selected number of reasoning strategies associated with a specified Piagetian stage of cognitive development. The main features of each of the tasks are summarised in Table 1.4.

Table 1.4: **Main characteristics of Science Reasoning Tasks (SRTs)**

Number and Name	**Range**	**Description**	**Number of items**	**Derived from:**
I Spatial Relationships	1-2B+	A test of student's perception and co-ordination of vertical, horizontals and perspective through a drawing task.	4	*The Child's Conception of Space* [36]
II Volume and Heaviness	1-3A	Tests conversion of substance, weight and volume. Also tests the use of proportional reasoning involved in density.	15	*The Child's Construction of Quantities* [37]
III The Pendulum	2B-3B	Tests the use of control of variables and deduction of the effects of weight, length and push on the time of swing.	12	*The Growth of Logical Thinking* [38]
IV Equilibrium in the Balance	2B-3B	Tests the use of inverse proportions in the balance problem and the 'work principle'	13	*The Growth of Logical Thinking* [38]
V The Inclined Plane	2B-3B	Tests the use of inverse proportions and the 'work' principle	14	*The Growth of Logical Thinking* [38]
VI Chemical Combinations	2B-3B	Tests combinatorial thinking and making deductions from evidence	16	*The Growth of Logical Thinking* [38]
VII Flexible Rods	2B-3B	Tests the use of control of variables and deduction of effects of length, thickness, shape, material, weight on bending of rods	17	*The Growth of Logical Thinking* [38]

One example of a task is that of the second in the series, *Volume and Heaviness*. This task is based on most of the chapters in '*The Child's Construction of Quantities*' [37]. Initially for a child the concepts of mass, weight and volume are not differentiated and grouped as mass. At the 2A (early concrete) stage, the concept of mass -conservation of substance- is differentiated. A little later at the 2A/2B (mid concrete) stage weight is conserved, and the concept of density is differentiated from weight. At the 2B/3A (transitional) stage, volume is conserved and differentiated from mass and weight. Finally, at the 3A (early formal) stage, the concept of density is established and the child sees that whether something floats is governed by its weight compared with the weight of the same volume of water. This particular task has 14 questions and it is hierarchically constructed. This is demonstrated by the following examples.

Question 1 on Task 2 (*Volume and Heaviness*), as shown in Figure 1.2, involves the administrator filling container A to the top with water, then pouring the contents into another container X and refilling A. The containers should be placed next to each other and the student must record whether they think there is more, less or the same amount of water in the containers A and X. This question demands an early concrete, 2A, type of reasoning and tests the conservation of volume.

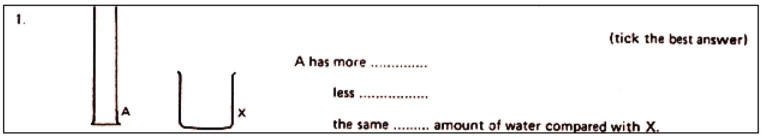


Figure 1.2: **Question 1 of *Volume and Heaviness* task [32]**

Question 13 on this *Volume and Heaviness* task is comprised of 2 parts, a and b, as shown in Figure 1.3. This task is introduced by the story of Archimedes and the King's new crown. The King asked Archimedes to find out if his new crown was pure gold, as he suspected that the goldsmith had stolen some of the gold while making up his new crown. The first question put to the students is classified as a 2B/3A question, while the second part involves an understanding of volume to weight ratios, an early formal operational (3A) thought process.

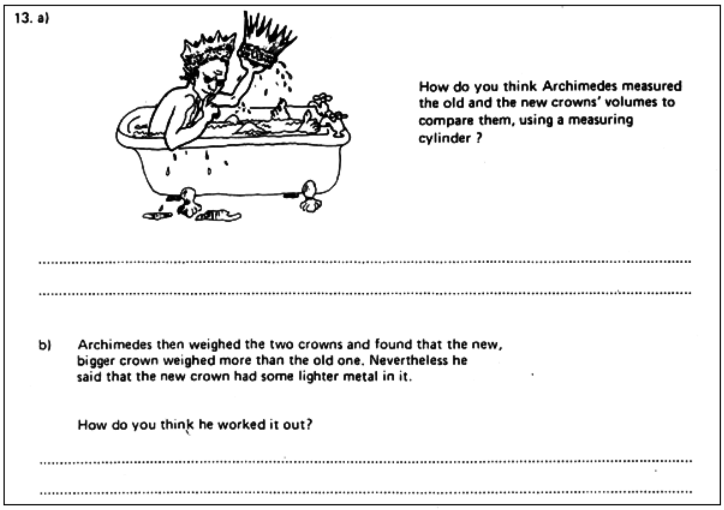


Figure 1.3: **Question 13 of *Volume and Heaviness* task [32]**

Testing the SRTs

The SRTs were developed and evaluated in a rigorous manner by the CSMS team. This will be discussed under the following headings; Discrimination, Reliability and Validity.

- Discrimination

Each question was ascribed to a sub-stage by inspection, using the descriptive framework of the stage theory, and Inhelder and Piaget's [38] description of characteristic responses. A good SRT item should be a sharp discriminator, implying that a stage 2B item should be passed by all subjects who are at level 2B or above, but failed by those who are not at the 2B level. Figure 1.4 shows good and poor discriminators, respectively, for the case of a 3A level item. In the development of SRTs, if any item behaved like the bad item it would be discarded from the test or modified until like the good item shown in Figure 1.4. In this way the published SRTs have been developed and refined so that the results are compatible with Piaget's stage theory model.

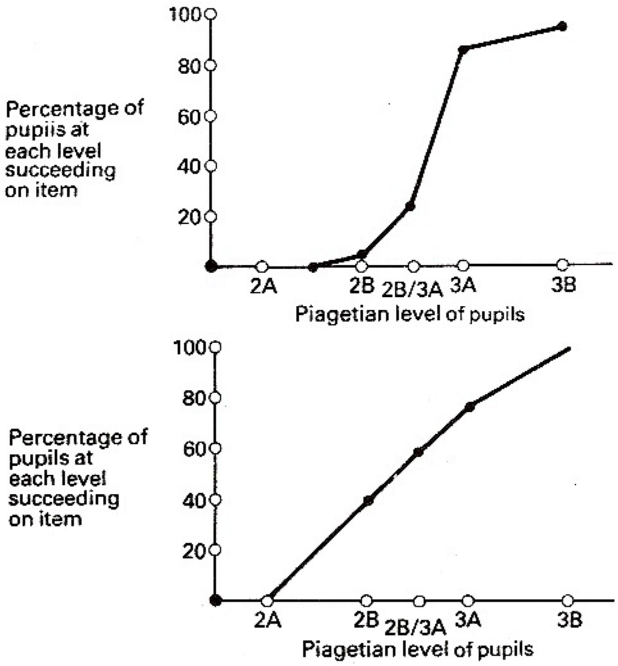


Figure 1.4: **Discrimination diagram of good item (top) and bad item (bottom) (taken from [1])**

- Reliability

The reliability of the tests were investigated in two ways. The internal consistency was measured by the Kuder-Richardson coefficient, r_{tt} and the values ranged between 0.76 and 0.86 for the set of SRTs. A r_{tt} value of 1 would imply perfect internal consistency, suggesting that all the tasks were telling the exact same story. The second method, test-retest reliability was used to measure the extent to which a task will tell the same story on two successive occasions. The same students were given the same task twice within a three to six week period and the reported values varied between 0.64 and 0.85, as shown in Table 1.5. The standard error of measurement for a single task is reported to be about 0.55 levels, on the seven point interval scale [39]. This means there is about 95 per cent probability that a subject's true score lies within a range of +/- 1.1 levels of the measured score. For instance, if a student attains a 3A level there is a one in twenty chance that the student's true score does not lie between the 2B/3A-3B range.

- Validity

Detailed studies of content, construct, concurrent and predictive validities have been carried out and reported by Shayer [3, 33]. The content validity test basically measured whether the SRTs measured the same thing as the original Inhelder and Piaget tasks. A sample of pupils who took each task were interviewed individually in line with Piaget's own technique. The results, shown in Table 1.5, show the correlation between levels assigned by the tasks and by the interviews. The correlations between the group tests and interview results are reported to be between 0.55 and 0.79. Furthermore, a comparison of SRT and individual interview mean levels show no systematic difference [35]. In addition, the group tasks were more reliable than the interviews as a measure of the stage of cognitive development. Shayer and Adey [1] believe that the extra source of variance in the interview technique arises from the personal interaction between the interviewer and interviewee.

The concurrent validity of the SRTs III to VII were tested with a sample of approximately five hundred 14-year old students [35]. The purpose of this test was to analyse the extent which each of the tasks agreed with each other in their estimates of cognitive development. The general trend of the result showed that if a student was deemed as formal operational on the *Equilibrium in the Balance* (Task IV) problem, they were rated the same in other tasks also. There was some variation from task to task in the proportion of students at different levels, but very little difference in the mean levels on the different tasks [35].

The final validity test of the SRTs was on their ability to predict the success or failure of individual pupils on elements of the science curriculum. Certain sections of the curriculum were analysed to determine the level of cognitive demand they make. A sample of 12/13 year olds were examined on their understanding of concepts on the physics, chemistry and biology sections of the Nuffield Combined science course. The pupils had just recently completed the sections of the course. Each pupil also completed both SRTs II and III and their mean Piagetian level was calculated from the results. The correlation between the mean score of the SRTs and their science concepts exam totals were 0.77 (N=26) and 0.78 (N=86). These results can be regarded as a good measure of the predictive validity of the SRTs for students' understanding of science.

Table 1.5: **Statistical Reliability and Validity of Science Reasoning Tasks (SRTs) [1]**

Number and Name	**Internal consistency**	**Test-Retest correlation (N)**	**Task-interview correlation (N)**
I Spatial Relationships	0.82	Not assessed	0.85 (7)
II Volume and Heaviness	0.78	0.84*(67)	Not assessed
III The Pendulum	0.83	0.79 (24)	0.71 (24)
IV Equilibrium in the Balance	0.84	0.78 (31)	0.55 (18)
V The Inclined Plane	0.76	0.82 (32)	0.63 (15)
VI Chemical Combinations	0.76	0.64 (28)	0.65 (23)
VII Flexible Rods	0.86	0.85 (38)	0.79 (23)

*Obtained by Johnson (1977)

Results of CSMS survey

Between 1974 and 1976, the CSMS team set about to obtain a reliable description of the Piagetian level range of the student population. At this time, the general age/stage picture, presented by Geneva was as shown in Table 1.6 [25].

Table 1.6: **Age/Stage picture [25]**

Piagetian Level	**Symbol**	**Age**
Early concrete	2A	5/6
Mid concrete	2A/2B	7/9
Late concrete	2B	10/11
Early formal	3A	11/13
Formal generalisation	3B	14/15

The CSMS team surveyed approximately 14,000 students, between the ages of 10 and 16 years, from nearly 50 (middle, comprehensive and selective) schools in Britain and Wales. There were between 1000 and 2000 students for each year of age. The results, as displayed in Figure 1.5, show the proportion of children at each age, who are at or above each stage of development. For example, the late concrete line shows that just under 40 per cent of 10 year olds were at or above that stage, while over

80 per cent of 15 year olds had reached this stage. What this figure does not show is the large variation in the proportion of pupils at each stage found in different schools. The 3A stage, that of formal operational thinking, was assumed by Piaget to develop between the ages of 11 and 15 years. Figure 1.6 shows the percentage of pupils at or above this stage in three samples; (a) the sample representative of all pupils in England and Wales, (b) a sample drawn from grammar schools (typically only students in the top 15 to 20 percent ability range are selected to attend such schools), and (c) a sample drawn from schools that typically select students in the top 8 per cent ability range.

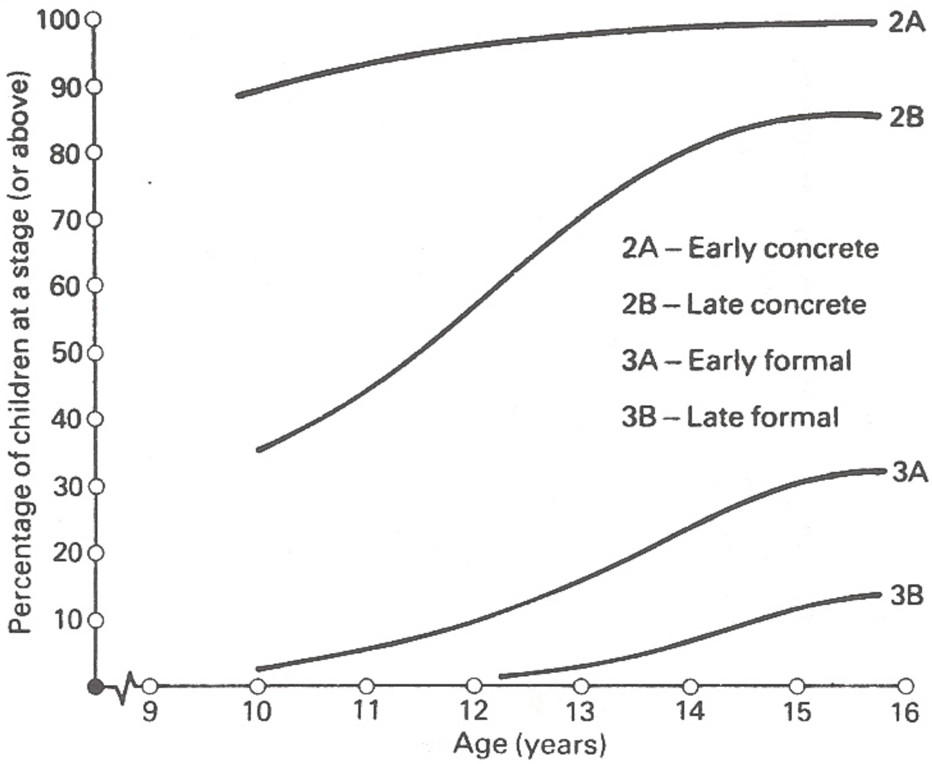


Figure 1.5: **Results from the CSMS survey; Proportion of children at different Piagetian stages in a representative British child population (taken from [1])**

The differences between the three groups shown in Figure 1.6 are clear. The data for the representative population shows that by the age of 14 years just over 20 percent of students are at or above the early formal operational stage of thinking. Not only does this contradict the Genevan age/stage model, it also highlights more serious implications in terms of meaningful engagement with science and mathematics. If only 20 percent of the sample population are at the early formal operational (3A)

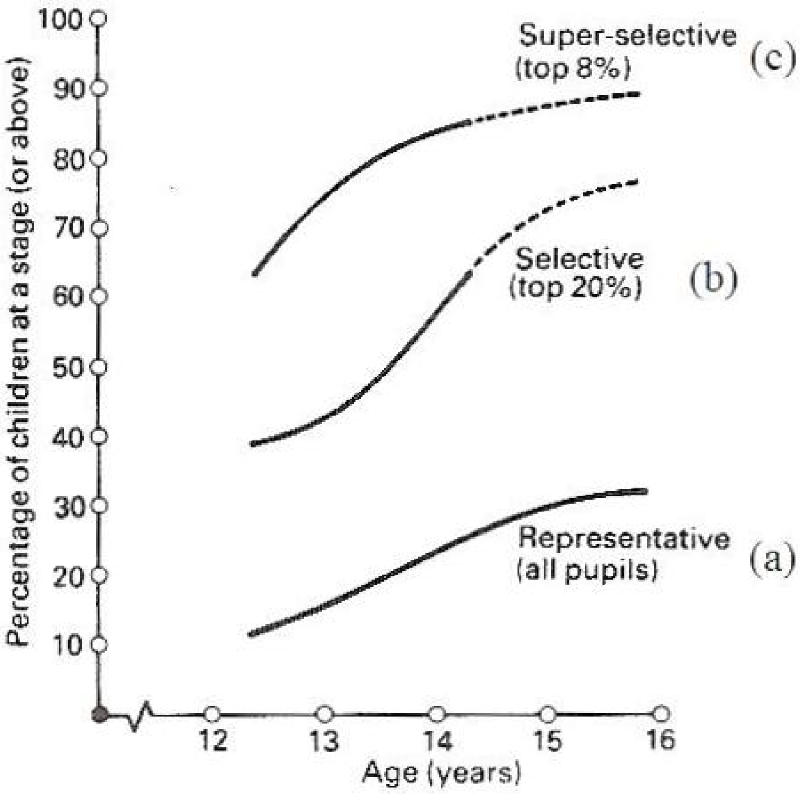


Figure 1.6: **Proportion of pupils showing early formal (3A) thinking in three different populations; a, b and c (taken from [1])**

mode of thinking it implies that up to 80 percent are not at this level and hence will have serious difficulties comprehending the sort of abstract models, such as atomic theory, that comprise much of the science curricula. Such a finding lead to the analysis of the science curricula for levels of demand which resulted in the development of the Curriculum Analysis Taxonomy (CAT) described in the next section.

In summary, the results from the CSMS survey showed that;

- The spread of ability was wider than expected. A school group, with an average age of 12 years, contained students who reason as average 8 year olds and others whose thinking is similar to the top third of 16 year olds;
- Only about 30 percent of students at the ages of 14/15 years demonstrated formal operational thinking;
- Small but significant gender differences were found for SRTs I and II with

girls performing worse than boys from ages 9 to 15+. This result reflects girl's poorer spatial ability and lower interest and motivation in mechanics;

- Task III showed no such gender difference up until age 13+. After this there seemed to be a stand-still in girl's development, one year earlier than for boys. This is shown in Figure 1.7.

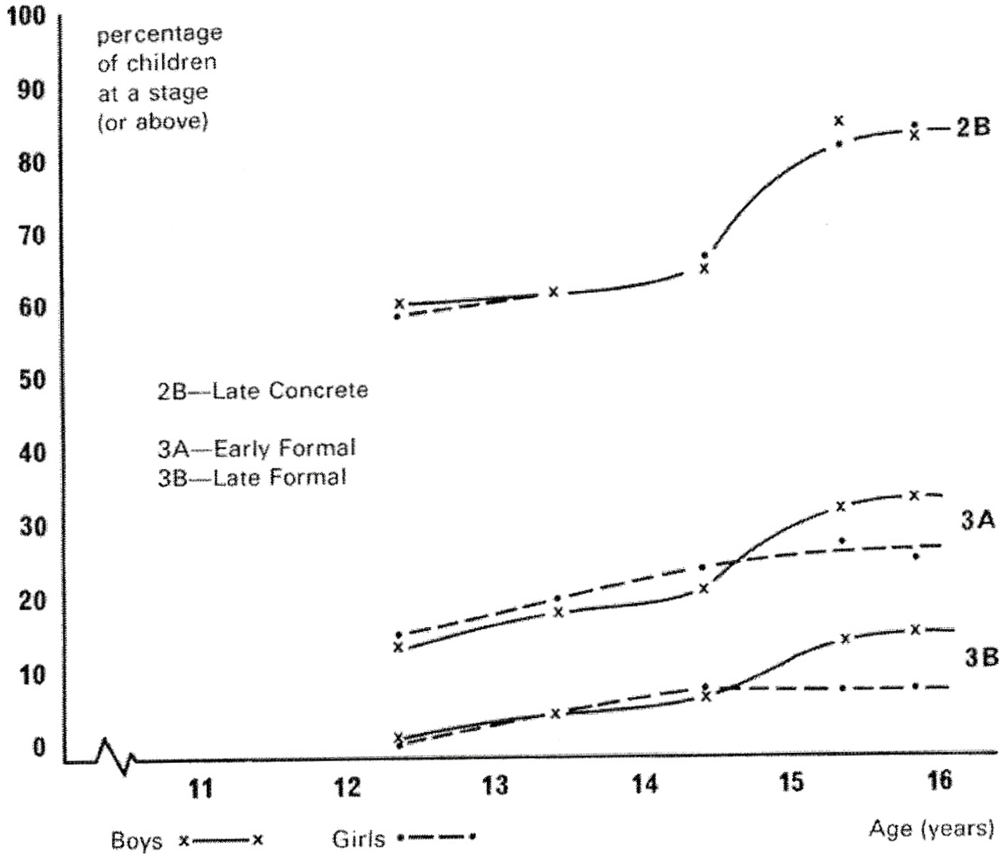


Figure 1.7: **Proportion of boys and girls at different Piagetian stages in a representative British population on SRT III: The Pendulum (taken from [35])**

Smaller surveys carried out in other countries, such as in Israel [2], Australia [40] and Pakistan [41] also verify that indeed about 70 percent of the adolescent population do not attain the formal operation level of cognitive development. More recent studies report no change in this trend [42, 43].

Analysis of Science curriculum materials-Curriculum Analysis Taxonomy

In light of the cognitive level profile of students depicted by the CSMS survey, Adey and Shayer decided to explore the cognitive demand made by the National Curriculum of England and Wales, particularly in the area of science. Piaget's schemata were used as the basis for constructing a descriptive curriculum taxonomy. The taxonomy arranged and classified curriculum objectives according to (i) the schema or reasoning pattern required, and (ii) the Piagetian stage of cognitive development characteristic of this schema [1].

Analysis of the Nuffield O-level science curricula was undertaken by Shayer in the seventies [44]. It was done by in-depth study of the works of Piaget on space, number, probability, physical quantities, causality and with reference to Piaget's publication, *The Growth of Logical Thinking* [38]. Shayer's approach was abstracted and described in two taxonomies and published by Shayer and Adey [1]. The first taxonomy deals with six categories that are descriptive of the mental abilities of the pupil. It describes psychological characteristics of children's thinking at the main five stages of cognitive development, from the pre-operational to late formal operational levels. The second taxonomy is comprised of nine categories and focuses on the schema of concrete and formal operations that are particularly relevant to specific scientific activity. For example, proportionality and equilibrium are used in many aspects of physics and chemistry, whereas correlational thinking is more often used in biology. Table 1.7 shows the categories within each taxonomy. The Curriculum Analysis Taxonomy will be discussed in much more detail in Chapter 4, where its use is extensively portrayed.

Table 1.7: **Categories of Curriculum Analysis Taxonomy (taken from [25])**

Taxonomy 1; Psychological aspects of children's thinking	**Taxonomy 2; Schema specific to science activity**
Interest and investigation style	Conservation
Reasons for events	Proportionality
Relationships	Equilibria of systems
Use of models	Mathematical operations
Type of categorisation	Control of variables
Depth of interpretation	Exclusion of irrelevant variables
	Probabilistic thinking
	Correlational reasoning
	Measurement skills

Application of this Curriculum Analysis Taxonomy to the 1991 National Curriculum for Science in England and Wales showed that there was a significant gap between the cognitive demand of the course objectives for 14 and 16 year-olds, and the levels of thinking available to them [25]. The National Curriculum was planned with the intent that approximately half of all pupils would be at the concrete generalisation stage, while the other half would be above the early formal level. Results from the CSMS survey showed that in reality only 14 percent of 14 year olds were at the early formal level or above. The first national SAT exam administered in May 1992 confirmed this glum estimation, with the results showing that the achievement of the 14 year olds was well below that even predicted by their potential from the CSMS survey [25]. This mismatch between expectations made of students and their ability fueled Adey and Shayer's proposal for the need for intervention.

1.1.3 Methods to accelerate cognitive development

After two decades predominantly occupied with investigating and assessing the cognitive developmental levels of the English and Welsh school population, Michael Shayer turned his attention to improving the curriculum material in order to raise the general intellectual capacity of students. In essence his question was; can cognitive development be accelerated? Piaget called this 'The American Question'. In 1975 Neimark wrote;

> *One of the more surprising gaps in reported research concerns what Piaget has called 'The American Question': the possibility of accelerating cognitive development through specific training...When more is known about the course of normal development and the variables which affect it, it is quite likely that sophisticated training research will begin in earnest. Piaget's prediction would be that all such attempts are doomed to failure* [5].

This 'American Question' initiated a whole set of other questions such as 'What is normal development?', 'Acceleration with respect to what?' and so on. However, fundamental to the question of the possibility of cognitive development in students, is the premise that development can be altered by environmental effects, such as mental stimulation ([17] (page 54)). If development was only determined by maturation, then promoting or accelerating it would have no significance. As Adey writes;

> *Methods of retarding normal cognitive development are easily imagined: lack of stimulation, de-motivating teaching, poor nutrition, or abuse. Methods of accelerating cognitive development are less easy to imagine* [45].

Adey and Shayer adapted a more positive approach in the light of this challenge. They decided to accept the Pascal wager set by Nickerson, Perkins and Smith;

> *The assumption that thinking skills can be taught, if they cannot should at the worst, lead to unsuccessful attempts to teach them. In time the futility of the search would become apparent, and the only loss*

would be the effort that has been devoted to the task. But suppose we reject the assumption that thinking skills can be taught when in fact it is true. How profound might be the consequences of failing to attempt to teach what so obviously should be taught [46].

By definition, the term 'cognitive acceleration' refers to the process of accelerating student's 'natural' development process through different stages of thinking ability, towards abstract, logical and multivariate thinking, which Piaget describes as formal operational thought.

The work of Piaget, Vygotsky and the pioneers of previous intervention programmes formed the basis of a theoretical platform on which Adey and Shayer built a mechanism to improve student's thinking. Essential features of this platform included;

- Higher order thinking skills can be well described by the reasoning patterns of formal operations;
- The evolution of formal operational thinking is developmental and occurs in response to a combination of variables including student's maturation, environment and history of development;
- One of the most important environmental factors is social mediation;
- Formal operations develop as a whole rather than each reasoning pattern developing independently;
- Formal operational reasoning patterns are not domain or subject specific.

Prior to Adey and Shayer developing a cognitive acceleration programme, they reviewed other's attempts to improve student's general thinking ability. In general, the programmes can be classified into two groups. A distinction can be made between approaches which aim to improve general thinking skills (context-independent) and those that aim to enhance thinking skills in a domain specific way (context-delivered), e.g., thinking in science, geography, arts, etc. The latter is the preferred approach in second level schooling, due to its practicality [47]. Another alternative to this is to adopt an across-the-curriculum approach by combining thinking skills across all subjects and lessons. Some approaches are very sophisticated in their implementation and evaluation, while others are more modest, but in general their common aim is to improve students' thinking levels and in doing so, provide a response to Piaget's 'American Question'. Some of the main programmes developed in response to this call are summarised below, and their key features and outcomes are highlighted.

Context-independent intervention

Context-independent intervention is delivered in special thinking lessons that are not within the context of a school subject. Two of the most well-known context-independent interventions, *Instrumental Enrichment* and CoRT, are discussed in this section in terms of their background, methodology and effects on cognition.

Instrumental Enrichment

Perhaps one of the most well known skills-based approaches is that of Reuven Feuerstein's *Instrumental Enrichment* (IE) [48], which originated in the 1950's. Feuerstein developed a highly successful course for learners with a record of low academic achievement. His intervention was deliberately not related to the context of ordinary school learning so that the students would not associate IE lessons with their previous experience of failure. The programme consists of 14 instruments, each containing between one and two dozen activities, and was intended to be taught at a frequency of five hours per week, over a period of at least two years. The target population were early adolescents from 12 to 14 years of age initially. Both the psychometric model of mental abilities such as spatial relations, verbal reasoning, or numerical abilities and the Piagetian account of different operations were used in the design of the course. The tasks are of a more or less abstract nature and the student does not need to have a high level of prior content knowledge to accomplish them. IE teaches 'thinking about thinking' and 'learning about learning' rather than specific subject matter. The instruments help the students develop strategies and working habits that they can apply to problem solving situations and generalise rules and principles which can be transferred to a wide range of curricular and extra-curricular domains and contexts. In order to create insight and reflective thinking, the students are encouraged by the IE teacher to come up with examples in which the newly acquired strategies and principles are bridged and applied in real life situations. In each lesson, as part of a paper-and-pencil exercise, the pupils with their teacher first discuss how best to find out what information they need to gather to work on the problems, and devise one or more plans for solving the problems (Input). After individual work on the problems, during which the teacher may interrupt to guide pupils out of unproductive avenues, the pupils again discuss, in terms of cognitive functions, their successes and difficulties with the task (Elaboration). This is followed by bridging, where other attempts are made to invent other applications, both in school learning and out-of-school activities, for the successful strategies (Output).

Feuerstein's methodology draws from social psychology, psychometrics and Piaget's theory. He refers to mediated learning experience (MLE) as being a causative theory of cognitive development [49]. He describes the learning of a child as being facilitated when the culture of the family and his/her social group is in a state of health. An important feature is the social interaction between experts, such as parents, teachers - who know more than the learner - and the student. Through 'mediation', experts structure the learning experiences of the students so that they are able to be more independent thinkers and learners. The activities and experiences that the experts present to the learners are named 'mediated learning experiences' (MLE). The essence of Feuerstein's theory is that;

> *Intelligence is not fixed. It is modifiable.*

Bridging was also another strong feature of Feuerstein's intervention. During and at the end of each IE lesson, students were encouraged to construct and talk through bridging examples where the principles they have learned and developed in the lesson are applied to contexts, within and outside school. This practice will be discussed in more detail in the following section.

At the end of the two year IE course, Feuerstein's students had shown modest gains in terms of increased IQ, when compared with a control group and they also demonstrated an ability to transfer learning from one situation to another. However, the most astounding results were found two years after the completion of the programme. The students of the IE programme, entered the Israeli army as part of mandatory service and on tests of general intelligence they were found to have an average equivalent to that of the general population. Before they started the IE programme they were three years behind. The control group did not show such development upon testing. Feuerstein attributed such gains to the ability that the students developed to teach themselves to be more intelligent. Originally designed for new immigrant students in Israel, Feuerstein's theory of MLE and IE proved to be beneficial for a wide spectrum of children and adolescents in different countries. The IE materials have been translated into at least seventeen different languages including English, French, German and Spanish.

Cognitive Research Trust-CoRT

Edward De Bono founded his Cognitive Research Trust (CoRT) in 1969, for creative and lateral thinking, but it was in 1976 that his book, *Teaching Thinking* [50], was published (one of 41 books which he has published on the topic, in 26 languages). The complete programme consists of 60 lessons made up of six sections with ten lessons each. Each section covers one area of thinking and each lesson builds on the skill addressed in the previous lesson. The programme is suitable for use with students from 12 years of age and has also been used as a management training tool for adults. The CoRT materials (1976) practise a range of procedures. For example CoRT I is concerned with helping students develop tools and habits for scanning widely around a thinking situation. Some of the following tools are emphasised; Consider All Factors (CAF), Plus Minus Interest (PMI), First Important Priorities (FIP), Other Points of View (OPV). The programme is based on an instructional approach, where the instruction is content free and is based on the strategies of thinking.

Evaluation of the programme in 20 British primary schools [51] showed no statistical difference between experimental and control classes in achievement post-tests of reading comprehension, arithmetical and logical reasoning. The average difference between the two groups was zero for the first year of study, and 0.17 σ (standard deviation) for the second year. In tests of creativity - the model underlying the intervention - the differences were also negligible. Edwards [52] reviewed a number of evaluations of the programme and concluded that the design of the testing procedures were weak and could not provide a basis for the detailed evaluation of the effects of CoRT. Results of a long term study by Edwards (cited in [25]) indicate that impressive gains at the end of a one-year CoRT programme are not evident after delayed post-test one year later. In light of work from Hudson [53] on diverging and converging thinking abilities, CoRT lessons, which are specially intended to enhance divergent thinking, may show effects on the above-average 14/15 year olds, who can make relevant use of their lateral thinking.

Context-delivered intervention

Context-delivered interventions involve an intervention programme being delivered within the context of a school subject, in which the students are familiar with. Two of the most well-known context-delivered interventions, *Philosophy for Children* and *Somerset Thinking Skills*, are discussed in this section.

Philosophy for Children

One of the best examples of a well-developed, consistent critical thinking skills course is Michael Lipman's *Philosophy for Children* [54]. Its influences have spread from the United States, where it originated, to widespread use in continental Europe and the United Kingdom. *Philosophy for Children* is not designed to teach philosophy to children, but rather to enable learners to think philosophically. The programme is not based on psychological theory but rather has its roots in the nature of philosophical thinking. Its goal is to create a spirit of reasonableness in a community of inquiry. *Philosophy for Children* is designed for students aged between 10-12 years, but it is progressive in complexity and also has a use with older students. The programme is usually delivered through the English or social science curricula. The materials include a series of 'novels' which play an important role in helping students to develop reasoning abilities applicable to a wide variety of situations. One of the key features of the programme is the encouragement of discussion between children. The aim of this discussion element is that students use a process known as metacognition, where they externalise their reasoning and in doing so become aware of their own thinking strategies. This process will be discussed in more detail in a later section.

The initial evaluation of *Philosophy for Children* showed that the experimental group (exposed to 18 40-minute sessions over nine weeks) made an equivalent gain of 27 months in a test of logical reasoning, compared with a comparable control group. This had an effect size of approximately 1 σ. The experimental group were also found to score significantly higher on a standard reading test two years after the initial intervention, implying that the programme had long-term effects on language use. Results from a larger scale evaluation showed that an experimental group (who were exposed to the programme over a one year period, at a rate of two and one-quarter hours per week) scored significantly higher in tests of logical reasoning, reading and mathematics compared with a control group. The programme required a considerable investment of time and resources, in terms of teacher training.

Somerset Thinking Skills

Blagg was influenced by Feuerstein's IE programme. He applied the learning skills developed in IE across a range of curriculum subjects and developed the *Somerset Thinking Skills* course [55]. This is an intervention programme that is based on the principles of Feuerstein's IE programme embedded into recognisable contexts of school learning. It was also influenced by information processing, analyses of intelligence, problem solving approaches and various curriculum projects. The course, designed for 10 to 16 year olds, aims to improve their level of skill and confidence in solving problems. The programme is visually based and is comprised of a series of materials arranged in modules, centered around specific themes, for example foundations in problem solving, comparative thinking, organising and memorising. The teaching of the programme is through mediation, inspired by Feuerstein's IE. It lies between being a context-independent and context-delivered type of intervention, suitable for use with a broader ability range of students. Evaluations show positive effects on a range of cognitive and related outcomes.

1.1.4 Cognitive Acceleration through Science Education

The mismatch between curricular demands and students' ability, discussed previously was highlighted in the United Kingdom with the demise of the selective school system, when for the first time, teachers in grammar schools had to teach the full range of students in the population, as opposed to the top 20 percent ability range that their previous students hailed from. In the United States, the problem surfaced a little later, upon entry to college when it showed up that many first year college students had a poor grasp of fundamental scientific concepts, previously covered at second level education [56]. Adey [57] suggests that world-wide the difficulty of science concepts tended to be masked by rote learning and so the issues that arise from learning or teaching for real understanding are avoided. Declining standards in education could either be addressed by altering the curriculum or attempting to increase students' cognitive developmental levels [25]. In response to the latter option, the Cognitive Acceleration through Science Education (CASE) intervention programme was developed.

Purpose of CASE

The CASE programme, pioneered in the early 1980's by a group - Adey, Shayer and Yates - at King's College London, was designed as an intervention in the science curriculum for students aged between 11 and 14 years. The main aim of the programme was to increase the proportion of second level students with formal operational thinking, as earlier research on both sides of the Atlantic [16] had shown that success in secondary school science and mathematics requires this level of processing. The development of CASE was inspired by three facets of previous research; [58];

- Piagetian theories on the mechanism of cognitive development;
- A review of literature on investigations of cognitive acceleration programmes with pupils aged 10+ in broadly scientific contexts;
- The experience and results of pilot studies with two third year classes in Sussex, U.K. and two second year classes in the Inner London Education Authority (ILEA).

The materials of the CASE project were called *Thinking Science* and were first published in 1989 [59]. There were 32 lessons in the original materials, a list of which are shown in Table 1.10 (on page 73). Adey and Shayer [60] outline several constituents that were central to each of the CASE activities, each of which will be discussed in more detail later on in this section;

- the introduction, through concrete activities of the terminology of relationships and the context in which a problem will be set *(conceptual readiness)*;
- the presentation of problems which challenge student's current level of thinking *(cognitive conflict)*;
- the encouragement of students to think about their own thinking *(metacognition)*;
- the linking of thinking strategies employed and developed within the context of the CASE lessons to other areas *(bridging)*.

The theoretical foundation of the CASE method is partly Piagetian, with an emphasis on providing conflict situations which encourage equilibration and the construction of the reasoning patterns of formal operations by students themselves. Of equal importance is the Vygotskyian influence, with an emphasis on social construction of reasoning, through metacognitive reflection and carefully managed use of the language of thinking. In particular, they were influenced by his proposal of a *Zone of Proximal Development* (ZPD) that proposes that children not only have a set of developed skills but they have some undeveloped cognitive skills, which they are capable of using successfully with the effort of the child or due to the mediation of a peer or an adult. Several aspects of the CASE strategy have potential to facilitate student's growth within Vygotsky's *Zone of Proximal Development.* The developers were also strongly influenced by the IE [48] programme and in particular the idea of bridging where a term or concept learned in one context is applied in a different but relevant area. This will be discussed later in this section.

Target population

The developers of CASE were concerned with designing the programme for use with the majority of the student population, for whom science appeared to be difficult. The authors specified their methodology for targeting the materials at a specific population in terms of ability and age.

- **Ability**

The target population, in terms of ability, was the middle 80 to 90 percent of students. This decision was a crucial one in terms of planning the experience of cognitive conflict. The exceptionally able child, who is using formal operations by age eleven, may find the materials enjoyably challenging while the child with learning difficulties, who may be at pre-operational stage at age eleven may not be ready for the demands of the lesson. Adey [57] admits that while careful design of activities and adjustable teaching can provide a wide range of levels of cognitive conflict within a particular activity, it was impractical to include the entire spectrum of abilities.

- **Age**

In terms of age range, the 11 to 14 years were targeted. This range was deemed most suitable as it is at this age that students prepare for formal operational thinking. Adey [57] refers to work by Epstein [61] who provides evidence that there are growth spurts for girls at age 11 years and for boys at age 12 years. This spurt may be part of a physiological maturation programme evolved to prepare adolescents for the intellectual requirements of adulthood. As stated earlier, results from the CSMS survey showed that only a small proportion of children complied with the age/stage picture of cognitive development presented by Piaget. Adey [57] suggests that such a result could indicate a lack of quality intellectual stimulation for the majority of students at home or school. In response, such a deficit should be rectified by providing appropriately designed stimulation at the right ages. There was also a more practical reason as to why this 11-14 age group was targeted. In the United Kingdom, students at the age of 11+ years transfer from primary school to secondary school. As in most countries, primary school teachers are non-specialised and teach a range of subjects. At second level the teachers are specialised subject teachers. Adey [57] proposes that an intervention set within the context of science requires science teachers who understand the nature of the scientific reasoning patterns which form the context of the intervention.

Context

With the decision made to run the intervention in the second level school setting, the next decision was how would the intervention integrate with the hectic school time-tables. The least attractive option was to have schools reconstruct their time-tables to include a new space for non-domain specific 'thinking lessons'. This had already been proved difficult by those wishing to implement programmes such as IE [25]. The obvious solution to this problem was to embed the CASE intervention into an existing subject on the curriculum. This imperative decision also shielded teachers and students from a potential unfamiliarity factor and almost immediately teachers and students alike could apply new thinking skills within a familiar context.

Another decision that needed to be made was the selection of the domain that the intervention would be delivered within. The early 1990's had seen an emphasis on the need and value of domain specific thinking skills and a disregard for the role of general cognitive processes [62, 63, 64]. The strong message from the education literature was to concentrate on strategic knowledge bases, characteristic of each of the domains of knowledge considered to be important for social, cultural or vocational reasons, and not to waste time on attempts to teach general thinking skills [25]. Adey and Shayer [25] reject the notion that science is in any elevated or esteemed position for the development of general thinking skills but the previous work done in the area of the science domain gave it certain pragmatic advantages over other subjects. In addition, Adey and Shayer's expertise lay in the field of science teaching and so the subject of science seemed the most obvious context for the cognitive acceleration programme to be set.

Time-frame

The CASE programme was designed for implementation over a two year period, at a rate of approximately one lesson every two weeks. The developers decision came in light of Lipman and Feuerstein's work, which suggests that an intervention programme must be run over a sufficiently long period of time if it is going to make a permanent difference to the way in which students learn and approach problem solving. Feuerstein reported that the students who received two years of his intervention, the IE programme, did significantly better than those who only did one year of the intervention programme [48]. However, Feuerstein does suggest that the increased effect on the subjects who undertook the intervention for the two year period may be due to the fact that certain instruments that could be responsible for the increases cognitive effect are only offered during the second year of the intervention programme. However, Adey and Shayer reside with Feuerstein's original view and argue for the value of the intervention being run over the longer period of time. Adey and Shayer [25] state,

> *If your [development of thinking] model includes some central processing mechanism of the mind which is supposed to develop under the influence of maturation as well as environmental stimulation, then it seems inevitable that any environmental influence will be slow acting and should be maintained for long enough to be effective* [25].

They make the case quite clearly that short interventions or exercises are fruitless in terms of cognitive development. In light of all the evidence from literature and their own pilot studies, Adey and Shayer interpreted this 'long period' to be two years.

One study by Kim, Hann and Shayer that contradicts the necessity of the two year period is that set in a Korean primary school [25]. Students in the penultimate and final year of primary school were given 26 out of the 32 CASE intervention lessons over a period of one year, in place of their regular science lesson. As a control group 50 children, of the equivalent range of ability, followed the normal science curriculum. The effects of the CASE programme were measured by the SRT II (*Volume and Heaviness*), the Raven's Matrices test, a school-based test of science achievement and the Korean test of science process skills. Results showed that there was an increase in cognitive ability for the final year (grade 6) students in particular. This study highlights the immediate success of the CASE intervention implemented over a one year period. One other interesting point that emerges from this study is the success of implementing the CASE programme in the final years of primary level. Adey and Shayer [25] however in light of these results recommend, that the more cognitively challenging of the *Thinking Science* lessons are removed and replaced with new activities orientated to the concrete generalisation/ early formal stages of cognitive development.

The pillars of the CASE programme

The theoretical model for CASE is one that evolved rather than was developed outright. Adey [57] admits that at the beginning of the development of CASE the designers did not have a fully articulated theoretical model. Adey and Shayer [25] compiled five features, which became known as 'pillars', and which now form the basis of the cognitive intervention programme, CASE. These are;

- concrete preparation
- cognitive conflict
- construction
- metacognition
- bridging

In developing the activities the 'pillar' of cognitive conflict was deemed essential and was recognised as the central process of cognitive acceleration. Constructivism was one of Piaget's main features of cognitive development. Concrete preparation was born out of practical necessity to any lesson. Similarly, bridging seemed of obvious importance to the developers if the schemata developed were to be generalised and applicable for further use to students. The importance of metacognition within the framework of CASE grew throughout the project and became an essential feature of the CASE methodology.

The lessons of the CASE intervention were designed around the schema of formal operations. These include control and exclusion of variables, ratio and proportionality, equilibrium, compensation, correlation, probability, compound variables and the construction of formal models. None of these were taught in a direct way, but each lesson in the programme had one of these reasoning patterns as their underlying focus. The pillars and the schema of formal operations, which are central to the CASE programme, were all influenced by psychological theorists. Table 1.8 shows the feature of the CASE lessons and the theorist who influenced them.

Each of these features are now discussed separately, with the pillars featuring first, in relation to their meaning within CASE and some relevant examples. Following this, the schemata of formal operations will be discussed.

Table 1.8: **Influence of Piaget, Vygotsky and Feuerstein on the development of CASE (taken and adapted from [25])**

CASE pillar	**Piaget**	**Vygotsky/ Feuerstein**
Schemata of formal operations	√	
Concrete preparation (i)	√	√
Cognitive conflict (ii)	√	
Construction (iii)	√	√
Metacognition (iv)		√
Bridging (v)		√

(i) Concrete preparation

Without context or meaning to a problem, a problem does not seem worthy of attention. This is the justification for the first pillar of the CASE methodology. As described by Adey and Shayer [25], to someone who has never seen a hat or a rabbit, it is not interesting to see a rabbit pulled out of a hat. The subject could well and truly believe that rabbits live in hats and hence there would be no such wonder to the trick. The same analogy can be translated to science.

Concrete preparation is the part of the lesson where the framework of a problem is set. Familiarity is established with vocabulary and apparatus and the students are presented with an opportunity to become acquainted with terminology. The first lesson in *Thinking Science*, called 'What varies?', is based on the concept of variables. The teacher displays a selection of books on the table and may ask in what way are the books different from each other. Answers would typically include 'colour', 'size' and 'genre'. The teacher would then introduce the term 'variable' to describe these differences and the values of this variable would include green, yellow, black, big, small, etc. In the same lesson, the term relationship is encountered. In order to allow students to become familiar with this term, in the context of variables, the shapes, shown in Figure 1.8, would be displayed to the class. Students would be asked to name the variables and values and then to determine the relationship between the variables, i.e., colour and shape. Following this, a different selection, the second combination, would be displayed, as in Figure 1.8, and the new relationship between these variables would be defined. i.e. size and colour. An extension to this would be presentation of examples where the students must establish that there is no relationship between the variables.

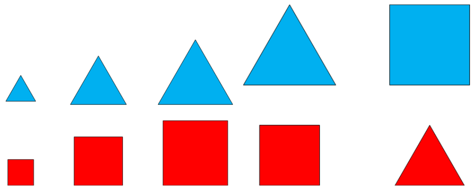


Figure 1.8: **Lesson 1; *What varies?*, First (left) and second (right) combination**

In essence, the purpose of concrete preparation in the lesson is to ensure that any difficulties encountered in the lesson are purely intellectual and not due to misunderstandings regarding vocabulary or equipment used during the lesson. To ensure that the majority of students (90 percent) can gain confidence in the use of vocabulary, before they are asked to use it in the light of an investigation activity which may require formal operations, it is suggested that the practise examples require processing at no more than the mature concrete (2B) level. Mostly, in conventional teaching of science and mathematics new vocabulary is never introduced until the subject-matter which requires its successful interpretation is first met. This has benefits in relation to the motivation of students, where they see the relevance and need for the more powerful vocabulary or concept. However, in this conventional way only a smaller percentage, maybe only 40 percent of the students in a mixed ability class, get to use and understand the new vocabulary if the context where application is made requires formal operational thinking, compared with 90 percent in the CASE methodology.

(ii) Cognitive Conflict

Central to the process of cognitive acceleration is the idea of setting problems which students cannot readily solve, using their present level of thinking. The pillar that addresses this is cognitive conflict. Cognitive conflict is a term used to describe a dissonance which happens when a child is faced with an event that he/ she cannot explain using their current conceptual framework or method of processing data [65]. Students are presented in each lesson with an event that they find puzzling and contradictive to their previous experience or understanding. The underlying principle is based on the Piagetian idea of equilibration and the Vygotskyian idea of ZPD. The CASE intervention provides activities designed to offer graded challenges to its target population of young adolescents.

Fensham and Kass [66] note that everything which a student finds surprising does not necessarily fulfill the potential of cognitive conflict. They suggest that the majority of surprising experiences are dismissed as 'inexplicable', 'uninteresting' or 'incapable of being explained'. Their message is that a cognitive conflict scenario must be, (i) within a context that is somewhat familiar to students and, (ii) not too far ahead of student's cognitive capabilities while still making a real cognitive demand. Kuhn *et al.* [67] thoughts on cognitive conflict reiterate the need for concrete preparation in the lesson. Students confronted with evidence which they find difficult to explain, often produce a series of irrational or self-contradictory statements in order to 'explain away' the apparent contradiction without fully engaging in it. For the event to have any effect on student's cognitive structure he/she must be prepared to either expect one thing or be ready to compare what does happen to other possible explanations. The conflict requires careful management by the teacher.

The goal of the CASE intervention lessons is to ultimately induce higher order thinking. The cognitive conflict scenarios provided should be such as to help students construct these higher order or formal operational reasoning patterns for themselves and not merely to engage in a scenarios where cognitive conflict arises concerning a particular topic and the aim of the activity is the construction of the concept. The aims of CASE are a higher risk strategy than the afore mentioned but the potential benefits are much more general.

Examples of cognitive conflict

Lesson 27 of *Thinking Science*, 'Floating and Sinking', aims to present the concept of density, through the CASE methodology with the underlying schemata of compound variables. After the concrete preparation part of the class, i.e. brief discussion of what substances float and sink, identification of variables to be investigated, etc., the students are presented with two sets of concealed jars. Five jars, A-E, are all the same size but vary in mass starting with A, which is weighted to 400g, up to E with 1200g. Six jars, 1 to 6 are all varying sizes but are each loaded with the same mass. The sets of jars are shown in Figure 1.9. Jar A and jar 6 are identical. The students are instructed to weigh each jar, drop it in a large bowl of water, observe whether it floats or sinks and then record the result. Considering jars A-E first, only two variables are involved: mass and buoyancy. From the results, students can create a model that 'heavy things sink and light things float'. The same procedure is repeated with jars 1-6 only carried out in reverse order. This leads to another concrete model: 'small things sink, big things float'. Now jar X, shown in Figure 1.10, is produced. It weighs the same as jar C, which floats and it is the same size as jar 3, which also floats. The models established so far would lead to the conclusion that jar X would float, but when it is placed in the water, it sinks. Here a conflict arises between the experience and the concrete operations used so far. Students at this point are puzzled and seek reasoning for this surprising result. The concrete operations employed will not provide an explanation for jar X sinking. A more complex formal operational reasoning model is necessary, namely that of the compound variable, density. A similar procedure is carried out with jar Y, which is the same mass as jar B and the same size as jar 5. Not every student will grasp the concept of density from this one conflicting experience but they will develop their collection of general ideas - in this case, on compound variables - which provide explanatory power in a wide range of situations.

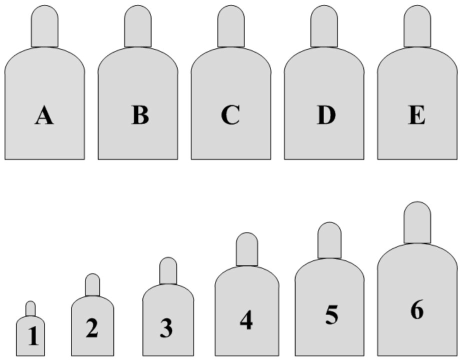


Figure 1.9: **Lesson 27; *Floating and Sinking*, Density jars A-E and 1-6**

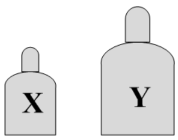


Figure 1.10: **Lesson 27; *Floating and Sinking*, Density jars X and Y**

Another example of cognitive conflict can be taken from Activity 8, 'The wheelbarrow'. This lesson yet again starts from the familiar exercise of identifying variables and recognising the relationship between them. Students practically find the relationship between effort and load for a number of loads, using the apparatus shown in Figure 1.11. Focusing on the constancy of this ratio they are introduced to the idea of proportionality. On a worksheet the students are asked to calculate values of lifts needed for loads they have not tried. Some may be done by interpolation and some by 'adding on' the same amount as the difference between two loads. These are both concrete strategies that work for smaller loads. These strategies become increasingly difficult to use with heavier loads, e.g., 29N, which causes cognitive conflict. At this point the teacher should encourage students to use a ratio method, and hence give value to the relationship between the two variables.

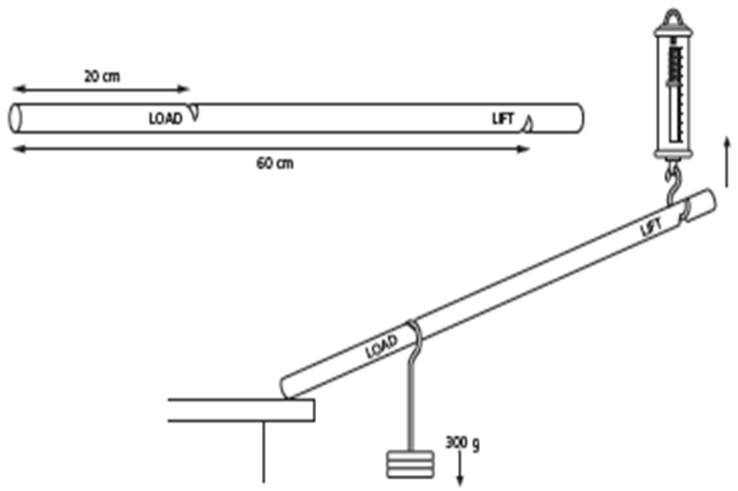


Figure 1.11: **Apparatus set-up for *Thinking Science* Activity 8, 'The wheelbarrow' (taken from [68])**

Both of these examples show that effective cognitive conflict is in the hands of the teacher. No printed materials could ever by themselves encompass the process. Lessons can be designed that provide excellent opportunities for the generation of conflict, but unless the teacher has professional ownership of the methods it is unlikely to produce the intended effects. Cognitive conflict can be a difficult pillar to implement. Adey [69] claims that the reason for this lies partly in the fact that teachers are essentially nice people and often instead of watching their students struggle and possibly become frustrated or uncomfortable, teachers often rush in with answers which they feel to be helpful, but in fact defeat the purpose of the CASE process. Providing cognitive conflict requires a fundamental shift in teacher's attitude to classroom practise and a greater understanding and appreciation of the philosophy of CASE.

The role of practical work in CASE

The discussion about the value of practical work in science teaching and learning is a lengthy and complex one [70, 71]. Hodson [70] argues against the value of doing practical work in science, although his criticisms are directed mostly at the recipe-following methods which constitute much of practical laboratory work in schools. Although such methods of science experience may teach students something about observing, following instructions and handling instruments and chemicals, they are in no way beneficial to the development of scientific thought. However, practical experience of the way things behave and operate is an essential part of the development of more powerful ways of processing data and thinking about the world. Adey [65] claims that is it only by interaction with reality that a learner can test their models of reality. Practical work offers this chance to test tentative theories against reality and this is the role that practical work plays in CASE. The philosophy of CASE is orientated towards making the activities intellectually demanding on students. The level of demand must be realistic for every individual in the class. However, if the level of demand is too high, students are left struggling helplessly and the activity is of little value to their cognitive development.

(iii) Construction

If cognitive conflict has disturbed the student's equilibrium or feeling of understanding, construction is the process which follows. This is the process where equilibrium is re-established through the development of a more powerful and effective way of thinking about the problem. Newman *et al.* [72] describe the 'construction zone' as the realm where two people's thoughts mediate and as a shared activity in which interpsycholgical processes can take place. They propose that if you engage the student in a complex shared activity with another, there is a 'chemistry' in the construction zone that allows one mind to appropriate another's thinking and that provides new meaning. The mind the student finds in this construction zone may be that of a teacher, expert adults or peers. White describes the construction zone as;

> *a magic place where minds meet, where things are not the same to all who see them, where meanings are fluid, and where one person's construal may preempt another's* [72].

Carloyn Yates, involved in the initial development of CASE, proposed a 'jig-saw' puzzle analogy for the process of construction [25]. She describes the analogy as two or more people sitting around a table completing a jig-saw, one person fitting in a piece often stimulates another. If one of the players is a teacher who knows well how the jig-saw goes together they can ask tactical questions to aid the process and occasionally add a piece themselves. However, unless students construct much of the jig-saw themselves it will not be their own and in learning terms, they will not have gone outside their present level of thinking. The ideal in the classroom situation is that the teacher floats from group to group, expending focused questions.

The overall aim of the construction zone in the lesson is to maximise the opportunity that each student has for constructing their reasoning patterns i.e. schemata, which he/ she will rely on for more powerful thinking in the future. Good cognitive acceleration lessons include a great deal of on-task discussion and constructive argument in small groups and between groups. Individuals and groups within the class must learn how to put their ideas across in a clear and tangible manner, how to listen to others and how to challenge ideas in a constructive manner. Managing this type of discussion can be a provocative and difficult task and in some ways is culturally the opposite approach to what would be regarded as good conceptual teaching. Often the teacher must take a risk and abandon the comfort of knowing where the lesson is going and value the quality and fruit of the argument, wherever it may lead.

(iv) Metacognition

This term, although somewhat over-used, according to Brown [73] simply means thinking about one's own thinking. An important part of the trick of developing thinking skills is for students to become conscious of and articulate about the thinking they employ to solve different problems. Thinking back and reflecting aloud helps to develop this consciousness. The requirement for consciousness means that it is a process that must take place after a thinking act since at the time a student is engaging in a problem-solving activity, their consciousness must be devoted to that. Only afterwards can they think back to the steps they took, and become aware how their own conceptualisation changed during the activity. Some literature that reviews the development of thinking [74, 46] claim that a common feature of programmes that claim success in improving problem solving, is their encouragement of metacognition.

Metacognition has various forms. We can think about what we know - metacognitive knowledge -, we think about what we are currently doing - metacognitive skill - and also we can think about our current cognitive state - metacognitive experience. In order to appreciate the difference of metacognitive thinking from other kinds of thinking, it is necessary to consider the origins of metacognitive thoughts. The source of metacognitive thoughts lie in the individual's own internal mental representations of external reality. This can include what the individual knows and feels about the internal representation and how it works. In the words of Flavell, metacognition is;

> *knowledge and cognition about cognitive phenomena* [75].

Adey and Shayer [25] describe metacognition as;

> *... the conscious attention in one's own thinking- going-above, as it were, and looking down on one's own thinking...*[25].

Nickerson, Perkins and Smith describe the objective of metacognition as;

> *to make one a skillful user of knowledge; and utilisation of the term metacognitive skills serves to remind us that more is undoubtedly involved in this than simply giving out some new information about cognition* [46].

While devising the CASE materials the authors were quite aware that metacognition was probably one of the features that could not be explicitly written in the printed materials [59]. It is not easy to illustrate from particular *Thinking Science* materials and for the most part it was built into the associated teacher training (INSET; in-service education for teachers), rather than written into the published materials. The CASE intervention sought to promote student's thinking about their own thinking processes, how to reflect on difficulties and successes they had with problems, discussion with others on how they succeeded or failed to solve problems and to increase their understanding of the vocabulary of reasoning, so that they could more easily transfer reasoning patterns from one context to another. It often requires a deliberate intervention by the teacher to make students undertake metacognition.

One example where the process is induced by the activity itself can be seen in Activity 21, 'Making groups'. This lesson is comprised of five activities, all with the objectives of students to classify groups i.e., animals, foodstuffs, chemicals, etc., according to their characteristics. The last section, shown in Figure 1.12, is explicitly a metacognitive section, where students are encouraged to think about the way they tackled the different classifications. In this worksheet, the students are asked to consider the classifications they have done, reflect on what was the easiest/most difficult and why. This encourages students to become accustomed to reflecting on the sort of thinking they were engaged in, make them conscious of it and ultimately to make it an explicit tool, which is then more likely to be available for them to use in a new context. Most metacognitive activity in *Thinking Science* lessons is mediated by questions from the teacher as they move from group to group or as a whole-class activity. The teacher encourages students to talk to each other about how they solved problems and reflect on what they were thinking when they approached the problem. The teacher can then encourage students to listen and question each other's methods of problem solving, classification, etc., using questions similar to the following;

What were you thinking about when you did that?

How did you get that answer?

You seemed to have a different way of doing it, can you explain how you decided you would do that?

Adey [76] refers to the use of appropriate terminology as the crystallising factor in the reflection of students on their own problem solving processes. In the early stages of the *Thinking Science* programme, students become familiar with terms such a variables, values, relationships, while later on in the series they begin to recognise proportionality, probability and compensation scenarios and they can use the appropriate words or terms to describe them. This is an application of what Vygotsky [15] describes as the use of language as a mediator of learning. If a student can recognise a problem as being a 'compensation' or 'classification' one in one context then it is an essential precursor to recognising those types of problems in all contexts. This subsequently is a precursor to the student being able to solve the problem in the other contexts [76].

Thinking Back

Put a tick by the classification activities you found easiest.
Put a cross by the one you found most difficult.

1. Living and non-living things ○
2. Chemicals ○
3. Store cupboard ○
4. Big animals ○

Why was the one you ticked the easiest?

____

Why was the one you marked with a cross the hardest?

____

Has everyone ticked and crossed the same thing as you?

____

Write a sentence about a friend, using the word characteristic.

____

Why do you think that it is useful to be able to classify things?

____

Figure 1.12: **Lesson 21; *Making groups*, Metacognitive activity (taken from [59])**

Metacognition is the most difficult pillar of CASE for teachers to manage [69]. The authors cannot precisely identify as to why this is so but they elude to the idea that until teachers have learned to question their own beliefs and found ways of reflecting on their own practise in an open and non-defensive manner, they will struggle to encourage its development in others. They suggest that it is very often not until the second year of teaching through CASE that teachers become capable of getting their students to probe their cognitive processes in a productive way.

(v) Bridging

Bridging, the final pillar in the CASE methodology, is the explicit link in the chain of developing, abstracting and generalising reasoning into other contexts. Bridging takes place when teachers transfer class management strategies, that characterise cognitive acceleration lessons, to the rest of their teaching. Before cognitive psychology became prevalent as a discipline, the area of 'bridging' had been recognised as been important in efforts to develop models of the mind [65]. In addition, it was generally received that transfer never occurred without quite explicit attempts on the part of the teacher to make it happen. The term 'bridging' is taken from Feuerstein's *Instrumental Enrichment* [48] and it is a feature of every IE lesson. Bridging can occur on a few levels in a class. One example would be where the concept developed in the class is transferred to other contexts that employ a similar technique. For example in Activity 26, 'Pressure', the concept of compound variables is introduced. Students design an experiment investigating the effects of weight and area on the depth that a rod sinks, using the materials shown in Figure 1.13. After carrying out the experiment and discussing the results, the term compound variable is used to name the two variables combined, i.e. weight/area.

The second example of how bridging may be achieved is in a regular science lesson, i.e., non-intervention, where the reasoning pattern previously developed is applied. After practising the reasoning pattern and naming it, the bridging part would involve seeking examples of its use in other lessons, topics and everyday life. An example of this is present in Activity 7A, 'Bean Growth 1' where the ideas of population variation and sampling variation are introduced at the concrete level. After carrying out an activity on the topic, the finale of the class involves linking what was learned in the class to its relevance in everyday life, i.e., how representative are opinion polls?

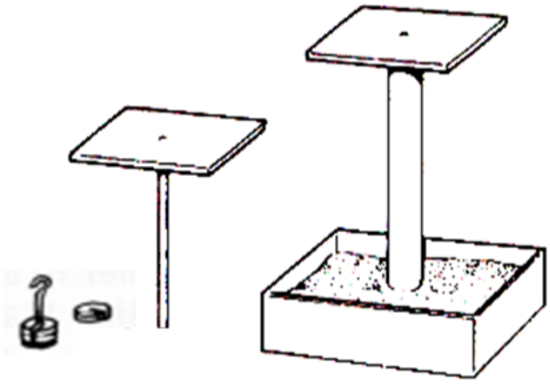


Figure 1.13: **Lesson 26; *Pressure*, Investigation apparatus (taken from [59])**

If the concept of bridging is extended even further it can include metacognitive awareness of problem solving strategies. Adey and Shayer [25] propose that for bridging to be effective, students need to have completed the metacognitive part of the lesson first, and the idea of bridging cannot be completely separate to that of metacognition.

> *If bridging is the conscious transfer of a reasoning pattern from a context in which it is first encountered to a new context, then the transfer is most likely to be effective if the reasoning pattern has previously been made conscious and verbalised* [25].

Shayer suggested that bridging by the teachers may be responsible for long-term large scale effects of cognitive acceleration, rather than the lessons themselves.

Figure 1.14 shows the structure of a CASE lesson in terms of Acts. Each *Thinking Science* lesson is comprised of one or more 3 or 4 Act cycles. Act 1 refers to Concrete preparation, Act 2 refers to Construction, where the class splits into groups. Act 3 is metacognition, while Act 4 is bridging.

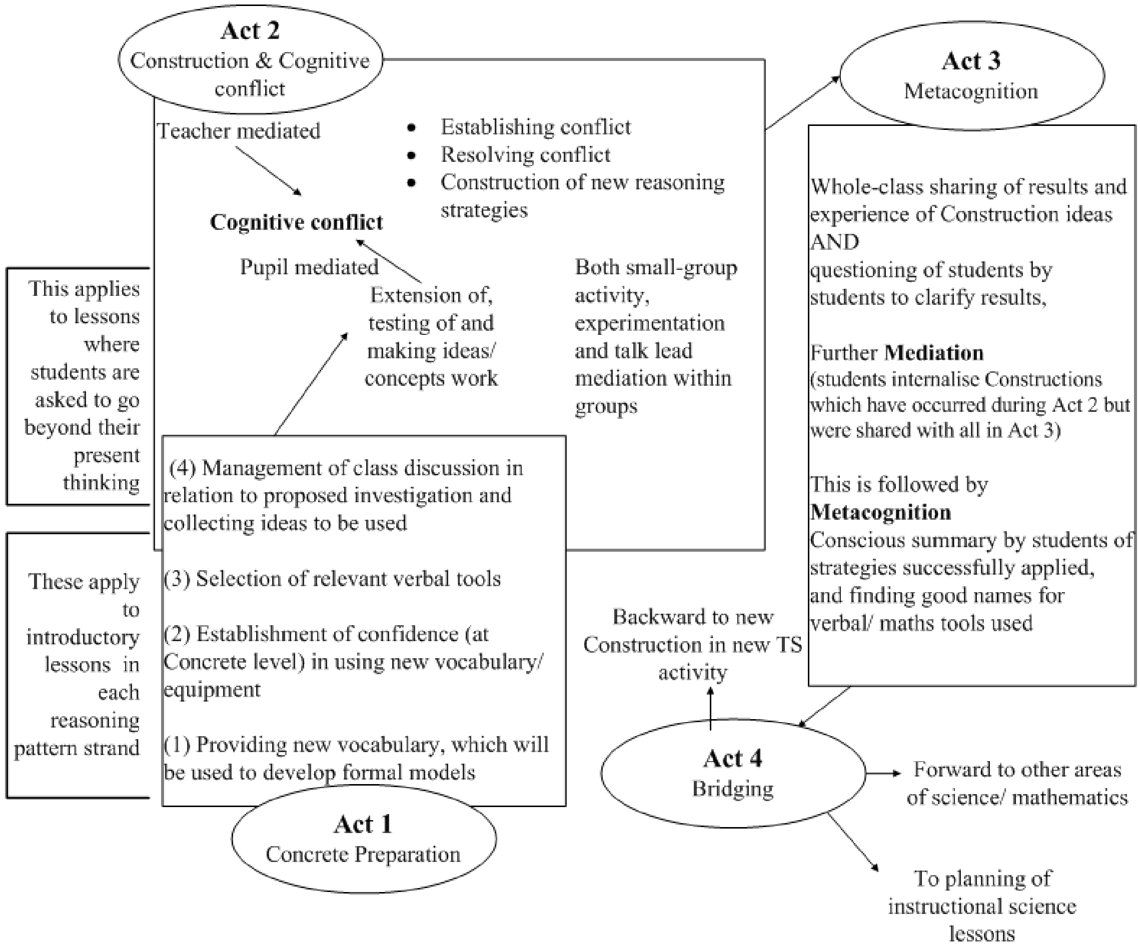


Figure 1.14: **Technical Phases of CASE (adapted from [77])**

Schemata of formal operations

Each *Thinking Science* lesson has underlying reasoning patterns, each of which are characteristics of abstract thought required for school science. Abstract thinking, as described by Adey [58], implies the ability to think and use concepts such as controlling variables, correlation or ratio, to solve problems removed from specific examples and contexts. There are several areas of abstract thinking that have been studied in depth, including control of variables, proportionality and ratio. Inhelder and Piaget [38] believed that formal operational thought was general to all domains and they proposed that the complete cognitive structure of formal operations includes a set of 10 reasoning patterns, or what Piaget termed as 'schemata of formal operational thinking'. They also proposed that all the schemata develop together over roughly the same time-span and an individual who is competent in a few of the reasoning patterns, can become competent in the use of all of them with some experience [33].

The main reasoning patterns of formal operations are grouped in as Figure 1.15.

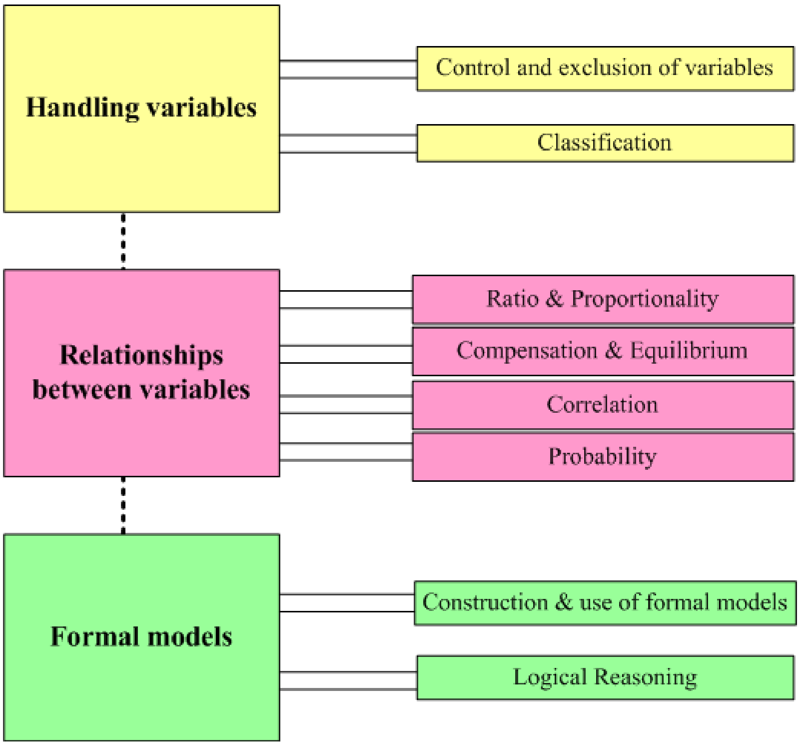


Figure 1.15: **Schemata of formal operations**

With the aim of the CASE project clearly in mind, to encourage the development of thinking from concrete to formal operations, the *Thinking Science* lessons were designed accordingly. Each lesson was designed to individually address each of the schemata of formal operations, and the content was incorporated into the principles of concrete preparation, cognitive conflict, social construction, metacognition and bridging.

It is important to note that the schemata were not the objectives of the lessons. The *Thinking Science* lessons were not designed to provide instruction on 'controlling variables' or 'doing proportionality problems'. The experience of many who have aimed to do this has ended in failure [65]. In addition, the model on which the activities are based does not predict, for example, that after three classes on probability that the schema will be mastered. It was not envisaged by the authors that each schema would be developed independently of the entire construction of formal operations.

It can be seen that in theory the characteristic of most of this formal operational stage of cognitive development encompass a large part of the agenda of school learning in science and mathematics. Studies show that second level science curriculum materials require students to use formal operational thinking [25]. Such thinking is necessary for the manipulation of formula, the design of rigorous scientific experiments and determining the relation between the experimental data and abstract scientific theory. The study of science for students who have not reached this formal operational period is likely to be excessively challenging and unproductive.

The schemata of formal operational thought are discussed below, in terms of their meaning and examples of how they were addressed in the CASE materials.

(i) Handling Variables

This group of reasoning patterns is vital for the sciences and many other domains. All experiments and investigations involve the notion of controlling variables. In its simplest form, a good experimental design involves changing one variable at a time, with respect to another and monitoring cause and effect. This relies on the subject having the ability to identify relevant variables and then identifying all the possible combinations. In addition, the ability to identify irrelevant variables to be excluded from a set of results, due to having no effect, is as important. The concrete operational thinker can deal with bivariate scenarios but their limitations are evident in terms of relationships between variables and multi-variate problems. Concrete thinkers tend to treat all associations as 'equivalence relations', so for example if X happens with Y, then Y will happen with X. Formal operational thinkers know the fact that two aspects are associated with each other does not necessarily define their relationship, and further investigation is necessary before this can be determined. In an investigation involving a simple pendulum, the mass of the bob, length of the string and strength of the push are easily measured and each of them are determined as factors that could affect the rate of swing of the pendulum. When the following question was posed only about 30 percent of 15 year olds, those capable of formal operations, could answer it (and similar types of questions) correctly [78];

> *Given a SHORT pendulum with a HEAVY weight and a GENTLE push, what other arrangements would you use to test for the effect of* ***length*** *on the rate of swing?*

In general, students at the concrete operational stage change more than one variable i.e, length and mass, or change two variables and account for the effect being due to both variables. The solution to this problem requires multi-variate thinking, a characteristic of formal operational thought. The three independent variables- length, mass and push- and the one dependent variable -rate of swing- need to be held in mind and the possible effects of each variable on the dependent variable need to be considered.

The first five *Thinking Science* lessons focus on the development of the concepts and language of variables. These lessons also act as a foundation for the rest of the programme. In Activity 3, 'Fair test' each group of students has a box of tubes. In the concrete preparation part of the class, the students when questioned by the teacher, identify the variables of the tubes - length, width and material - and their associated values. The students are then asked to blow across the tubes and listen to the note produced. The aim of the investigation is for the students to find out what affects the note that you get when you blow across the tube. The students have some free exploration time and then share their ideas and explanations with the teacher or other students. The phase of cognitive conflict and construction follows. The students offer their claims to the class and for example, one student may come up with the claim that the width of the tube affects the note produced. The teacher may then ask for the student to show why they think this and they may demonstrate with two tubes of different width that produce two different notes. The teacher may at this step point out that the tubes are also different lengths or made of different materials and ask 'How do you know whether it is the length or the width that affects the note?'. Here the teacher establishes cognitive conflict. Typically, a concrete operational student may answer that 'both the width and length affect the note'. The teacher at this point pursues the conflict and asks the student to pick another pair of tubes that will give a distinctive answer as to what variable affects the note produced. The point of this activity is that the students must construct for themselves a strategy for controlling the variables. Students who are capable of formal operational thinking may find this activity particularly easy and may be guided to complete a higher-level task, i.e., to investigate the interaction between the variables. But the majority of 12 year old students, at the pre-operational or concrete operational stages, would experience sufficient conflict in the development of their control of variables strategy.

More complex variable problems arise later in the programme, with compound variables being the theme of Activity 26 and 27. The effect of combined variables is investigated in terms of pressure and density in these activities. However, prior to these activities the students would have more extensive experience with variables and also in the handling of ratios. Compound variables are the brain-child of scientists who find they are useful shorthand to talk about phenomena which cannot be explained in terms of simple variables. Density, for example is a compound variable - made up of a ratio of two others - and is not directly perceivable. It can only be determined by finding the mass and volume of the object and then calculating the ratio between the two. Until the child has reached the stage where he/she can abstract the density concept from individual cases, they cannot use the concept to solve other novel problems. Indeed it is not impossible for pupils to learn tactics for finding 'density' and simply employ this tactic in the solving of problems but this does not demonstrate understanding of the abstract concept of density.

(ii) Classification

Classification is described as another reasoning pattern typical of that developed in the formal operational stage. Classification does not require formal operational thought in the basic sense. A student at the concrete operational stage can classify objects according to obvious criteria, i.e., whether they float or sink, whether they are 2-dimensional or 3-dimensional, and so on. The aspect of classification that does require formal operational thought is the multi-layer consideration with which classification can be carried out - the adequacy of categories and whether one particular criteria allows for the prediction of others. Classification processes are abstractions and the process can be seen as a hierarchical one. For example, a snake is a reptile, a reptile is a vertebrate, a vertebrate is an animal, and finally an animal is a living thing. These abilities to classify are abstractions and they require the classifier to stand outside the process itself and observe the nature of the process. Formal operational thinking allows a person to realise that any classification operation involves inclusion and exclusion and is part of a hierarchy. An example from the *Thinking Science* activities shown in Figure 1.16 [25] shows shapes that can be classified by their difference in shape, size and colouring. Using concrete operations only, you can tell that there is a relationship between the two variables in size and colour.

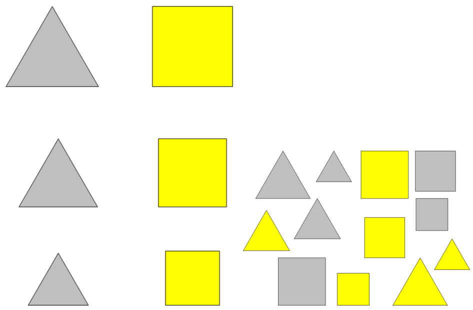


Figure 1.16: **Lesson 1; *What varies?*, Classification triangles (left) and Classification triangles 2 (right)**

If one were to look at the cards on the right hand side of Figure 1.16 and were asked to select a set of cards which shows a relationship between size and shape, which cards would you select? This involves formal operational thought as one must stand outside the system and invent the classes which will demonstrate a relationship. Two of the *Thinking Science* activities are devoted to the classification strategy. In the second of the classifying activities, *Thinking Science* Activity 22 'More classifying: birds', students are asked to classify birds from a set of pictures that they have been given. First they are asked to sort them by size and through experience they learn that classifying by such a term is not useful. Pupils in groups however will have to come to common agreement as to what they classify as 'small' or 'medium', but some cognitive conflict will have been provided in this exercise. The students are then asked to sub-categorise the birds. Further cognitive conflict arises when the teacher gives each group a picture with a humming bird and asks the students to fit it into their system. This proves to be difficult or impossible, depending on prior classification but the idea is to invoke in the students, questions about the process of classification, i.e. the sample of British birds might not accommodate a bird from a different environment.

(iii) Relationships between variables

The extent to which variables are related can be relatively straight-forward, but some relationships are more complex and quantitative. The characteristics of these relationships are discussed under ratio and proportionality and compensation and equilibrium.

- Ratio and Proportionality

These two concepts are closely related. Ratio, being the essential precursor, describes a constant multiplicative relationship between two variables. The ratio of one number to another may be found by division, and ratio problems have the mathematical form y=mx, where x and y are variables and m is the proportionality constant. Inhelder and Piaget [38] claim that children cannot solve problems involving ratios until they reach the formal operational stage. This claim supports the fact that most experts in mathematics education believe that fractions should not be introduced until children have reached 11 or 12 years of age [79].

The concept of ratio must be grasped to deal with the following problem [68];

The ratio of pedal turns to wheel turns of a bicycle is 2:5. If the pedals are turned six times, how many times will the wheel turn? [59]

Proportionality is a very closely related concept and involves the comparison of two ratios. For example, comparing 3:12 with 7:28 and seeing that they are equivalent ratios. Types of questions/examples dealing with proportionality include the following [68];

1. Anna needs a 24 N effort to lift a 8 kg load in his wheelbarrow. Tracey needs 18 N effort to lift 6 kg in hers. Whose wheelbarrow makes lifting easier? [59]
2. Rajit's lemonade has 5 spoonfuls of sugar and 10 of lemon juice. Fred's has 4 spoonfuls of sugar and 8 of lemon juice. Which of the two's lemonade is sweeter? [59]

Inhelder and Piaget's method for studying the proportionality scheme involved the balance beam, similar to that shown in Figure 1.17. They reported from their work that children do not discover the proportion relations until they reach the formal operational level. Before the age of 7 years, children have difficulty equalising weights on a balance. After the age of 7 years (concrete operational) children discover that a large weight can balance with a small one if placed further from the fulcrum but they do not co-ordinate the two functions of weight and length as a proportion. They tend to solve each separate balancing task by trial and error.

This principle (W1/W2 = L1/L2) becomes apparent around the age of 13 years, coinciding with the development of formal operations. At this stage, the child becomes aware that an increase in weight on one side of the fulcrum can be compensated for by an increase in distance from the fulcrum on the other side. If a child does not comprehend ratio as an abstract notion, he/she will not develop the general ability to solve this type of problem. For example, it may be possible to teach children how to get correct answers to each of the types of questions outlined above - bicycle gears, lemonade concentration - but each type of question will have to be dealt with individually. The general reasoning patterns of ratio and proportionality have to be abstracted from examples before they can become part of children's abstract thinking stock [58].

Piaget [80], Karplus [81] and Hart [82] describe in detail the types of errors made by children with ratio and proportionality problems. The most common error made by the children is to use addition instead of multiplication in the solving of the problems. Adey [83] gives an example where when given an L shape with arms of 2cm and 3cm and another L shape with a short arm of 4cm, children are asked to work out the length of the longer arm. Most commonly children give the length of the longer arm as '5'. The typical reasoning is highlighted from this child's reply 'in the given L the long arm is 1cm longer than the short arm, so I must add 1cm to the length of the short arm in the new L' instead of 'the ratio of the short to long is 2:3, so I must multiply 4 by 3/2'.

The *Thinking Science* materials address this scheme in Activity 8, 'The Wheelbarrow' after the introduction of ratios in two prior activities. The relationship is quantified by finding ratios between effort and loads for a number of different loads, using the apparatus shown in Figure 1.11.

The conflict arises in this activity when students are asked to calculate values of lift needed for loads they have not tried. This is where the strength of the proportional relationship has value and this scenario lends them an opportunity to discover this

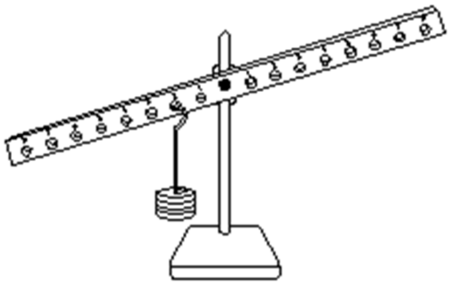


Figure 1.17: **Lesson 10; *The balance beam*, Balance beam equipment (taken from [68])**

value for themselves.

- Compensation and Equilibrium

Compensation involves the relation between two variables, where while one variable increases the other decreases. Compensation has the mathematical form, yx=m. As y goes up, x must come down proportionally, to keep m constant. Compensation can be multiplicative or additive. Additive or qualitative compensation is easily comprehensible at the concrete level. For example, with cold water you must use more soap to get the same washing effect as with hot water. The understanding of multiplicative compensation comes long after the additive form. The concept relies on a sound concept of ratios and proportionality. Inhelder and Piaget [38] claim that from a psychological point of view, although the organisation of proportions begins with the discovery of compensations, the opposite does not always apply. Inhelder and Piaget studied cases of multiplicative compensations in terms of the potential canceling out of effect between certain factors in flexibility [38]. The following cases of compensation were examined;

1. For equal lengths, a round thin steel bar has the same flexibility as a round thicker brass bar;

2. For equal lengths, a round thin steel bar has the same flexibility as a flat brass bar with a larger cross-section surface;
3. For equal lengths, a round thick steel bar has the same flexibility as a square narrower steel bar.

A child was shown each of the pairs of bars, and they were asked to explain why did the rods bend equally when the same weights were applied. The three problems could only be correctly explained at the formal operational level. The first problem at the early formal operational level, and the second and third at the late formal level. In the case of the first problem, children at the concrete operational stage cannot be sure that the difference in flexibility, due to the metal composition, is being compensated for by thickness alone. After experimentation, when the lengths and degree of bendiness are the same, the child is led to believe that the metal is less important than first believed. Only when the factors are both separated and integrated at the same time can the child conceive that the two factors compensate each other exactly. Problems 2 and 3 are further unintuitive as metal and thickness compensate for each other. While the metal form differs, the difference in thickness is not given perceptually and must be judged using hypothetical possibility. In problem 3 nearly everything must be deduced by the subject, and this deduction is beyond the realm of the concrete operational thinker.

Equilibrium is a concept that is closely related, but it is more complicated as it involves the equating of two compensations. Its mathematical form is xy=ab, which looks similar to the compensation relation xy=m, except that the constant m is replaced by a pair of variables, a and b. In many ways, the schema of equilibrium refers to the student's grasp of Newton's action-reaction principle. Inhelder and Piaget [38] set up the experiment involving a balance beam with unequal weights at unequal distances from each other. This scenario forces the question of proportionality. Previous research [84] showed the notions of proportions does not appear until early formal operational thought. The discovery and explanation of the law of equilibrium in the balance starts to be discovered only at the early formal stage when the subject is allowed to hang weights simultaneously on two arms of the balance. It takes the form of the proposition W/W'= L'/L, where W and W' are two unequal weights and L and L' are the distances that the respective weights are placed. This law is obvious at the formal operational stage. However, on further suspension of weights, the subject's attention turns to the different degrees of inclinations and the distances in height to be covered - this may lead to explanation in terms of work and such a explanation rarely arises before the late formal operational stage. At the late concrete stage, it has often been noted that subjects search for a common denominator of two relations that they compare, but it is thought to be additive. Instead of W/W'= L'/L, the child at the 2B stage would derive the law as W-W'= L'-L. At the 2B stage, a small weight combined with a great distance is equivalent to a large weight with a small distance but subjects fail to generalise in all possible cases. The generalisations found at the 3A and 3B levels are where the notions of compensation and reciprocity come in.

(iv) Correlation

Correlations are the type of evidence that we get in everyday life and they require us to draw deductions from statements in order to judge their validity, for example, speeding kills! This statement represents correlations and is far removed from the hardcore scientific data we experience in the laboratories. In order to understand the nature of a correlation, even just between two single variables, one has to consider four possibilities. This correlation schema is present at the formal operational stage, according to Inhelder and Piaget. Correlation is a notion that derives simultaneously from probability and proportions. It does not appear during the concrete stage.

In order to study the schema in more detail, they set a problem for subjects involving a simple correlation between eye and hair colour. Subjects were shown 40 cards, with a face drawn on each of them. They were then given a set number of cards and asked whether they think there is a relationship between eye and hair colour, from the given data. The instructor could proceed by either letting the subject form his own classification or giving them the cards already classified, hence there is more emphasis on the possible numerical combinations. At the early formal operational stage, the subject can often begin considering associations independently without understanding that the other cases are just as crucial. Subjects at the early formal stage tend to view correlations as a simple probability - which is not the case - but this coincides with their acquirement of multiplicative ratios. The idea of correlation is more truly discovered at the late formal stage as a consequence of the utilization of propositional logic. The groundwork for the introduction of correlation is done in Activity 17 of the *Thinking Science* lessons, 'The behaviour of woodlice'. The students are encouraged to review their ideas about variables, their possible combinations and the notions of fair testing and probabilities in a scenario where they must investigate the preferable living conditions of woodlice. In Activity 18, the theme of correlational reasoning is strengthened by numerous explorations of correlation and the introduction to the term itself and its true meaning and value.

(v) Probability

Generally speaking, biology is the first encounter that students have with the concept of probability. Piaget is reported to have said that the development of the probability scheme depends on the development of formal operations, and the development of the proportionality scheme in particular [20]. His hypothesis was that subjects cannot understand what sort of events are probable unless they understand what events are absolutely necessary. In accordance with this view the world of intelligence can be divided into two categories; (a) one where things must happen because they are governed by natural laws, i.e., a pen thrown out of a window must fall due to the law of gravity and (b) things that should only happen if they are not governed by any natural law, if you flip a coin hundred times, you should get around 50 heads. The division of events into these two classes is at the heart of the probability scheme. According to Piaget, the development of the probabilistic scheme consists of three global stages that correspond to the pre-operational, concrete and formal operational levels. During the pre-operational stage, children fail to grasp the distinction between things happening due to natural law and events happening by chance. They tend to think that chance events may actually be governed by natural law. In the next stage, children become able to distinguish chance events from lawful ones but they have great difficulty in distinguishing between events that are more or less likely to happen. For example, they might not understand that of all the possible results of flipping a coin 100 times, 50 heads and 50 tails is a much more likely result than 10 heads and 90 tails. They do not appear to understand the frequency principles that govern systems of chance events. These principles are not discovered until the formal operational period is reached and, according to Piaget, this coincides with the proportionality schema.

Piaget and Inhelder [20] used a very simple experiment to study the probability scheme. It involved drawing different coloured objects from an opaque bag. A mixed set of red, yellow, blue and green objects were in the bag and children were asked to withdraw a pair of objects from the bag and guess the colour of the objects.

Although guessing was required, two rules could be used to maximise the number of correct predictions given. First, there was an identical set of objects visible to the child outside the bag and the child could see that certain colours were more frequent than others. Secondly, by matching up each pair of withdrawn objects with a set of visible objects, the subject could see that the frequency was changing. Piaget and Inhelder reported that formal operational children made use of both of these principles and so grasped the probability concept. Children at the concrete operational level made use of the first rule but not the second. They failed to see that colour frequencies were changing as objects were withdrawn and hence the accuracy of their guesses degenerated over several trials.

However, work published during the 1960's and 1970's [85, 86, 87] reported that the concrete operational, and in some cases pre-operational children, were capable of operations that were within the probability scheme, contradicting the work of Piaget and Inhelder [88]. They proposed that the performance competence problem may have been the issue, as Piaget and Inhelder's procedures for measuring subject's understanding of the concepts also measure other skills and children's poor performance in the tests may have been due to these additional factors.

In the *Thinking Science* lessons, Activity 7 and 13 are the first lessons in the probability series. In Activity 7, students are introduced to the ideas of population variation and sampling variation and the necessity for adequate sample size. In Activity 12, 'Spinning coins' they take this idea further so they arrive at an intuitive idea of how large a sample should be if they want to estimate a simple underlying proportion. In addition to this, by focusing on the frequency of the different runs of heads or tails, the student realises that there are describable patterns underlying chance. In Activity 15, 'Tea tasting', students are faced with the questions, 'What is the chance of getting four out of five guesses correct', or 'How many times does someone have to get something right in order for you to know they are not guessing?' Through the process they should conclude that making arguments from single cases is pointless and enough data and a measure of probability is necessary to eliminate whenever something happens outside the realm of chance.

As with the other formal schema, getting a handle on the schema of probability opens the student's mind up to many of the qualities that constitute scientific investigation. Going back to the control of variables problems, one takes ten peas rather than one in the hope that the probability of randomizing the uncontrollable variables is high enough. Counting a plant population and their distribution within an area can be determined at random and enough sections need to be chosen to raise the probability of the sample been representative of the whole to an acceptable level.

(vi) Formal models

A formal model is a working model in which the 'moving parts' are abstract entities which have to be imagined. One such example of a formal model is that of the kinetic model of matter. In this model, solids consist of particles held together in a fixed position, liquids are still in some way attached to each other but have the freedom to move around, while in gases the particles have no attraction to each other and they have the freedom to move anywhere. These particles can only be imagined though and so are deemed formal models. They are useful as they explain alot about the behaviour of the three states of matter and the models can be used to reliably predict the behaviour of matter and so in some sense they represent reality. Models are used in all sciences including weather forecasting, sociology and economy. Once models are encased into an algorithm they require no more than concrete operations to read the predictions. However, formal operational thought is required when the prediction fails or when the significance of the prediction in relation to the evidence needs to be interpreted.

Activity 23 of the *Thinking Science* materials [59], 'Explaining states of matter', is the first in a set of three lessons based on the formal scheme of formal modeling. In this lesson, students witness the heating of ice, stearic acid, wax and sulphur. When asked 'How did the liquid get from the bottom to the upper part of the tube?' students discuss their views and postulated models. There is no expectation on the students to come up with an articulated particle theory of matter but rather the idea is for the students to become aware of their processes of observing, describing and in particular, explaining. They are encouraged to find a model which explains what they observe and hence the idea of an explanatory model should start to develop.

(vii) Logical Reasoning

This describes the ability to analyse the combinatorial relations present in information given. Adey and Shayer [25] illustrate a test of logical reasoning taken from Bond's test of logical thinking (BLOT) [89]. The example taken illustrates the logical operation of implication;

A prospector has found that some rich metals are sometimes found together. In his life he has sometimes found gold and silver together, sometimes he has found silver by itself, every other time he has found neither silver nor gold. Which of the following rules has been true for this prospector?

1. Gold and silver are found together, never apart.
2. If he found silver then he found gold with it.
3. If he found gold then he found silver with it.
4. If he found gold then he did not find silver.

Bond's test of logical thinking is a hierarchical development test item that was derived from the *The Growth of Logical Thinking* [38]. Although developed independently of each other there is a strong correlation between the BLOT test and SRT III '*Equilibrium in the balance*' [32]. Bond also reports a strong relationship between BLOT scores and achievement in secondary school science [90].

CASE compared to instructional teaching methods

In order to appreciate fully the different methodology that CASE adopts it is useful to compare it to characteristics typical of good quality instructional teaching. The pedagogical implications of CASE are summarised in Table 1.9. The pillars of CASE are the criteria which distinguish CASE from other educational programmes and hence attribute to the valuable effects of CASE, recorded over the past two decades in a variety of contexts.

Both styles of teaching are complementary to each other and each offers outcomes that are unique to itself and valuable in terms of learning experience.

Table 1.9: **Comparison of CA-type intervention and high quality instructional teaching (taken from [69])**

CA-type intervention	Instructional teaching
Follow direction of argument	Carefully ordered and planned
Virtual objectives	Specific objectives
Students often confused	Information sizable and re-enforced
Not much content delivered	Lots of content delivered
No obvious notes taken	Students have notes to revise
Not sure what has been covered	Clear list of what has been covered
Seems risky	Relatively easy

The CASE materials

The materials of CASE (2nd edition) were published as *Thinking Science* [59], and included 32 activities intended as an enrichment to the regular science curriculum suitable for use within Years 7 and 8 in the second level system in the United Kingdom. They were recommended for use at a rate of about one activity every two weeks, over a period of two years.

The estimated operating range of the original lessons and their associated reasoning patterns are shown in Figure 1.18. The number in the circle represents the Lesson number and can be referred to in Table 1.10. Both the reasoning patterns and the range of difficulty of each lesson are shown in Figure 1.18. Wherever a new reasoning pattern is introduced explicitly for the first time, the 'entry level' of cognitive demand is dropped. As the lessons proceed with the same reasoning pattern the level of cognitive demand increases. The reasoning patterns are not necessarily grouped together as they are not discrete entities. The development of one reasoning pattern interacts and enhances the development of another.

Table 1.10: **The *Thinking Science* activities and their associated reasoning pattern (denoted by √)**

Lesson Number	*Thinking Science* Activity	Variables	Proportionality	Probability	Compensation	Correlations	Equilibrium	Classification	Formal Models
1	What varies?	√							
2	Two variables	√							
3	The ‘fair’ test	√							
4	What sort of relationship?	√							
5	Roller ball	√							
6	Gears and Ratios		√						
7	Scaling: pictures and microscopes		√						
7a	Bean growth 1			√					
7b	Bean growth 2			√					
8	The wheelbarrow		√						
9	Trunks and twigs				√				
10	The balance beam				√				
11	Current, length and thickness				√				
12	Voltage, amps and watts				√				
13	Spinning coins			√					
14	Combinations	√							
15	Tea tasting			√					
16	Interaction	√							
17	The behaviour of woodlice					√			
18	Treatments and effects					√			
19	Sampling: fish in a pond			√					
20	Throwing dice			√					
21	Making groups							√	
22	More classifying birds							√	
23	Explaining states of matter								√
24	Explaining solutions	√							√
25	Explaining chemical reactions								√
26	Pressure	√							
27	Floating and sinking	√							
28	Up hill and down dale						√		
29	Equilibrium in the balance						√		
30	Divers	√							

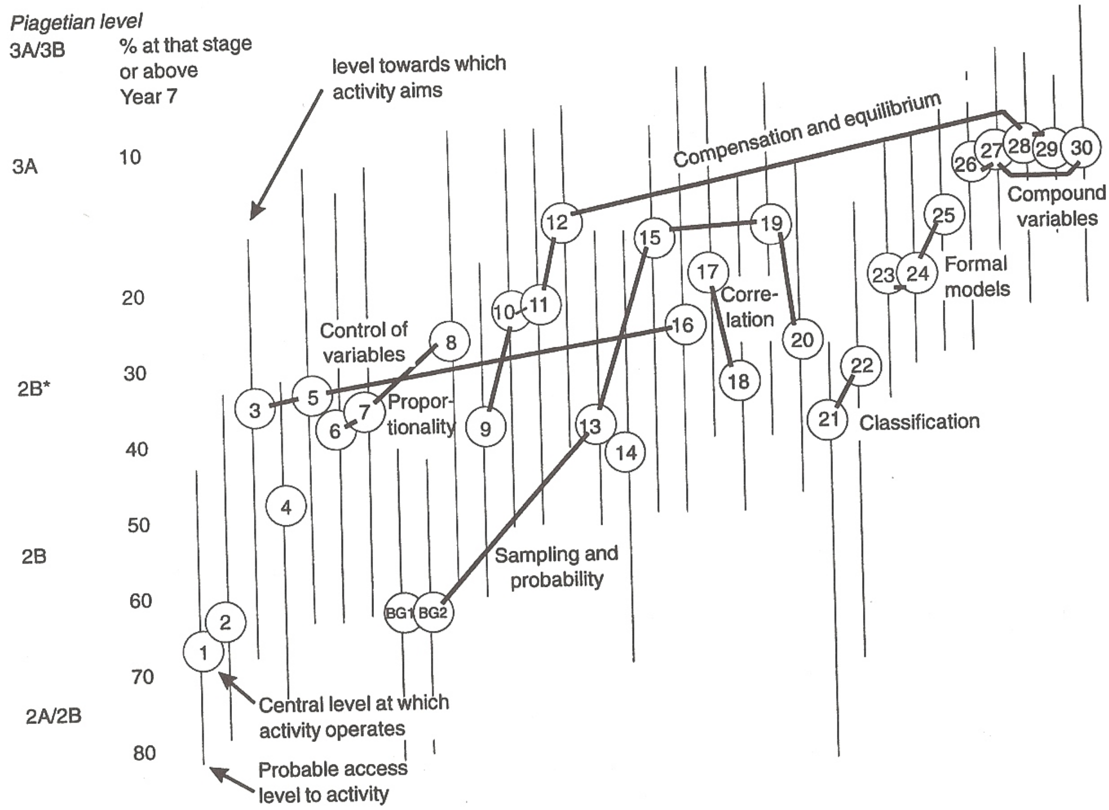


Figure 1.18: **Estimate of operating range of *Thinking Science* lessons (taken from [25])**

1.1.5 The CASE II experiment

Sample and Design

The CASE project began with an exploratory project known as CASE I (1981-1983). The main project, CASE II (1984-1989), followed and the short and long term effects of the programme were evaluated. Adey, Shayer and Yates subsequently spent six years refining the programme. The CASE III programme (1989-1991) focused on the effective teaching skills for the intervention and an extensive professional development programme accompanied this. The CASE II programme was the most extensively researched in terms of the effectiveness of the programme on students' cognitive development and examination performance [91, 25, 65, 92, 93]. Pre-tests, post-tests (immediately after end of the intervention) and delayed post-tests (one year after the intervention) were carried out with experimental and control groups in Year 7 (with ages 11+) and Year 8 (with ages 12+) in second level, using the SRTs [32]. Finally, two years later the national General Certificate of Secondary Education (GCSE) examination results were obtained for both the Year 7 and Year 8 groups.

Treatment of results

In order to allow for individual differences in starting cognitive levels, all data was analysed by Residual Gain Score (RGS) analysis [94]. This involved finding the regression line for each post-test score on pre-test cognitive measures, for the control group. These were used to predict the post-test score for the experimental group. The predicted post-test score was subtracted from the actual score obtained in the post-test. The difference in these scores is the RGS. In brief, it is a measure of the extent to which the development or learning has been different from that of the initially matched control group. If there has been no difference between the development, of the control and experimental group then a RGS of zero would be expected. However, if the experimental group had undergone greater development, a positive RGS would be expected. Similarly if the experimental group had not developed, in accordance with the control group, a negative RGS would be expected. Some of the key results of the CASE II programme are discussed below. The results are reported in terms of post-test, delayed post-test and GCSE results and are shown in Table 1.11.

Post-test

Sets of post-tests were given immediately after the end of the two year *Thinking Science* programme. Both control and experimental groups were tested. The immediate effects of CASE on cognitive development were shown to be rather limited. The 12+ boys groups were the only group to make highly significant gains compared to their comparable control group. However, the results appeared to be bimodal. This will be discussed in more detail later in this section. The distribution of scores for the 11+ girls group were also bimodal, but overall their significant gain was no greater than that of the comparable control group. However, more recent studies have shown larger immediate effects of the CASE programme on cognitive development [6].

Table 1.11: **Mean Gains and effect sizes for successive tests after completion of two-year CASE intervention, based on pre-cognitive tests (09/84) (adapted from [57])**

	Group (N)	Mean gain	Effect size (σ)
Cognitive post-test (07/87)	11+ boys (29)	-0.21	
	11+ girls (27)	0.08	
	12+ boys (65)	0.70**	0.75
	12+ girls (52)	0.03	
Science achievement (07/88)	11+ boys (37)	2.72	
	11+ girls (31)	7.02*	0.60
	12+ boys (41)	10.46**	0.72
	12+ girls (36)	4.18	
GCSE Science (1989)	12+ boys (48)	1.03**	0.96
	12+ girls (45)	0.19	
GCSE Maths (1989)	12+ boys (56)	0.55**	0.50
	12+ girls (54)	0.14	
GCSE English (1989)	12+ boys (56)	0.38*	0.32
	12+ girls (57)	0.41*	0.44
GCSE Science (1990)	11+ boys (35)	-0.23	
	11+ girls (29)	0.67*	0.67
GCSE Maths (1990)	11+ boys (33)	1.59	
	11+ girls (29)	0.94**	0.72
GCSE English (1990)	11+ boys (36)	0.26	
	11+ girls (27)	0.74*	0.69

*denotes significance at 95 percent confidence level

** denotes significance at 99 percent confidence level

Delayed post-test and science achievement test

One year after the intervention was completed, the cognitive levels of the control and experimental groups were tested again. Initially it was reported by Shayer and Adey [95] and Adey and Shayer [91], that none of the experimental groups showed any overall difference from the control groups in these measures of cognitive development. However, Adey and Shayer [25] report that this claim was flawed, due to the lack of delayed post-tests for two control groups and the skewering of results by the large control group in school 9. Table 1.12 shows the mean pre- to delayed post-test gains for schools and groups. It can be seen that in general the differences in the experimental and control groups are maintained until delayed post-test. Exceptionally, in school 9 the control group had a mean higher than that of the experimental group. The boys in this control group gained 0.9 levels during the period from post-test to delayed post-test. The explanation that Adey and Shayer [25] provide for this result is that the effect may be due to the teacher of the CASE class in this school also teaching the control class. Figure 1.19 shows results of cognitive development for experimental and control classes where Philip Adey and Carolyn Yates trialled the *Thinking Science* lessons. The intervention for this experimental group started in Year 7, with an 11+ group. It can be seen that the experimental group gained in terms of cognitive levels throughout and after the intervention period, despite starting at a lower point on the scale, at approximately 5.1, compared to 5.6 for the control group. This experimental group made a gain of 24 percentile points during the period of the intervention.

Table 1.12: **Mean pre- to delayed post-test gains for schools and groups (taken from [25])**

School	CASE mean (N)	Control mean (N)	Predicted mean
3	0.76 (25)	n/a	0.60
7	0.93 (19)	0.63 (19)	0.62
8	1.71 (21)	n/a	0.62
9	1.04 (25)	1.41 (45)	0.62
11	1.24 (17)	0.72 (22)	0.66

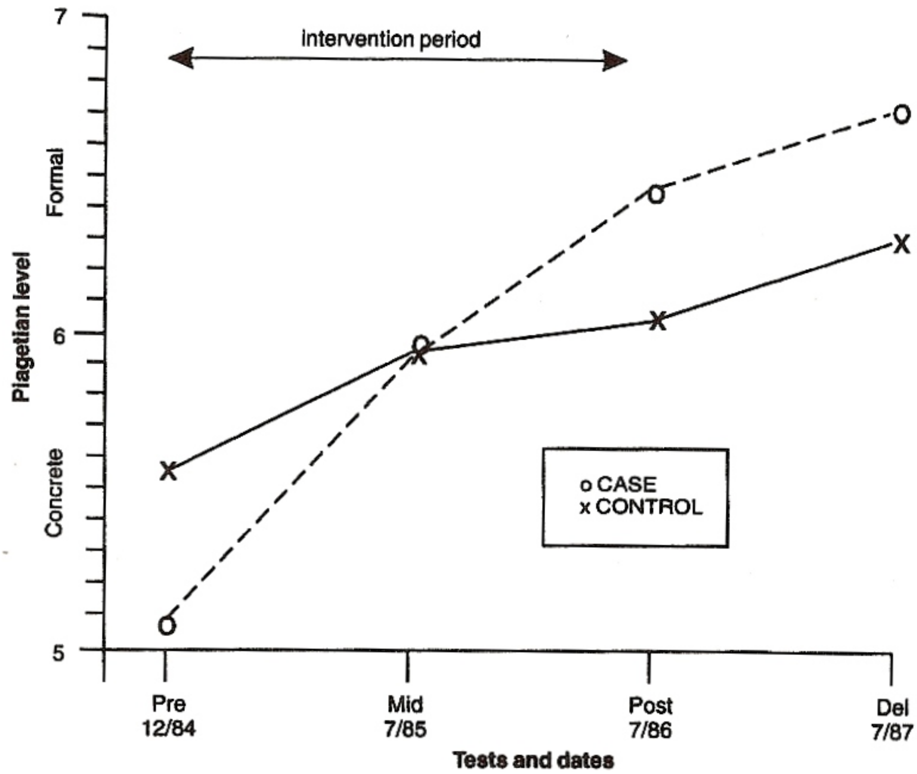


Figure 1.19: **Cognitive development of CASE experimental group over two and half years compared with a control group laboratory school (taken from [25])**

During the period of the intervention, no gains in science achievement were found in the experimental classes. The results of the experimental and control groups performance in an end-of-year examination in science was obtained, one year after the completion of the CASE intervention [7]. The mean effect size on science achievement for the boys aged 12+ years was the largest, with a value of 1.14 σ. The mean gains for the control and experimental 12+ girl groups were significant and were equivalent to an overall effect size of 0.40 σ. However, for both the 12+ male and female groups, the gains had a bimodal distribution. Also this is the case for the 11+ girl group, with an overall effect size of 0.60 σ. The 11+ boy group, was the only group with no reported bimodal result for science achievement. The mean gain of this group had an effect size of 0.20 σ, but this was not significant.

GCSE examinations

The 12+ group sat their GCSE two years after the completion of the intervention, while the 11+ group sat it three years after the intervention. The GCSE results for the 12+ group is stronger than those reported in the delayed science achievement results. This 12+ group averages one grade higher than the control group after individual pre-test differences are taken into account, representative of an effect size of 1 σ in science. The 11+ girl's GCSE results show approximately an effect size of 0.6 σ for science, maths and English, when compared with students in the control group. Considering they sat the GCSE exam three years after the end of the intervention, this was considered a long term effect. There was a strong 'far transfer' effect with significant gains not only in science, but in maths and English for the 11+ girls and 12+ boys. The results for English show significant effects in three out of the four groups, although they were rather weak in the case of the 12+ boys group. Even the one group, the 11+ boys, that shows no significant overall effect, the result shows very marked bimodality of distribution. This far transfer implies that the intervention programme, delivered by science teachers through activities with a strong scientific context, produced significant effects on students' achievement in other contexts, namely mathematics and English. This implies that the intervention had broad effects on students' intellectual functioning.

Shayer [96] published results from a study on groups that used the CASE *Thinking Science* activities in Year 7 and 8, between the years of 1994 and 1996. The report highlighted the added-value estimate of grades, attained three years later in their

1999 GCSE examinations. The data set is from eleven schools (shown in Figure 1.20 as A-K). Figure 1.20 shows the plot of the average science grade added-value. The solid circles represent the CASE schools, and the extent to which these lie above the regression line for the controls is a measure of the added-value, that is the extent to which the mean GCSE grades are higher than would be expected. The average added-values were equivalent to 1.02 grades and must be due to the CASE intervention, as it was the only systematic difference between the 'CASE' and control schools. Data presented as the percentage of students achieving C-grade and above shows an added-value mean of 21 percent for the eleven CASE schools. If the results were repeated nationally, the percentage of C-grades and above would rise from 50.8 percent to 77.2 percent. The added-value in maths for CASE schools in the study is similar to that of science, with an added-value grade of 0.95. In terms of C-grade and above the mean Added-Value percent is approximately 19 percent. Similarly, there was an effect on GCSE English with a mean added-value of 0.90. This data as well as confirming the long term (at least after three years after the completion of CASE) far-transfer effect, also falsifies the claim that cognitive acceleration techniques only work with less able students. School B in this report represents a girls' grammar school while school C represents a boys' independent school. Both of this schools have performed comparably well and have made the largest gains in GCSE grades, beyond those expected, adding to the generalisability of the effect of the CASE programme.

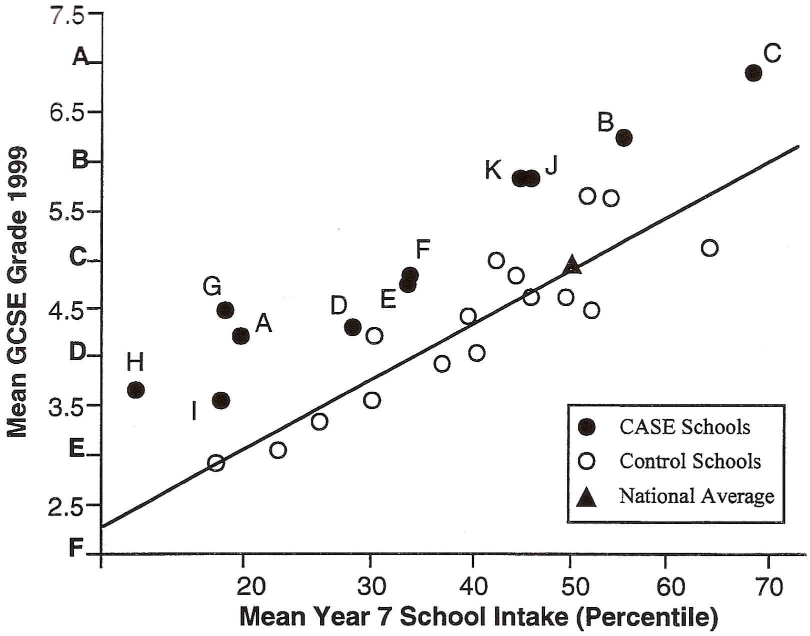


Figure 1.20: **GCSE 1999 Mean Science Grade Added-Value (taken from [96])**

Bimodality

Another feature of the results mentioned earlier is bimodality. This refers to the distribution of gain scores within the group. Some students within a group make very large gains, while others make gains little more than the controls. Upon investigation of the higher gainers, Adey and Shayer [25] noted no commonalities between their origins or characteristics. They suggest that a possibility for the bimodality is that the *Thinking Science* approach suited some students better than it did others and within a class those that became more cognitively engaged simply benefited more from the intervention.

Possible explanations for the success of the CASE intervention programme

The most striking feature of the results are the long-term far-transfer effects of the intervention. The CASE programme, set in the context of science, after meticulous testing procedures proved to enhance state-set achievement tests in English, up to three years after its completion. Adey and Shayer propose that this evidence has potential importance for models of cognition. They imply that the results support the hypothesis of a general cognitive processor which can be positively influenced by intervention set in the context of the curriculum [25]. For many years, since the first results of CASE were published, researchers and theorists have tried to explain the reason for the remarkable results. Adey and Shayer consider explanations proposed by others, to support the success of the intervention and these are discussed below.

Motivation

Leo and Galloway [97] describe three types of motivational style, namely learned helplessness, self-worth motivation and mastery oriented. The first style describes students who perceive failure as inevitable. The self-worth motivated style students are concerned with the impact of their performance on a task on their self-esteem. The last style, mastery oriented, describes students who perceive learning as valuable and intrinsically worth-while. They suggest that CASE requires children to be mastery oriented before successful intervention or perhaps that CASE changes children's motivational styles from the learned helplessness and self-worth motivation to mastery oriented. They suggest that the CASE teaching techniques may have less of an impact on self-worth motivated children, unless their perceptions of the classroom environment has changed significantly. The post-intervention effects on girls may be due to their learned helplessness motivational style in science.

However, Adey [98] argues that motivation style, at least as described by Leo and Galloway, does not offer an explanation for the results of CASE, unlike their own hypothesis of observed brain growth spurts as precursors for the development of formal operational thinking. Adey also critiques Leo and Galloway's attempted explanations due to their un-testability. The authors do not describe how the motivational styles of children might be assessed in one domain. Adey suggests that to do this researchers would need to assess the motivational style of each child in a class, make predictions about how they would interact with a CASE class and then test their predictions against gains in cognitive development over a one to two year period.

McLellan's study [99] aimed to explore this potential relationship between motivation and cognitive gain arising from the CASE programme. She concludes to say that motivation can only provide a partial explanation for cognitive acceleration effects but she accounted for improved motivation in 75 percent of the students in CASE schools, in her study.

Confidence

Adey and Shayer [25] display no conviction in believing that confidence provided an explanation for the effects of CASE. To begin with, they suggest that confidence developed in science is unlikely to affect performance in other subjects [100]. They support this argument with empirical and theoretical evidence. First of all, they suggested that if confidence was the cause of, or partially the cause of, increased cognitive development then the immediate post-test scores would be considerably higher than those of the group that had not received the intervention. This evidence however is not the case and differences really only become apparent between one to three years after the intervention has being completed. Adey and Shayer also object because they say that theoretically there has been no mechanism that links confidence with enhanced achievement, and if such a mechanism were to be conceptualised, then it would involve a cognitive model which would lead back to the starting point. In essence, Adey and Shayer [25] were content to conclude that confidence was not a helpful explanation to support the positive findings of the CASE intervention.

Direct training effect

It has been proposed that the *Thinking Science* programme, which is set in a science context, encourages reasoned discussion amongst students and the exploration and use of new vocabulary to describe physical events and verbalise inner-thoughts. It is suggested that this activity involving language has a permanent effect on linguistic development and hence gives rise to the comparably greater scores achieved by the experimental group in the GCSE English examination two-three years after the intervention had finished. However, Adey and Shayer [91, 25] reject this language-development effect as being the main reason for this enhanced achievement. The proposal that the intervention programme affected scientific, mathematical and linguistic capabilities, in parallel to one another, and almost incidentally without being linked to some central processing mechanism seems unlikely.

Language develops language

Adey and Shayer [91] suggest that the intervention may enhance student's linguistic development, so new linguistics skills would be more easily acquired. This in turn would allow for improved learning in language and hence greater achievement in English. Such a self-promoting system, characteristic of true development, would be included in one of the desired outcomes of the experiment. This explanation relates to the development of a domain specific function and not necessarily linked with the development of scientific and mathematical competency.

General cognitive development

The evidence of the long-term far transfer effects support the notion that the CASE intervention, by directly promoting the development of underlying cognitive structures, raises the general intellectual processing power of students and subsequently enables them to make better use of all the learning experiences provided by their schooling. Such development is not necessarily detected in the Science Reasoning Tasks but rather can be explored by considering the relationship between gains in cognitive development during the intervention and the subsequent gains in GCSE examination. It is done so for the following groups;

- 11+ girls

19 out of 29 CASE students attained a residual gain score of more than 1 σ in one or more of the GCSE subjects (science, mathematics or English). All of the experimental students had residual gain scores at the post-test SRT greater than one standard deviation and also gains in GCSE science of over 1 σ. Therefore, increased Piagetian level is a sufficient condition for higher-than-expected performance in science but not a necessary condition as five girls with residual gain scores in SRTs

under 1 σ also had high science RGSs. For the 11+ girls, high performance in maths and science seems to be related to language skills which they share with English, as well as from the kind of thinking assessed by the Piagetian tests. Also analysis of these results showed that bimodality of the results was not simply due to the CASE style suiting a minority of students. Although only 40 per cent of the CASE 11+ girls had RGSs above 1 σ in any one subject, 66 percent of the girls had RGS above 1 σ in at least one subject.

- 12+ boys

In the case of 12+ boys, high Piagetian level gain is a sufficient condition for high performance in science or mathematics. 63 percent of the CASE boys achieved RGSs of more than 1 σ in at least one subject, compared with 19 percent of the control boys. 53 percent of them achieved RGSs of more than 1 σ in science, compared with 17 percent of the controls. There was no significant difference between CASE and controls for the 12+ boys who achieved less than 1 σ RGS at post-test.

- 12+ girls

For this group there was no significant difference between CASE and controls on the post-test SRT. Yet there appeared to be a substantial difference between the groups in GCSE achievement. Analysis also showed that there was no difference between CASE and control students whose RGS at post-test SRT were above 1 σ. As with the 11+ girls results there is a pattern of higher achievement in maths, English and science which is not correlated with Piagetian post-test results.

These results suggest that as well as the intention of the intervention to effect achievement in science (and other subjects), school achievement was affected for girls through factors that did not show up on Science Reasoning Tasks. Adey and Shayer [25] suggest that it may be the Vygotskian element of the CASE intervention that explains this. In addition to contributing to gains in Piagetian levels, CASE assisted the female cohort in particular in the use of language as an action element of learning. Their hypothesis is that the extra experience of collaborative discussion reaped benefits, not just in English but also the students had increased confidence in approaching mathematics as a language.

Professional Development

The original CASE project was most concerned with the evaluation and development of the activities and the assessment of their effectiveness on students' cognitive development. The Professional Development (PD) aspect of the programme was very much based on an 'in-service- on-service' model, which originated in Indonesia and involved selecting instructors from amongst the best secondary school teaching practitioners in each province, training them in both content methods of modern science and maths teaching, and then sending them back to their provinces. Initially, they went back to practise teaching their new methods and then after one term they started to run INSET (in-service education for teachers) courses for teachers in their locality. The CASE INSET tried to replicate the following important features of these courses;

- The courses were spread over anything from 3 to 4 months to one year, so were relatively long-term;
- They involved a mixture of in-service workshops and work by instructor's in teacher's own schools.

Adey [69] admits in the first two years of the intervention the professional development of teachers was not the main concern. The instructors were occupied with working closely with the teachers, finding out the support they needed and from observation in classes the features of CA that needed special attention. The development of the in-service teacher education programme was carried out very much as they went along. In CASE II, for the most part one teacher from each school was involved in the project. They would have initially had some interest in the project and with help and support from the research team they carried out on the methods and activities of CASE with the designated 'experimental' group in their school. However, at the end of the project very few of these teachers continued with the CASE project as part of their curriculum. This outcome was one of the main learning points from the professional development phase of the project. The lesson learned was that for any change to take place in school it is essential that the teachers involved work together in the sharing and discussing of new methods and practices. When this support network is lacking it becomes harder to implement such a demanding methodology and very often the enthusiasm to do so also dwindles. Having learned this lesson the hard way from the CASE II phase, Michael

Shayer undertook the CASE III project to scale up the introduction of CASE from one teacher in a school to whole science departments.

In CASE III, from 1989 to 1991 Shayer worked closely with three schools with two main aims in mind. The first was to gain a deeper insight into the classroom practices which maximise cognitive stimulation. The second was to work with a number of teachers together in each school and encourage them to share their experiences of CASE with each other. The PD of this phase was more structured than the previous and the following features were deemed essential for an effective PD programme [69];

- The PD must last the duration of the intervention programme itself, two years for the CASE programme;
- It must include both centre-based in-service days and in-school coaching;
- The PD course must include all members of the science department in a school;
- The in-service programme should have the majority of centre based days near the beginning of the two years but contact should continue throughout the PD period (and beyond if possible).

As well as the logistics of the PD programme it is important to mention the content of the programme itself. Within the in-service the following areas need to be covered. The content of the programme focused on some key areas; theory, practical implementation of the programme and management.

- Theory

The CASE-INSET programme provides theoretical understanding of the nature of concrete and formal operational thought, possible mechanisms for cognitive development and what can be done to encourage them. In the case of CASE III this content is delivered through a series of short lectures and discussion, and the application of the theoretical principles to practical activity design and analysis of classroom scenarios is also covered. Adey and Shayer [25] stress the importance of the role of theory, particularly psychological theory, in changing practice and promoting true engagement with the CASE methodology among teachers. It is necessary for the teachers to have some knowledge of the underlying learning theory so they understand why they are making the changes to their normal teaching practice.

- Practise

Joyce and Weil [101] claim that teachers need up to 30 hours of practise to perfect a new teaching technique. The in-service part of the PD programme provided opportunities for practising new techniques in an environment where teachers can feel safe. The on-service part provides such opportunity in a real classroom situation. For CA PD there was more time dedicated to on-service practise, but time was allocated in the in-service for teachers to work with new CASE activities and apparatus. Of equal importance is the opportunity to reflect on practice where teachers, through giving feedback provide their own reflection on what has happened. The process of debriefing a series of lessons in a professional environment gives teachers a safe opportunity to re-live experiences and bring to the fore-front the extent to which the structure of the lesson was managed.

- Management

When change is being implemented into a whole science department good management becomes vital. In any department change is met with open-arms by some, while others are more resistant. Good management involves embracing and engaging both types while keeping the whole department on track and learning from one another. Any PD programme must provide support and help in the management of this process. In the CA PD there is some guidance provided to the CA co-ordinator and head of department in running effective PD within the school. This helps to ensure the initiation of the programme is successful and the innovation is maintained over long term.

- Technical Questions

Often at the beginning of any innovation or new practice the most common questions are those which are technical and are not necessarily the ones that invoke deeper understanding about the innovation. For example, 'what special equipment is needed for Activity 3?', 'Where will I get it?', 'Where do I get the print materials?', 'How do I access the materials on the website?', and so on. These genuine concerns need to be addressed but also time spent on these concerns needs to be limited and questions need to be focused on the bigger picture. The challenge for the PD instruction is to not allow for the big aims of the programme to become over shadowed by the attention to detail.

- Sense of belonging

Any innovation in either business or the classroom involves some element of risk. If one feels part of a movement it helps deter the feeling of isolation one may feel. It is important that the people who are part of the innovation, i.e., the CASE teachers, feel a sense of value and belonging within the group. This sense is one that can keep people going through difficult times and can be built into the PD programme as part of a social or apparent extra-curricular activity.

- CA atmosphere

Teaching thinking is a subtle, complex process that cannot be trimmed down to a set of activities for teachers to follow [57]. The development of higher-level reasoning in children requires that they be given an opportunity to exercise their minds, engage in critical assessment of their thoughts, share their opinions and then have them challenged in a rational but constructive manner by peers and the teacher. The teacher needs to create a friendly and safe environment, complimented with intellectual accuracy so that children feel comfortable taking cognitive risks and so ensuing cognitive development. According to Adey [57], the teacher needs to have the following in order to create such an atmosphere;

- Clear objectives on the type of reasoning being developed in the thinking lesson;
- Familiarity with the underlying theory of cognitive acceleration;
- Knowledge and understanding of the range of reasoning and arguments displayed by their students;
- Mastery of techniques such as asking leading questions, suspending judgement, setting challenges appropriate to particular children and the ability to interpret students articulation in terms of the type of thinking they are employing.

It can be argued that each of these requirements are part of every good teacher's skill-base, but for the development of reasoning in children each of the needs must be present to a higher degree or applied to specific methods and materials different from normal content-based curriculum.

1.1.6 CASE in other countries and contexts

CASE in Ireland

Maume conducted research, awarded with a Masters, on the implementation of the CASE programme in the first year of second level school, over a one year period [102]. The study was conducted to attempt to discover ways to reduce the cognitive difficulties that students were having in understanding science. Thirty of the CASE lessons were taught to an experimental class of 12+ year old boys. The lessons were taught, both within and out of normal class time. The cognitive ability of the students was measured using the Science Reasoning Tasks [32], the Richmond test of maths concepts, and the school-set end of year science exam.

The results of the study showed an increased cognitive ability of almost 1 σ in the experimental group, compared with the control group. The results of the SRTs were analysed using the Residual Gain Score (RGS) technique. The experimental class had a mean gain of 0.6, compared to 0.05 for the control group. This difference was significant. There was no statistical significant difference between the control and experimental groups in terms of mathematical ability, as measured the Richmond test. In addition there was no significant difference between the science exam results for the control and experimental group. However this study does indicate that the beneficial short term effects of CASE, as shown by Shayer and Adey, are also present after implementation of the programme over a one-year time-frame.

CASE in Australia

In 2000, Endler and Bond [40] reported their efforts to investigate children's cognitive development over a 5 year period and subsequently examine the influence that the CASE *Thinking Science* programme had on the students' development and on their scholastic achievement. The sample of students selected attended a co-educational private school (Years 8-12) in Northern Queensland and they received the intervention at a rate of about one lesson every three weeks, over a period of two years (1993-1994). The effectiveness of the intervention was measured using Bond's Logical Operations Test (BLOT) [89], which is a paper and pencil test and was developed as an alternative method to the clinique interview technique of Inhelder and Piaget.

Only 29 students remained in the school over the five years, and these were tested on three occasions. Results showed significant increases in cognitive development over the 5 years and the greatest change occurred between the ages of 13+ and 15+, with a large effect size of 0.8 σ. The results of Endler and Bond's study is in support of this research by Adey and Shayer. In addition the study showed a strong relationship between the results of BLOT and publicly accredited scores of scholastic achievement. The results on cognitive development showed that the group that were taught science through the *Thinking Science* intervention were more cognitively developed than their peers who joined school later. Large gains were made by students from a wide range of starting cognitive levels, and gender seemed insignificant to success. Although boys as a group were more cognitively developed than girls in Years 8 and 10, but no difference was found on the rate of cognitive change based on gender. A significant correlation was found between cognitive development and scholastic achievement in both years 10 and 12 and students who had experienced *Thinking Science* were more cognitively developed than students who joined the school after the intervention had taken place [40].

CASE in US setting

Endler and Bond [42] later report on their efforts to implement CASE in a school district in Oregon (USA) in order to address concerns about student competence in scientific inquiry. The US version of the CASE programme was titled the *Scientific Thinking Enhancement Project* (STEP). A feature of this study that made it very different from other CASE projects is that the teachers received very little professional development or in-class support from the CASE facilitators. The number of CASE lessons delivered varied according to the teachers' disposition and for this reason it could be implied that this study employed CASE in a sub-optimal setting. The STEP intervention was delivered at a rate of about one lesson per three weeks in replacement of the regular science curriculum. The total number of lessons delivered varied from 13 to 21, at the discretion of the individual teacher. After some alteration the intervention was confined to 7th, 8th and 9th grade classes over a 32 month period between September 2000 and the end of the 2002-2003 school year. Bond's Logical Operations Test (BLOT) was used to measure cognitive development levels on four different occasions- pre-intervention, twice during the intervention and post-intervention. The scholastic indicators used in the research were Rasch-modeled Oregon State Scores obtained from state tests of science, mathematics and reading and literature tests.

Results yet again were positive for the CASE intervention, despite the narrow focus on professional development. By the end of the study, all 3 STEP cohorts were at a higher mean cognitive developmental level than the cross-sectional control sample. The achievement results, although not as strong as those reported by Adey and Shayer [25], provide evidence that the STEP programme might have influenced the scholastic achievement of students. Statistical analysis also suggests that that there is consistent and strong correlations between the cognitive level of students, as determined from BLOT and their achievement in the Oregon state tests.

CASE in Pakistan

Findings from a study by Iqbal and Shayer [41], on the cognitive demand of the Pakistan science curriculum, showed that the demands on 11 to 13 years olds was far in excess of the levels of thinking of the students, measured by Piagetian tests. The CASE project was used in an attempt to raise the cognitive level of students and hence improve their school achievement, in the context of Pakistan secondary education. The SRTs [32] were used in the testing of this programme. SRT II (*Volume and Heaviness*) was used as a pre-test, while SRT III (*The Pendulum*) was used as a post-test. Both tests were administered in Urdu. Analysis of the data showed that the initial cognitive levels of the control groups were higher than that of the experimental group and so the effectiveness was studied in terms of different scores rather than making general comparisons.

Overall, the post-test mean levels of the intervention group was in the early formal level (7.1), whilst the mean for the control group was in the concrete generalisation level (2B*)(6.24). More rigorous analysis in the form of RGS analysis was performed and showed that boys exposed to the CASE intervention had made greater gains, with a higher mean gain over the girls in the same group, but attributes of this may be due to the large effects of the Government funded schools. The study led for some interesting reading in terms of the cultural implications of CASE. In government schools in Pakistan, and in many other parts of the world one can assume, the percentage of time teachers spend on active learning, enhanced reception learning (where the teacher intervenes with ideas/suggestions) and reception learning (where the teacher tells the students how to use apparatus) are 6, 7, and 91 percent, respectively. In the private schools this varies marginally with the proportions at 7, 7 and 86 percent, respectively. In a well managed CASE lesson the relative proportions may be 70 percent active learning, 20 percent enhanced reception and 10 percent reception learning. In conclusion to this study it was recommended that the cultural problem relating to general school ethos and the use of the CASE methodology be addressed.

CASE in Malawi

This study [103] was undertaken in response to concern about the relatively poor performance of Malawian students in science examinations, compared to other subjects. The focus of this study was to explore whether changing pupils' cognitive ability would improve their performance in science, the question posed by Shayer and Adey [1] two decades previously in the United Kingdom. In addition, the critical period for cognitive acceleration was tested in this study. Th average age for girls and boys in this study were 16 and 17 years respectively. The design of the study was quasi-experimental and involved seven schools, four of which were control and three were experimental. The teachers of the experimental classes attended eight training workshops over a period of three years and were visited in schools at least twice in every term. The effectiveness of the CASE programme on the students' cognitive development was measured by the SRTs, *Volume and Heaviness* (pre-test) and *The Pendulum* (post-test). In addition, the Malawi School Certificate of Education (MSCE) examination results in physics, biology, English and mathematics for each student were analysed in order to see if the CASE intervention improved the academic performance of pupils.

The effect of CASE on cognitive developmental levels of students was analysed by RGS analysis. The results of this analysis showed that there was a significant difference between the experimental and control groups, for both boys and girls. The effect size for girls was 0.9 σ and for boys it was 1.3 σ, higher than those in the English study. Unlike in England where it was only boys that started the intervention in Year 8 who made significant gains [91], in Malawi both boys and girls had significantly higher residualised gain scores. These results rule out any suggestion of a critical period. The intervention with the older students was every bit as successful, in terms of gains made in cognitive development. The effect of CASE on MSCE examination performance varied according to gender. Boys in the experimental group out-performed those in the control group in all four subjects tested. However, the girls in the experimental group only out-performed the control group in physics. Although both groups benefited in terms of cognitive development, the results indicate that CASE had a greater effect on the examination performance of the male cohort, especially younger males, than females.

CASE for different age groups and contexts

Since CASE there have being many other cognitive acceleration programmes developed and implemented on a large scale. CASE @ KS 1 (Key Stage 1) and CASE @ KS2 were programmes developed for pupils aged between 5 and 6 years, and 7 and 8 years respectively. The programmes were based on the pillars discussed earlier in this chapter. They were developed within the Piagetian schema of concrete operations. The materials of CASE @ KS1 were published as *Let's Think!* [104] and the materials of CASE @ KS2 were published as *Let's Think through Science* [105]. Also *Let's Think through Science! 8 and 9* was published for 8 and 9 year olds.

In addition there are several CA programmes developed for use in different contexts, including CAME (Cognitive Acceleration through Mathematics Education), CATE (Cognitive Acceleration through Technology Education) and The Wigan Arts, Reasoning and Thinking Skills (ARTS) project. These programmes are designed to promote formal operational thinking with adolescents, between the ages of 11 and 14 years.

The details of some of these programmes and their use in other countries is shown in Table 1.13.

Table 1.13: **Details of CA programmes in other countries**

Country	Programme	Year	Main researcher/s
Australia (Perth)	*Let's Think!* [104]	-	Grady Venville (Curtain University)
Australia (Townsville)	CASE	2001	Lorna Endler and Trevor Bond [40]
Finland	CA, CASE [59], CAME [106]	1980's, 2002	Jarkko Hautamåki *et al.* [107] (Helsinki University)
Germany	*Thinking Science* (German version)[108]	1992	Adey, Shayer and Yates
Holland	*Thinking Science* (Dutch version) (cited in [69])	-	Martin van Os and Peter van Aalten
Israel	*Thinking Science*(Hebrew version) (cited in [69])	-	
Korea	CASE	2002	Choi and Han [109], Nam,Choi,Lee and Choi [110] (National Teachers University)
Palestine	CASE *Let's Think!* (cited in [69])	1997	Carolynn Yates and Dua' Dajani
Slovenia	CASE (cited in [69])		Dusan Krnel, University of Lublijana
USA (Arizona)	CASE (new activities)	1992	Forsman, Adey and Barber [111]
USA (Oregon)	STEP	1999	Lorna Endler and Trevor Bond [40]

1.2 The Transition from Primary to Second level education

In this section the context for which this study is set is outlined, including many of the findings from research on the transfer from primary to second level education.

Continuity and progression across the primary and second level curriculum

The transfer from primary to secondary school is one that has been the subject of considerable research [112, 113, 114, 115, 116, 117, 118]. Despite measures to improve continuity and progression students still have problems with learning when they transfer from primary to second level education. To begin, in the context of science education, continuity is described by Braund [118] as being;

> *concerned with ways in which the education system structures experience and provides sufficient challenge and progress for pupils in a recognizable curricular landscape* [118].

Braund describes progression as;

> *pupils' personal journeys through education and ways they acquire, hone, apply and develop their skills, knowledge and understanding in increasingly challenging situations* [118].

Problems emerge in terms of student's progression through non-curricular and curricular issues. Rice [119] termed these transitions, that interrupt the continuity of life in the students, as 'institutional discontinuities' and categorised them as organisational and social. There is evidence to show that student's non-curricular problems or 'social discontinuities' are not long lived and in adequate time they quickly integrate into secondary school [120]. Data from a study by Galton and Willcocks' [121] shows that motivation and enjoyment, for most students, remained at a high level throughout the year of the transfer from primary to secondary school. These feelings were at their highest in the first few months at the new schools. However, one concern that arose out of such studies was the quality of learning in the transfer year. Croll [122], in a study of transfer of two schools for 9-13 year olds, two schools for 12-18 year olds and two for 12-18 year olds, noted that there was an interruption to the progression of students' basic skills.

> *All classes and almost all children in the primary schools made progress [in the basic skills]. However, this was not so in the first year of transfer to secondary education. Not only were average levels of progress a good deal lower in the first year after transfer...but for the first time substantial numbers of pupils made losses in absolute terms* [122].

It has also been suggested that motivation and interest decline during Key Stage 3 as pupils see that work is repeated and lessons under-estimate what they are capable of and have already achieved [123].

In the Irish context, a report carried out by the ESRI (The Economic and Social Research Institute) [124] on academic progression of transfer students, found that the majority of students did not show any improvement in test scores on reading and mathematical computations over the course of the first year. Only one fifth of the sample experienced a significant improvement in reading and one-tenth experienced a significant improvement in computation. The report suggests that the lack of progress may be related to the fact that the first year curriculum focuses on the development of a broader set of competencies across a greater range of knowledge areas than reading and computation, the areas tested. Also they suggest that first year represents a period of adjustment for students.

Previous studies, highlighting the differences between subjects taught and teaching methodologies used in the Irish primary and post-primary levels, show that a substantial number of students experienced discontinuity in learning experiences between both levels [124]. A significant proportion of first-year students surveyed did not see the second level curriculum as following on naturally from that at primary level and also the majority see the teaching methods as quite different. The issue of curriculum continuity was not unique to students, however. Greater than two third's of the first-year second level teachers surveyed felt that the primary curriculum was not a good foundation for their subject. Only half of the teachers claimed to be familiar with the nature of the primary curriculum, as shown in Figure 1.21.

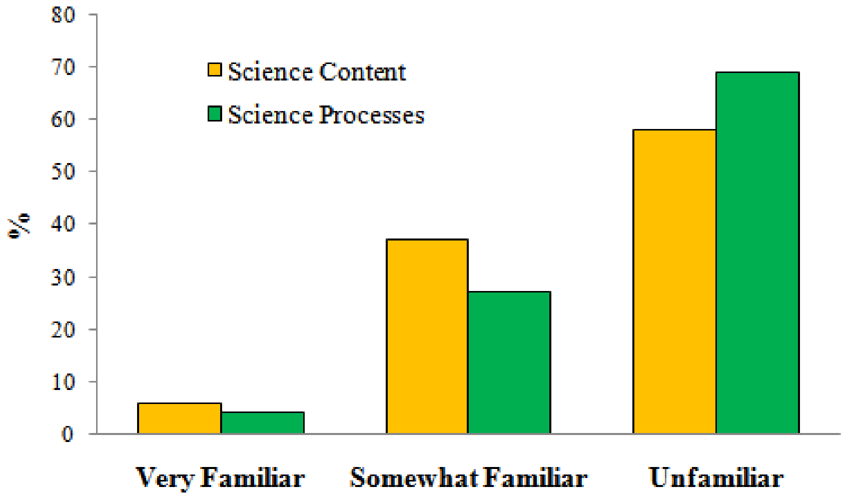


Figure 1.21: **Percentage of science teachers reporting various levels of familiarity with aspects of the SESE curriculum for Fifth and Sixth classes (adapted from [125])**

Some of the main differences in the teaching methodology of science at primary and second level are shown in Table 1.14.

Table 1.14: **Differences between primary and second level science in Ireland**

Primary level Science	Second level Science
Science compulsory since 1999	Science not compulsory in all schools
Non-specialised science teachers	Specialised science teachers
'Open' investigations/ experiments	Formal experiments
No assessment	Formal and informal assessment
'Hands-on' approach	Theory orientated

In the United Kingdom, post-transfer regression is reported to be worse in science than any other subject, including English or mathematics. Evidence shows that nearly one-third of pupils fail to make the expected grade in science tests at the end of Key Stage 3 (age 14). This expected grade was calculated by performance at the end of Key Stage 2 (age 11) [118]. This regression is not as severe for English and Mathematics. In addition, levels of engagement also fell more in science. After transfer the number of pupils 'fully engaged' fell by 26 percent in science, compared with 5 percent in English and 12 percent in mathematics [126].

There is research providing possible suggestions for this regression. Classroom based research by Galton [127] suggests that second level student's concentration declines more in science than it does in either English or mathematics. Research by Peacock [115] suggests that second level science teachers use terminology in class without being aware that the students have already encountered and are familiar with the terms. Both of these findings point very much in the direction that science in primary school has taken off and second level science teaching has not quite caught up since. The 1999 OFSTED (Office for Standards in Education) report [128] questions the quality of secondary science teaching in light of such findings.

Literature on primary/ secondary transition suggests that four main factors explain the post-transfer regression [129]. These are;

1. Pupils repeat work done at primary school, often with no added challenge, change in procedure or context [130, 123]. Jarman [131] reported, in an extensive study on the school population in Northern Ireland, that pupils claimed that much of their science done in primary school was repeated when they entered second level.

2. Teaching style and language as well as classroom environment is very different in secondary schools compared with primary schools. Students often find it difficult to get used to this change in learning culture [132, 127]. One class study found that whole class teaching occupied twice as much time in secondary school than it did in primary school [121] and this style is not suitable to all students, with Gorwood [120] recording some concern over this change.

3. Second level teachers fail to make reference to student's previous learning experiences. In addition, transferred information on student's previous attainments is rarely used to plan curriculum experiences [133, 134, 114]. An Irish study questioned second level science teachers on their familiarity with the current primary science curriculum, in terms of science content and processes for 5th and 6th class (pre-transfer) [125]. The results, shown in Figure 1.21, indicate a relatively limited teacher's knowledge of aspects of the primary science curriculum. Less than 6 percent of teachers surveyed were very familiar with the science content or processes of the curriculum for these classes. 58 percent reported that they were unfamiliar with the science content, while 69 percent were reported to be unfamiliar with science processes in the Primary School Curriculum. A review of numerous studies show that secondary school's 'fresh start approach' is to blame [113].

4. Teachers in second level schools distrust the levels that their students have been assessed at in primary schools. For example, they may claim that these levels may have been artificially inflated by intensive revision for statutory assessment at the end of the primary phase [114]. This reason may be used as a justification for second level teachers to 'start from scratch' when planning learning experiences for their students [135]. Huggins and Knight [113] define poor liaison as one of the main explanations for a lack of progress in the first year of second level.

These factors appear to be not unique to the UK, with studies from USA [112], Australia [136] and Finland [137] reporting similar problems.

In 1999 Galton *et al.* [126] published research on the efforts that schools were making to solve, or at least ease the problem of post-transfer regression. The authors categorised efforts by schools into four areas or 'bridges'. These included administration, social, curricular and pedagogical. Research in the 1990's showed that efforts were mainly in the administrative and social areas, but very little work was done to address continuity/progression in areas of curriculum or pedagogy. Galton made recommendations for easing discontinuities and disruption in teaching and learning and they are summarised as follows;

- There should be a selection of successful strategies, matched to specific experiences of transfer and transition, suitable for schools to use in their own settings;
- Schools should develop post-transfer strategies that address both academic and social concerns. These strategies should encourage pupil's personal responsibility for learning and to become professional in their approaches to learning;
- Schools should develop teaching and learning strategies in subject areas that help pupils sustain their enthusiasm and excitement in learning through experiences of transfer and transition. In addition, there should be strategies that encourage those that have become disengaged in learning;
- Schools should, with support, pay attention to pupils' accounts of why they disengage or regress at certain points, such as following transfers and transitions;

- Schools should research, in unison, what factors influence pupils' progress and attitudes to learning and the findings should be translated into strategies that other schools can use.

A report on the transition from primary to second level in Ireland highlighted the need for [124];

> *greater awareness among post-primary teachers of the primary curriculum* [124]

and information needs to be provided to primary teachers about the curriculum and approach taken within post-primary school. Further recommendations include the need for;

> *greater co-operation between the primary and post-primary sectors in terms of curriculum development and transfer of good practice in relation to teaching methodologies* [124].

Driver [138] suggests that although curricular continuity cannot guarantee progression, it does structure learner's experiences and ideas in a way that helps move student's conceptual understanding forward.

Comparison of English and Irish systems

The CASE project originally designed for the English secondary school system has since been implemented successfully in many countries throughout the world, including Malawi [103], Pakistan [41], Holland, Germany, Denmark, Finland [107], Ireland [102] and the American state of Arizona, and in some cases the materials were adapted into different languages. Before beginning to adapt CASE into the Irish system it was necessary to evaluate the differences between both primary and second level systems in both countries, in order to gauge whether the existing CASE programme complied with the Irish system. The approximate age typical at each stage for both systems is shown in Figure 1.22.

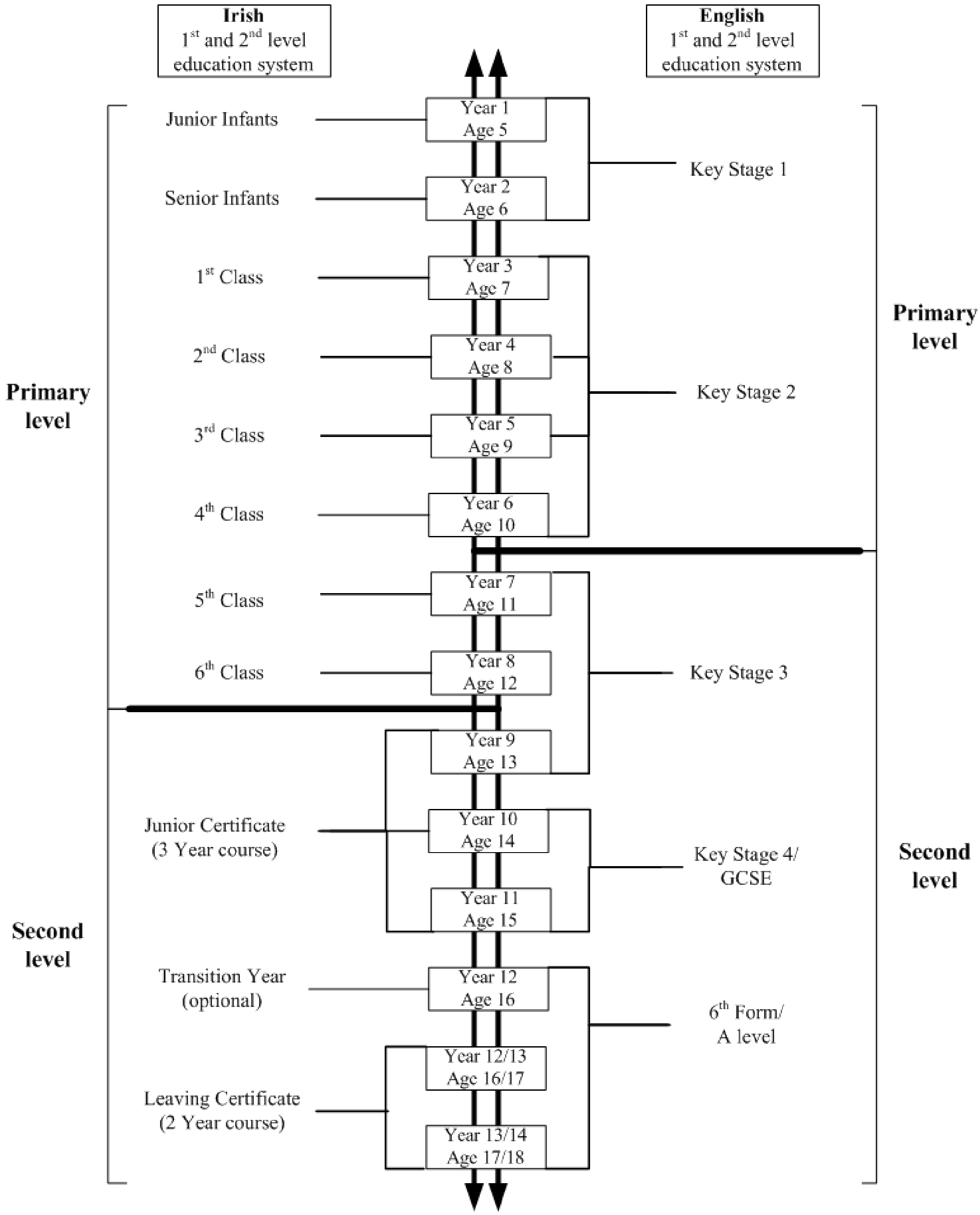


Figure 1.22: **Main age and stage features of Irish and English education systems**

In England, a child may begin in the primary system at 4.5 to 5.5 years of age. At the end of primary school they sit the Key Stage 2 examinations in English, mathematics and science. The GCSE (General Certificate of Secondary Education) exams take place after four years in secondary school. Meanwhile students sit SAT

(Standard Assessment Tests) examinations in English and mathematics on three occasions and in science on two occasions.

In Ireland, a child starts primary school at approximately 5 years of age and completes this level at approximately twelve years of age. There is no formal assessment in the Irish primary education system. Upon entry to second level education students study a three year course which is marked to completion with a terminal examination, the Junior Certificate. Following this there is an option in most schools to do a Transition Year. Alternatively, one may directly enter the final two years of second level and do the Leaving Certificate course, which finishes with a terminal examination, necessary for completion in order to progress to third level education.

The following sections describe the emergence and scope of science at primary and lower second level education in Ireland.

Science in the Irish Primary Education system

Science at primary level in Ireland is a relatively new development having been reintroduced as part of the Social, Environmental and Scientific Education (SESE) curriculum in 2003. Previously science at primary level was in the form of the Nature Study and Elementary Science programme, implemented since 1971. The emphasis of this programme was on the study of biology and botany.

The new SESE curriculum aims to provide;

> *opportunities for the child to explore, investigate and develop an understanding of the natural, human, social and cultural dimensions of local and wider environments; to learn and practise a wide range of skills; and to acquire open, critical and responsible attitudes* [139].

In reality the situation has many complications. Anecdotal evidence suggests that many Irish primary school teachers feel inadequately prepared to teach science. The 2002 Task Force on Physical Sciences report shows that only a minority of primary teachers took a physical science subject to Leaving Certificate level. Although this level is not required to be able to teach science in the primary school it may be reflective of teachers' lack of confidence in the science area. There are major concerns about insufficient priority and time within pre-service teacher training to fully address both pedagogy and content relating to science [140].

Another issue arising from the re-introduction of the science curriculum has repercussions at second level science. Anecdotal evidence suggests that when the students who have done science at primary level enter secondary school many of them become bored by repetition. The exciting experiments, previously done in second level science have now been done in primary level. Students' interest may become diminished and their understanding of the experiments may be minimal. As a result students do not engage as much with the subject. The difficulty for the second level science teacher is motivating students that have done science before and teaching those that have not.

The Junior Certificate Science programme and PISA performance

The Junior Certificate programme is a three-year course, taken in the first three years at second level. Ireland is unusual in that it is not compulsory for students to study science at second level. At present a significant number of junior cycle students study neither science nor a technology-based subject. At lower secondary, while very few students go to schools that do not offer science, over 10 percent of the total lower secondary cohort is not enrolled in science. Within all-girls schools, the non-participation rate is 20 percent [140]. The report of the 2002 Task Force on Physical Sciences expresses the concern that a significant number of students do not study science at Junior Certificate level and supports the argument that science should be made a core component in the education of all students. In the junior cycle,

> *the study of science contributes to a broad and balanced educational experience for students, extending their experiences at primary level. It is concerned with the development of scientific literacy and associated science process skills, together with an appreciation of the impact that science has on our lives and environment* [141].

Irish performance in PISA was relatively good; the mean scientific literacy score of Irish students was significantly higher than the OECD country average (9th overall).

It is not surprising that students who took Junior Certificate science achieved a significantly higher mean score in scientific literacy than students who did not study science. However, this result does point to the fact that the 11 percent of Irish students, who do not take Junior Certificate science, are lacking important scientific content knowledge [142].

In 2004 the revised Junior Certificate Science Syllabus (rJCSS) was introduced and it differs from its predecessor in a few ways. These differences are summarised below;

1. The rJCSS places a greater emphasis on practical work and student investigation, in an effort to help students to develop a better understanding of science concepts, and also to gain experience of science process skills [125]. For the first time, 35 percent of student's marks in the Junior Certificate science examination are based on their performance in two practical elements of the course. The assessment arrangements are illustrated in Figure 1.23. This is a significant move away from the former, more traditional practice, i.e., where the terminal examination accounted for 100 percent of students' Junior Certificate science grade.

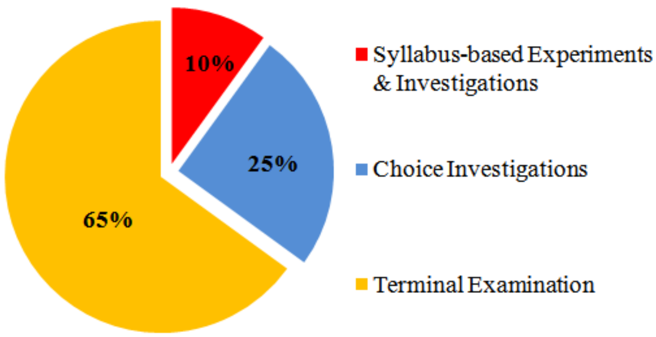


Figure 1.23: **Junior Certificate Science assessment arrangement**

2. The rJCSS also aimed to increase student interest in science and consequently increase the uptake of science subjects at upper second level and third level. One of the findings causing most concern was that from a study reporting the low uptake of physics and chemistry at Senior Cycle in Ireland [140]. Only 6 percent of the overall 80 percent transmission to Leaving Certificate takes physics. Another indicator of the low up-take of science at Leaving Certificate level is that approximately 90 percent of all points (Note; grades in Leaving Certificate examinations are converted to points for ranking for entry to third level programmes) achieved come from arts subjects [143]. The rJCSS aims

to address this concern by ensuring a better balance between the three core science subjects; physics, chemistry and biology. Students can no longer choose between optional topics, unlike in the previous syllabi where students favoured biology.

3. The rJCSS was designed to be less content-based, and more outcome-based. For example, in Table 1.15 the old and revised syllabi highlight the change in approach from knowledge of a learned list, to discovery-based learning, through investigation.

Table 1.15: **Examples of learning objectives in the old and revised Junior Certificate science syllabi**

1989 Syllabus	**Revised Syllabus**
List metals in order of increasing reactivity K, Na, Ca, Mg, Zn, Fe, Cu, Ag	Investigate the relative reactivity of Ca, Mg, Zn and Cu based on their reactions with water and acid

4. Increased emphasis is also on the Science-Technology-Society (STS) approach, which emphasises a linkage of scientific facts to everyday life. In theory at least, one of the reasons for this was to establish a better match between primary and post-primary syllabi.

1.2.1 Conclusion

In this chapter Piaget's and Vygoysky's influence on what we now know about cognitive development was discussed, as well as some of the methods of accelerating cognitive development. In particular, the methodology of the CASE programme was outlined as well as the very positive effects that it has had on children's cognitive development, in the United Kingdom and elsewhere. In addition, the area of transfer from primary to second level education was discussed, particularly in the context of science.

This thesis reports the Piagetian levels of a sample of Irish 6th class primary school pupils and 1st year second level students, in order to generate a profile of their cognitive development. Based on the earlier discussion on the research into CASE, the programme was adapted for use in primary and second level science classes in Ireland and implemented with approximately 500 pupils and students. The effectiveness of the interventions on pupils' and students' cognitive development was examined. The CASE programme was chosen as the most suitable method of cognitive acceleration for this study due to the age range suitability, its context specificity and due to it being a two year programme and so suitable for the use across the primary and second level transition as well as the positive effects of its implementation elsewhere. The design of the study was a classic experimental one, with pre- and post-tests conducted at the beginning and end of the implementation of the programme, at both levels.

The adaptation of the CASE programme for suitability for use at both primary and second level is discussed in Chapter 2, as well as the details of its implementation and the outcomes of the programme on pupils' and students' cognitive development.

Chapter 2

The Adaptation, Implementation and Results of CASE across the Primary and Second Level Transition in Ireland

Introduction

This chapter is comprised of three sections. The first section details how the CASE programme was adapted for use in the Irish primary and second level systems. The implementation and evaluation of the programme at both levels are also outlined. The second section details the results of the programme on pupils' and students' cognitive development. The third section reports the results of a small-scale study of the cognitive levels of 1st year university students. This was done out of interest and to gauge the cognitive development of students that have just recently come through the second level education system.

2.1 Adaptation of CASE for primary and second levels in Ireland

2.1.1 Background

In Ireland, there is very little articulated pedagogical continuity between primary and second level education, both in practice and theory. In an effort to address this, and the problem of the 'difficulty of science', as perceived by students and highlighted in the previous chapter, the CASE methodology was implemented at the final stage of primary level (6th class) and the first stage at second level (1st year). This programme was introduced to enhance student cognitive development and better help them to cope with the demands of the second level science curriculum. The anticipated benefits of the programme are summarised as follows;

- Primary school teachers would be trained and exposed to an established teaching methodology for science that they know, at least, some of their pupils are going to continue into second level;
- Second level teachers are aware and trained first-hand in a teaching methodology that some of their incoming first year students have used at primary level and in science topics that they have covered previously;
- The effects of part of the intervention on the final year primary school pupils can be compared with the first year second level students to examine if the programme is more effective at one or other of the levels;
- The effects of the two-year intervention can be monitored on the pupils who received the intervention in both primary and second level to see if they benefited more significantly than pupils who received the programme at only one level;
- The long term effects of the CASE programme on the pupils who had received part of the intervention in primary school but not second level could be monitored to assess if their cognitive development was permanently enhanced, compared to that of the non-intervention group.

The use of the CASE programme materials, *Thinking Science*, at both primary and second levels, required them to be adapted to suit the Irish system. The design of the study is discussed under the following three headings - time-frame, selection of schools and adaption. For use in the Irish system the *Thinking Science* materials were divided into two separate programmes, one for use in the 6th class of primary school and the other in first year of second level school. The programmes were named *Thinking Science 1* and *Thinking Science 2*, respectively.

Time-frame

In total there were three phases to the study. The word phase is used to describe the length of time that the intervention lasted, i.e., over the final year of primary school and the first year of second level. Two phases were completed, while a third phase lasted for one year, in the final year of primary level.

The CASE programme for primary school, *Thinking Science 1* was first implemented in January 2006. The time-frame of this first phase of the study is shown in Figure 2.1. Some tasks from the Science Reasoning Tasks series [144], developed by the CSMS team, were used as pre- and post-tests. The pupils in all intervention and non-intervention primary schools were given a pre-test, upon which their initial cognitive levels were determined. The intervention groups were taught science through *Thinking Science 1* for six months and this was followed by a post-test given to all intervention and non-intervention pupils. A cohort of these intervention and non-intervention pupils were tested again in September 2006, upon their entry to second level education. This test acted as a delayed post-test to this group and a pre-test to the cohort of students at second level that were not part of the study at primary school. These 1st year students were assigned into intervention or non-intervention classes. The intervention group at second level received the *Thinking Science 2* intervention programme in the time of their science lessons, in addition to their normal science classes. The non-intervention group did not receive the intervention. Finally, the intervention and non-intervention students at second level were given a post-test in May 2007.

The study was replicated in Phase 2, beginning in September 2006 in 6th class at primary level and ending in 1st year at second level in May 2008. The time-line of Phase 2 is shown in Figure 2.2.

There were two complete phases to this study, i.e., two cohorts were tracked from 6th class at primary level to 1st year in second level. However, pre- and post-tests were administered to three 6th class groups who received the *Thinking Science 1* intervention programme from September 2007 to June 2008, in the third phase. There was no non-intervention group for this third phase of the study and the pupils were not tracked into second level, due to the completion of the study.

In total there were 375 pupils who were taught through the *Thinking Science 1* intervention over the three phases. Three hundred pupils were part of the non-intervention group at primary level.

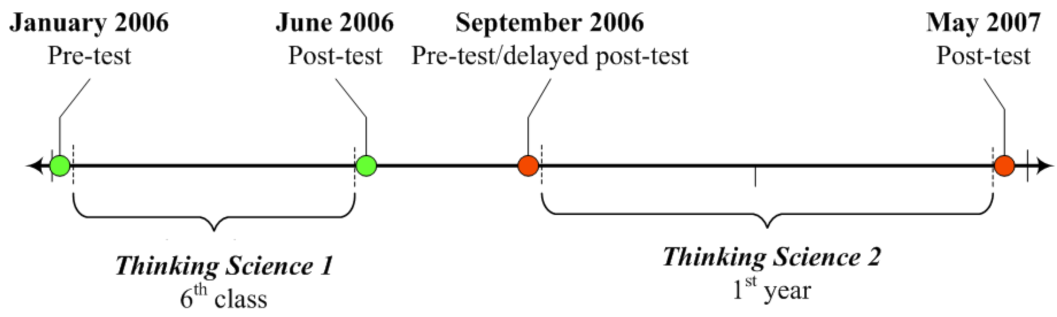


Figure 2.1: **Time-line of Phase 1; January 2006-May 2007**

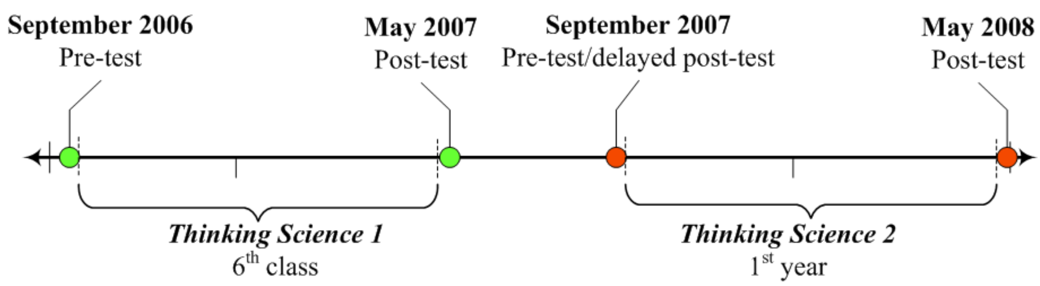


Figure 2.2: **Time-line of Phase 2; September 2006-May 2008**

Selection of schools

As one of the main aims of the project was to examine the effects of the intervention across the primary and second levels, the selection of schools to be involved was important. An important part involved selecting feeder primary schools to second level schools, with a large enough cohort of students to follow through for effective analysis to be possible. This selection process involved gathering anecdotal evidence from second level schools about their main feeder schools. However, in some cases this evidence was unreliable and numbers of students transferring from selected primary to second level schools was smaller than expected. A semi-random convenient sample of schools was chosen to include urban and rural, single sex and co-educational schools as well as schools that had compulsory and non-compulsory science to Junior Certificate level. Six second level schools agreed to become involved in the study and the details of these schools (in Phase 1 and 2) are shown in Table 2.1. Each second level school is denoted by a number, from 1 to 6. In each school, intervention and non-intervention groups were identified and these are denoted by E and C respectively.

Table 2.1: **Profile of second level schools in Phases 1 and 2 of the study (E=intervention group, C=non-intervention group)**

Phase	**School Code**	**Type**	**Number of science class groups**	**Number of students doing science**	**Group in study (number of classes)**
1	1	Semi-urban/ co-educational	2	50	C
	2	Semi-urban/ All-girls	3	81	C
	3	Urban/ All-boys	4	109	C
	4	Urban/ All-girls	4	95	C
	5	Urban/ All-girls	3	57	C(1) E(2)
	6	Urban/ All-boys	2	38	E (2)
2	1	Semi-urban/ co-educational	2	51	C
	2	Urban/ All-boys	3	90	C
	3	Urban/ All-girls	4	91	C
	4	Urban/ All-girls	3	56	E (3)
	5	Urban/ All-boys	3	67	C(2) E(1)

Meetings were held with the Head of Science in each of these schools and they were briefed on the purpose and plan of the study. After they provisionally agreed to become involved in the project in the following year (when the 6th class pupils entered their second level schools), the largest and main feeder primary schools were identified. It was also ensured that the sample of primary schools selected was representative and included both urban and rural, single-sex and co-educational schools. Although it was harder to identify, it was also intended to have on board primary schools with varying degrees of interest/emphasis in science.

The evidence obtained about the largest feeder school to each of the second level schools was, for the most part, anecdotal and subject to variance from year-to-year. When approached about becoming involved in the study, eleven out of twelve primary schools agreed. The mapping of the primary schools to their main feeder second level schools is shown in Figure 2.3. Meetings were arranged with the Principal or science co-ordinator and the 6th class teacher(s) in each primary school. The designation of the intervention and non-intervention groups was done selectively, prior to this meeting, so as to include a demographically balanced population. The class teachers of the selected intervention groups were informed about the aim of the study, what it entailed for them - teaching of CASE classes, dedication of time for training, feedback - and the level of commitment they would need to give. They were given time to think about whether they would become involved and they were also provided with the *Thinking Science 1* materials to help them make an informed decision. Eight class teachers gave their commitment to be part of the intervention group for this project.

The class teachers of the non-intervention groups were informed about the purpose of the study and the method of measuring pupils' cognitive levels.

The details of the primary schools in the first, second and third phases of the study are shown in Table 2.2. Each primary school is denoted by a letter, from A to K. The intervention and non-intervention groups within each school are denoted in the table by the letters E and C, respectively. Each school is identified by the unique letter throughout this thesis, i.e., School A was involved in all three phases of the study.

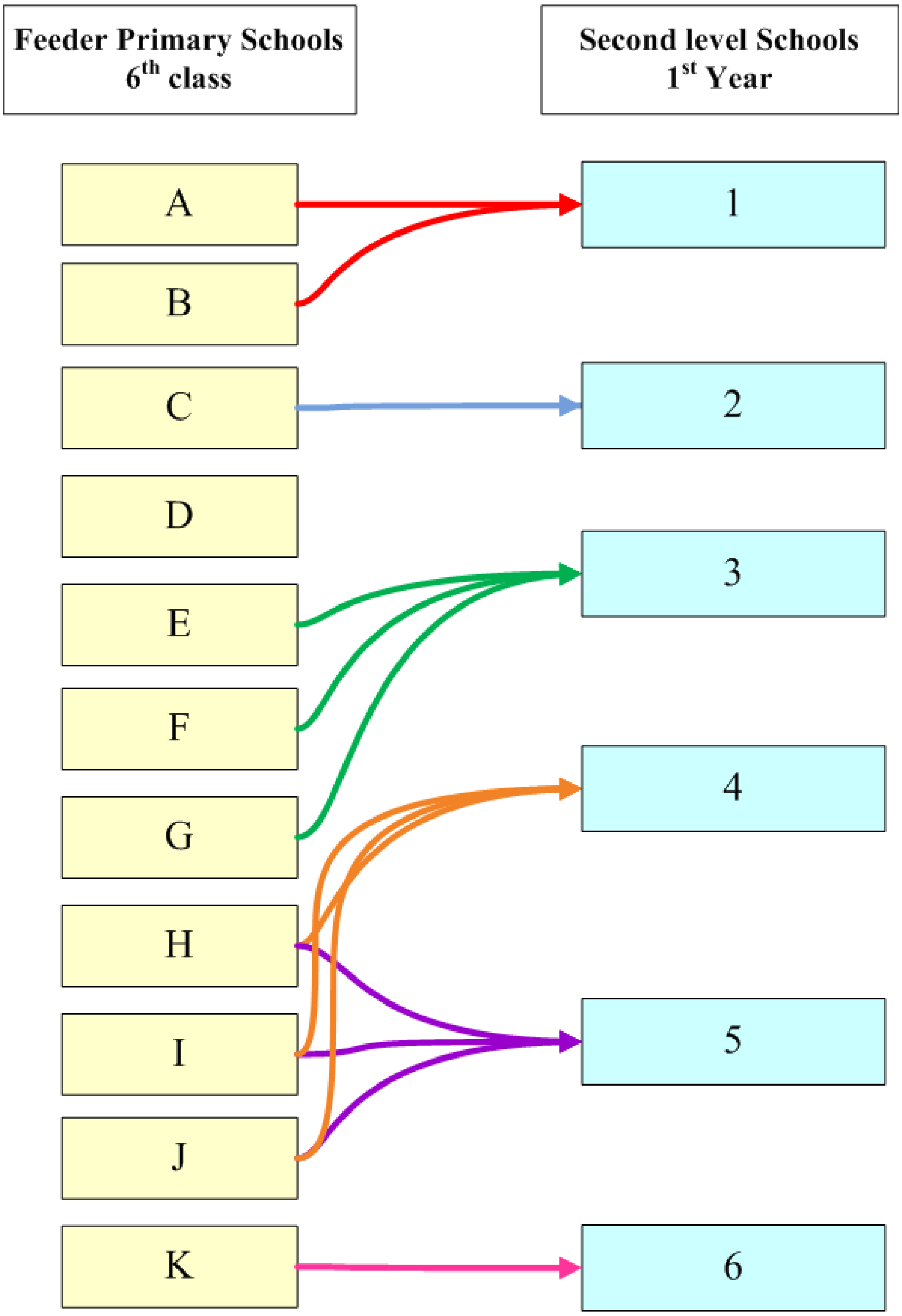


Figure 2.3: **Feeder primary schools to second level schools (Phase 1)** (Letters A-K denote primary schools, Numbers 1-6 denote second level schools)

Table 2.2: **Profile of primary schools in Phase 1, 2 and 3 of the study (E=intervention group, C=non-intervention group)**

Phase	School Code	Type	Number of 6th classes	Number of pupils	Group
1	A	Rural/ co-educational	1	27	E
	B	Rural/ co-educational	1	35	C
	C	Urban/ All-girls	1	31	E
	D	Urban/ co-educational	1	27	C
	E	Urban/ All-boys	2	41	E
	F	Urban/ All-boys	2	63	C
	G	Urban/ co-educational	1	26	E
	H	Urban/ All-girls	1	34	E
	I	Urban/ All-girls	2	59	E
	J	Urban/ All-girls	2	39	C
	K	Urban/ All-boys	1	27	C
2	A	Rural/ co-educational	1	23	E
	E	Urban/ All-boys	1	23	E
	G	Urban/ co-educational	1	26	E
	I	Urban/ All-girls	2	61	E (1) and C (1)
	J	Urban/ All-girls	1	25	C
	K	Urban/ All-boys	2	54	C
3	A	Rural/ co-educational	1	22	E
	I	Urban/ All-girls	2	58	E

Evaluation

As specified earlier this study had a classical experimental design with pre- and post-tests conducted at the beginning and end of each programme, both in 6th class at primary level and 1st year at second level. As the CASE programme aimed to enhance the cognitive development of the primary school pupils and second level students it was essential that the tests used assessed cognitive ability. The Science Reasoning Tasks [32], developed by the CSMS team, were designed to test the ability of children or adults to use concrete and formal operational reasoning strategies, essentially the type of reasoning encouraged by the CASE programme.

One task was used on each occasion of pre- and post-test and on each occasion the tasks used were different. The tasks over this part of the study ranged from Task I to IV, increasing in cognitive demand over the time of the programme. Although each task assessed a different reasoning pattern there was a strong concurrent validity among the tasks, as reported by Wylam and Shayer [35] and discussed in Section 1.1.2 of this thesis. As a result of this it was deemed reasonable to determine the cognitive level using one task only on each occasion of testing. In addition it was deemed preferable that the same task was not used twice. Each of the tasks used at primary and second level will be discussed in Section 2.1.3 and 2.1.4 respectively.

2.1.2 General Adaptations of the CASE programme

The aim of this study was to implement the programme across the primary and second level systems over a period of two years. The content of the original CASE lessons did not change, but the selection and presentation of the lessons to suit the primary and second levels required careful attention. It was hoped to have the number of intervention lessons spread evenly over the two years so that pupils and students who were not part of the study for one year would still receive a sufficient amount of the intervention programme. In this way, it was more helpful when making judgements about whether the intervention had more effect on those who did it just in primary school, those who did it just at second level or those who did it at both levels. Logistically, the materials required altering to suit such a purpose. The materials adapted for the primary and second level were named respectively, *Thinking Science 1* and *Thinking Science 2*.

Order and selection of lessons for *Thinking Science 1* and *Thinking Science 2* programmes

The ordering and selection of lessons was one of the key features that was taken into account in the adaption of the materials, to make them suitable for use in the Irish primary and second level systems.

The lessons for both the primary and second levels were arranged in a hierarchical manner, as were the original *Thinking Science* materials. For continuity, a collection of three or more lessons with the same reasoning pattern were placed in the one collection. For example, all the lessons with the formal schema of proportionality (Lessons 6, 7 and 8) were placed in the *Thinking Science 1* collection. The reasoning patterns were not necessarily grouped together within the collection, as they are not discrete, implying that the development of one reasoning pattern interacts and enhances the development of another. The chart of the estimated operating range from the second edition of the original *Thinking Science* lessons [4] is shown in Figure 2.4. The numbers of each lesson can be matched with the name and details of the lesson in Table 2.3.

The authors of *Thinking Science* give a clear word of warning about the random selection of activities to suit a purpose in a class and also about tampering with the order of the activities [4]. The objectives of the activities relate to the development of general reasoning patterns, and if the activities themselves are chosen at random to suit a need, their benefits may be fruitless and the main aim of enhancing cognitive development will be lost. For example, if a teacher looks at Lesson 9, 'The wheelbarrow' and sees that it fits in with the class work they are covering on levers, there is a danger that the science knowledge related objectives (e.g., types of levers, manipulation of force) will take precedent over the *Thinking Science* objective (the development of proportional thinking).

This presented a logistic challenge in this study as the programme had to be split into two, for use in 6th class at primary level and 1st year in second level. Upon examination of the primary and second level science curricula and deliberation with teachers at both levels, it was clear that there were varying degrees of freedom within the two systems. To begin, complying with the recommendations of the authors to keep the *Thinking Science* lessons separate from the content curriculum was feasible at the primary level, but no such possibility was present at second level. In fact, it

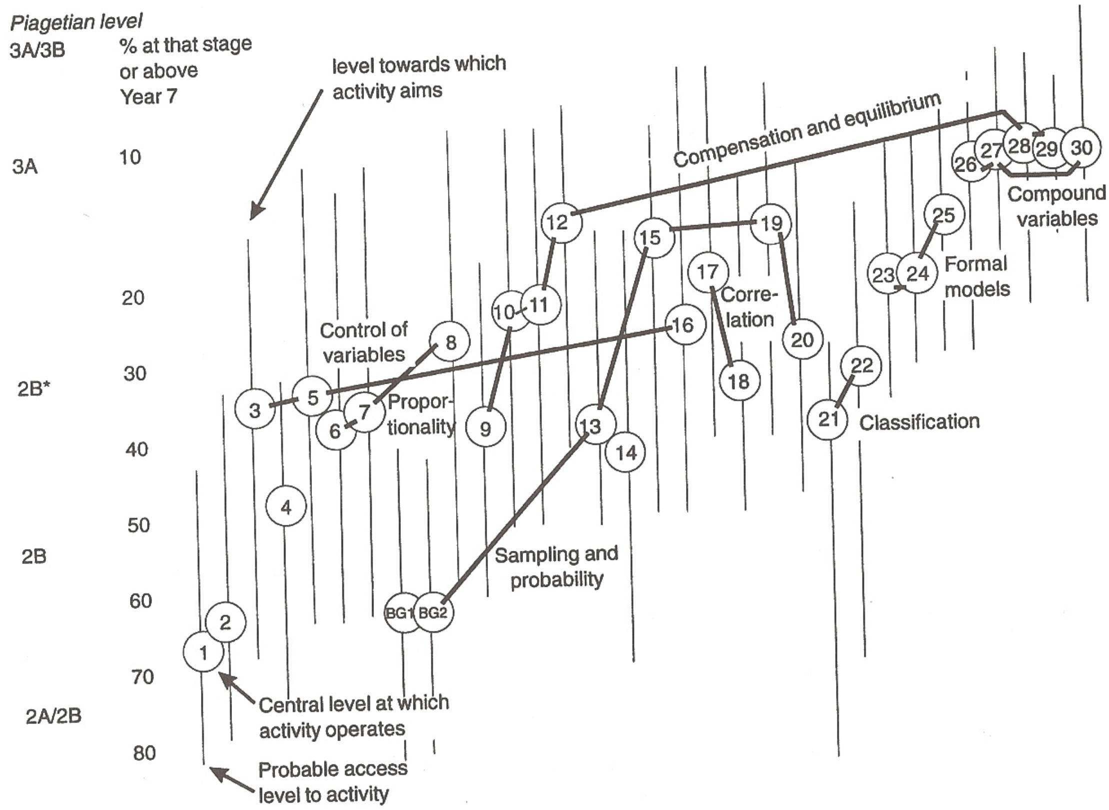


Figure 2.4: **Estimate of operating range of *Thinking Science* lessons (taken from [25])**

Table 2.3: **The original *Thinking Science* lessons and their corresponding schema (denoted by √)**

Lesson Number	***Thinking Science* lesson**	**Variables**	**Proportionality**	**Probability**	**Compensation**	**Correlations**	**Equilibrium**	**Classification**	**Formal Models**
1	What varies?	√							
2	Two variables	√							
3	The 'fair' test	√							
4	What sort of relationship?	√							
5	Roller ball	√							
6	Gears and Ratios		√						
7	Scaling: pictures and microscopes		√						
7a	Bean growth 1			√					
7b	Bean growth 2			√					
8	The wheelbarrow		√						
9	Trunks and twigs				√				
10	The balance beam				√				
11	Current, length and thickness				√				
12	Voltage, amps and watts				√				
13	Spinning coins			√					
14	Combinations	√							
15	Tea tasting			√					
16	Interaction	√							
17	The behaviour of woodlice					√			
18	Treatments and effects					√			
19	Sampling: fish in a pond			√					
20	Throwing dice			√					
21	Making groups							√	
22	More classifying birds							√	
23	Explaining states of matter								√
24	Explaining solutions	√							√
25	Explaining chemical reactions								√
26	Pressure	√							
27	Floating and sinking	√							
28	Up hill and down dale						√		
29	Equilibrium in the balance						√		
30	Divers	√							

was stressed by science teachers that the intervention programme must be very much related to the Junior Certificate science curriculum, if it was to be implemented.

In a third version of the original *Thinking Science* materials [68], the sequence of the lessons was changed slightly from the second version because of the outcomes of a more thorough analysis of the levels of difficulty and cognitive accessibility of each lesson. This revised sequence was used in the design and adaptation of *Thinking Science 1* and *Thinking Science 2* lessons for 6th and 1st year classes. These new levels of difficulty are reported in the *Thinking Science 1* and *Thinking Science 2* lessons operating charts in Figure 2.5 and Figure 2.6, respectively. These figures show the activities selected for the *Thinking Science 1* and *Thinking Science 2* programmes. The main Piagetian level required for the lesson is shown on the left hand side of each of the figures, with the sequence of the lessons being indicated by their position on the chart from left to right. Each lesson can be identified by matching the number on the charts with the number of the lessons on Table 2.3.

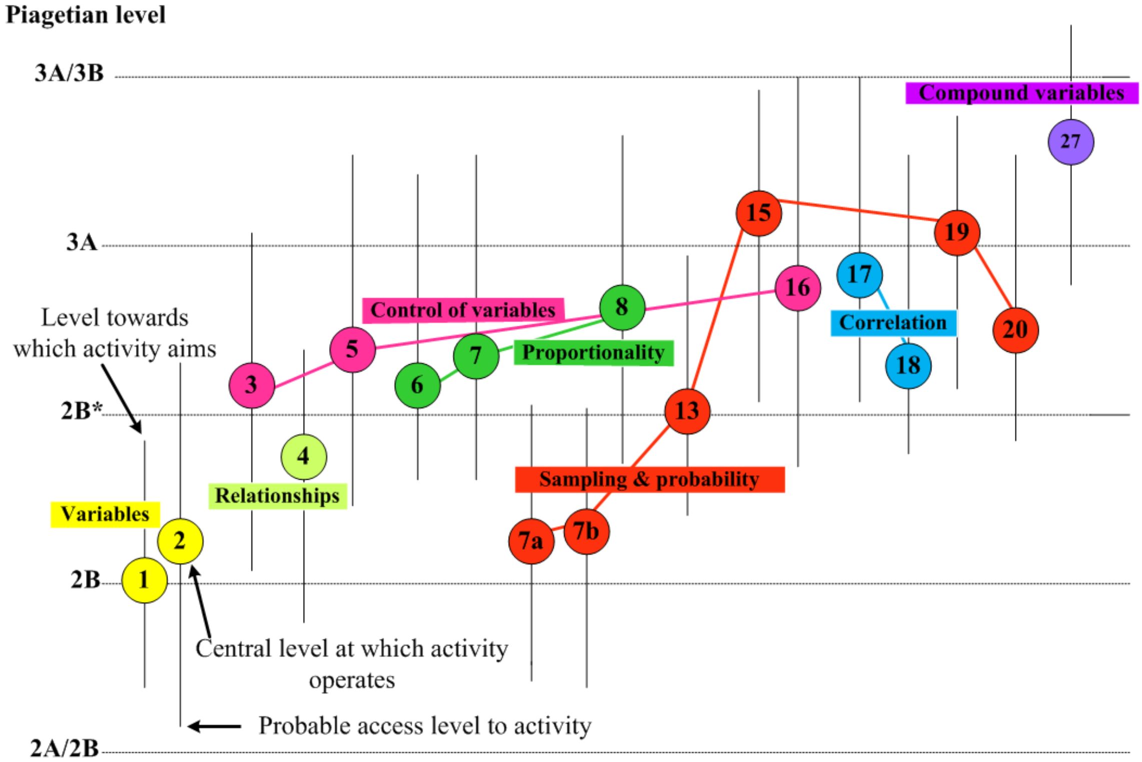


Figure 2.5: **Estimate of the operating range of the *Thinking Science 1* lessons**

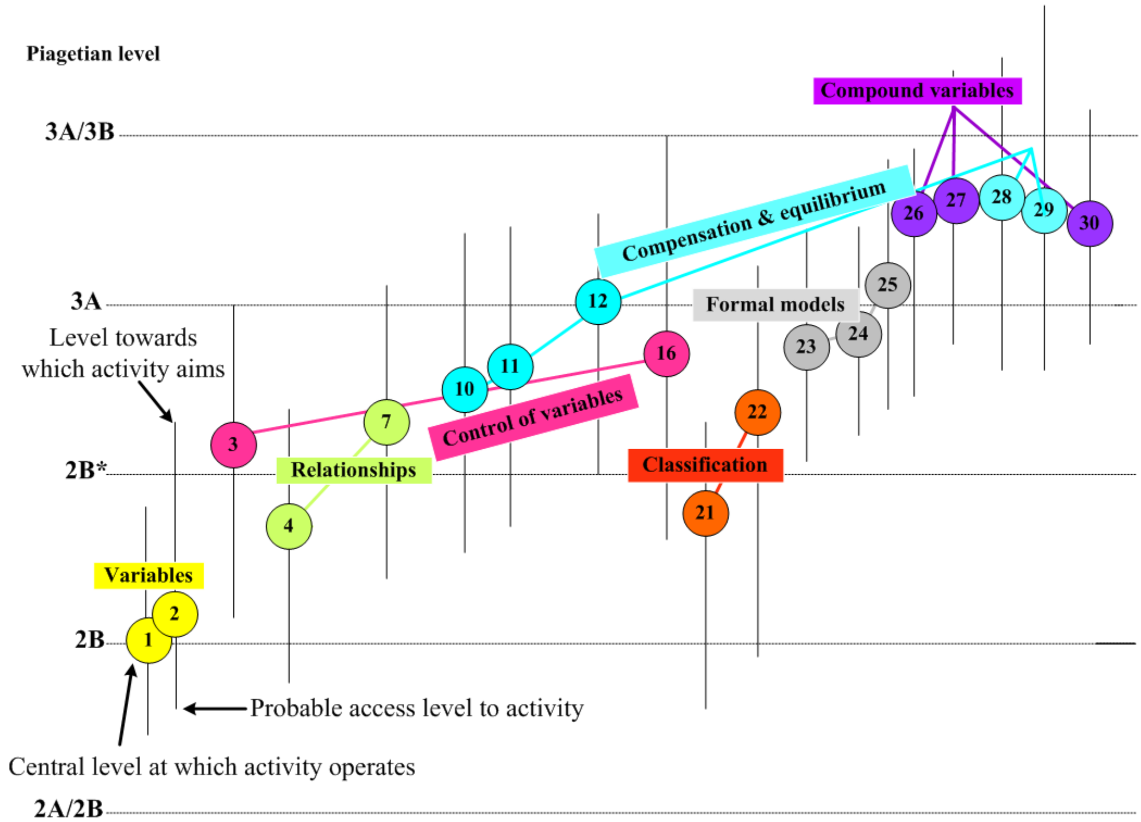


Figure 2.6: **Estimate of the operating range of the *Thinking Science 2* lessons**

In order to make the CASE methodology more instilled and attractive for use in the Irish science classroom some of the Junior Certificate mandatory experiments were presented as activities, with a distinct focus on the cognitive acceleration methodology. Lesson 16, 'Interaction' was further divided into three separate lessons to incorporate the programme more with syllabus demands. These lessons were - Rusting Nails, Respiring Yeast and Germination of seeds. The lessons were taught un-sequentially and in the style of the original Lesson 16 with the only change being the context in which the lesson was taught.

It was deemed preferable that pupils who received the intervention in 6th class and in 1st year did not repeat the same lessons, as this may prove to be of little value and repetitive for them. The exception to this rule was in the case of the first four *Thinking Science* activities where the concepts of variables and fair testing are addressed in an explicit manner. As most of the *Thinking Science* lessons require reference to the notion of variables, developed in these four activities, it was decided that they needed to be repeated in 1st year, to give the students who had not received the *Thinking Science 1* intervention (N=119) a good grounding in the schema. In order to avoid the same routine for the students who have done the activities before, the four lessons were amalgamated into three. Other adaptations included Lessons 1 and 2 which were combined into one lesson in the *Thinking Science 2* programme. This was due to restrictions on the amount of class time that could be dedicated to the programme in the intervention schools.

The specific adaptations of the CASE programme for use at the primary and second levels are discussed in the following sections.

2.1.3 Adaptation and implementation of CASE for use in 6th class in primary school- *Thinking Science 1*

The aim of the *Thinking Science 1* programme was to encourage cognitive development, in the context of science, in the final year of primary school. In order for the CASE programme to be used successfully at primary level some areas needed consideration, that was not necessary for the original *Thinking Science* materials [4]. These issues, and how they were dealt with, are discussed below.

1. **The Social, Environmental and Scientific Education curriculum**

   The Primary School science curriculum, known as Social, Environmental and Scientific Education (SESE) was re-introduced in 1999 and has been implemented since 2003. The syllabus is divided into units and strands, as shown in Table 2.4. The schools involved in the study showed an interest in seeing how the intervention programme related to the curriculum in place. It was also of additional benefit if the CASE lessons could cover material that was already featured on the school's yearly scheme of work. Although this was not always possible, it was stressed that the content of the materials is secondary to the developmental thinking processes involved. In the *Thinking Science 1* materials provided to the 6th class teachers, each lesson, as far as was possible, matched the objectives of the SESE 5th and 6th class curriculum. The lessons in *Thinking Science 1* and how they match corresponding strands in the SESE curriculum are shown in Table 2.5. It can be seen that some of the lessons incorporated more than one of the curriculum strands, while others did not directly match any.

Table 2.4: **Content strands and strand units on the SESE curriculum recommended for 5th and 6th classes (taken from [139])**

Strand Unit	**Content strands**
Living things	Human Life Plants and animals
Energy and Forces	Light Sound Heat Magnetism and Electricity Forces
Materials	Properties and characteristics of materials Materials and change
Environmental awareness and care	Environmental awareness Science and the environment Caring for the environment

Table 2.5: **The *Thinking Science 1* lessons and corresponding strands on the primary school SESE curriculum (denoted by $\surd$)**

Lesson Number	***Thinking Science 1* lesson**	**Living things**	**Energy and forces**	**Materials**	**Environment**
1	What varies?				
2	Two variables	$\surd$	$\surd$		
3	The ‘fair’ test				
4	What sort of relationship?		$\surd$		
5	Roller ball		$\surd$		
6	Gears and Ratios		$\surd$		
7	Scaling: pictures and microscopes				
7a	Bean growth 1	$\surd$			
7b	Bean growth 2	$\surd$		$\surd$	
8	The wheelbarrow		$\surd$		
13	Spinning coins				
15	Tea tasting				
16	Interaction	$\surd$		$\surd$	
17	The behaviour of woodlice	$\surd$			$\surd$
18	Treatments and effects	$\surd$		$\surd$	$\surd$
19	Sampling: fish in a pond				
20	Throwing dice				
27	Floating and sinking	$\surd$			

2. **Non-specialised science teachers**

   As mentioned in Chapter 1, one of the main differences between primary and second level education is the previous education and training of teachers in science. Many primary level teachers have not studied science since their school days and yet their duty is to teach this subject in an informative and exploratory manner.

   The original CASE materials provided teachers with a Teacher's Guide complete with an introduction, apparatus summary, procedure summary and a detailed lesson plan. The introduction provided information on the main purpose of the lesson and the main points of the lesson. There was a lack of background on the scientific detail in the original materials, as they were focused at science teachers in second level. For this study it was deemed necessary to provide primary teachers with some content knowledge on the area covered in each *Thinking Science 1* lesson. This served two purposes, firstly it cut down on extra time that may have been spent by teachers sourcing information and researching additional material on the content and secondly to subsequently instil confidence in non-specialised teachers and make them feel more adequately prepared for the lesson. It is reasonable to suggest that a lesson is more likely to run smoothly and be of more value to pupils if the teacher is confident and well-briefed on the content. This is particularly true of the CASE material. The essence of any CASE lesson is the underlying reasoning patterns and the cognitive conflict induced on students and the re-construction of their way of thinking to accommodate new evidence. If the teacher is unsure of the content in which this is set, their scope for scaffolding this cognitive conflict is grossly limited.

   However, it was unrealistic to think that by providing more background material to a teaching resource that these aims could be achieved. The clarification of concepts and areas of confusion, as well as more detailed explanations, was provided in the teacher-training part of the *Thinking Science 1* programme. This was a more ideal setting as each individual teacher's own misconceptions could be addressed and they could seek clarification on information that did not necessarily make sense for them in text.

3. **Materials provided**

   In order to aid the schools that participated in the *Thinking Science 1* programme, they were provided with all the materials needed for the designated set of lessons and instructions for how to set these up. These were prepared in a ready-to-use fashion, in order to cut down on material preparation time, giving teachers more time to prepare the delivery aspects of the class. This was deemed necessary, as generally primary schools in Ireland have no technical support staff.

4. **New material**

   Some new *Thinking Science 1* lessons, conforming with the CASE methodology, were developed for the 6th class programme and implemented in the second phase of the study. A selection of teachers were interested in incorporating the 'design and make' element of the SESE curriculum with the CASE methodology. Also, other primary schools wished to incorporate social and environmental issues into their science education. They also were impressed by the cognitive acceleration aspect of the lessons and were interested in combining the two. As a result, some lessons were compiled to include both features. These additional lessons are listed in Table 2.9 on page 133.

The complete list of lessons part of the *Thinking Science 1* programme and their corresponding formal schema are shown in Table 2.6.

Table 2.6: **The *Thinking Science 1* lessons and their corresponding formal schema (denoted by $\surd$)**

Lesson Number	***Thinking Science 1* lesson**	**Variables**	**Proportionality**	**Probability**	**Compensation**	**Correlations**	**Equilibrium**	**Classification**	**Formal Models**
1	What varies?	$\surd$							
2	Two variables	$\surd$							
3	The 'fair' test	$\surd$							
4	What sort of relationship?	$\surd$							
5	Roller ball	$\surd$							
6	Gears and Ratios		$\surd$						
7	Scaling: pictures and microscopes		$\surd$						
7a	Bean growth 1			$\surd$					
7b	Bean growth 2			$\surd$					
8	The wheelbarrow		$\surd$						
13	Spinning coins			$\surd$					
15	Tea tasting			$\surd$					
16	Interaction	$\surd$							
17	The behaviour of woodlice					$\surd$			
18	Treatments and effects					$\surd$			
19	Sampling: fish in a pond			$\surd$					
20	Throwing dice			$\surd$					
27	Floating and sinking	$\surd$							

Teacher training

Research on teacher professional development suggests that changing teacher pedagogy cannot be done through short, one-off courses [145, 146]. In contrast, it requires extended opportunities to engage in professional development, with good illustrations of the kind of practice advocated and informative feedback [147].

The *Thinking Science 1* activities can be considered little less than time-fillers if the underlying theory is neglected in the training of the teachers. The key players in any educational change are the teachers, and as Fullan and Stiegelbauer suggest;

> *Educational change depends on what teachers do and think - it's as simple and as complex as that* [148].

In this study, resources were limited but the training of teachers was modeled as far as was possible on the original, and since developed, Cognitive Acceleration Professional Development (CA PD) model, proposed by Adey [69]. Due to the teachers voluntarily agreeing to become involved in the study and receiving no bursary for doing so (apart from the potential increased cognitive development of their students!), it was decided that the researcher would accommodate the teachers as much as possible, in the facilitation of training in the use of *Thinking Science 1*. The researcher visited each teacher in his/her own school environment at a time that suited each individual teacher.

There were three types of teaching arrangements that the lessons were taught through. The details of the arrangement of how the *Thinking Science 1* lessons were taught over the three phases are shown in Table 2.7. Some teachers opted to teach the lessons by themselves, others opted for a team-teaching arrangement in conjunction with the researcher, while others asked the researcher to teach the lessons.

Each of the four teachers who were teaching their class alone were visited by the researcher on at least three occasions prior to the commencement of the programme, as well as two visits during the programme. The first two visits involved an overview of the aim of the *Thinking Science 1* programme, the underlying theory and schemata of formal operations, the structure of the lessons, and a briefing on the science behind the lessons. After this the teacher was asked to go through two/three activities with the materials and equipment provided, to deal with any practical problems, and take notes on any areas of difficulty or concern they may have, especially with the methodology. Those areas of concern were addressed in the third visit and the class was taught in an improvised manner where the researcher probed the teacher's understanding and the grasp of the methodology, in a non-threatening way. The fourth visit took place roughly five or six weeks into the teaching of the programme, in order to receive verbal feedback from the teachers and address areas of difficulties they may have been having. There was a final visit towards the end of the programme where the teachers gave extensive feedback about the methodology and its successes/failures within their class setting.

Three of the eight teachers agreed to become involved if the researcher delivered the set of lessons while they observed, while in one case the class teacher asked the researcher to be part of a team-teaching arrangement. In the case of these four teachers, the delivery of the programme incorporated much of their training. An initial visit involved an overview of the programme, a run through lessons and planning of how the delivery would work. Teachers received a presentation on the underlying theory of CASE and the researcher and class teacher practised the delivery of some lessons together. This was followed by a visit from the researcher to clarify any arising issues and to reinforce the theory. In the case of School A, where the researcher and the class teacher were team-teaching, there was a practise run through the first three lessons, without pupils being present, where roles in the delivery of the lesson were roughly mapped out. In general, the way it worked was that the teacher retained the overall control of the class and the time, while the researcher stepped in to offer alternative approaches and to re-enforce the CASE methodology throughout the lesson. As the teacher and researcher grew more accustomed to each other's practice their roles became less defined, more spontaneous and the classes ran smoother. The team-teaching classes were always followed by a discussion between the researcher and the class teacher and an appraisal about what could have been done differently. In the cases where the researcher delivered the *Thinking Science 1* lessons, there were feedback sessions with the class teacher. The individual teachers highlighted strengths and weaknesses of the class but the most valuable aspect for the teacher was their first-hand experience of the pillars of CASE in action.

Table 2.7: **Teaching arrangements of *Thinking Science 1* for Phase 1, 2 and 3**

Phase	School Code	Class Teacher	Team-teachers	Researcher
1	A		√	
	C			√
	E	√(x2)		
	G			√
	H			√
	I	√ (x2)		
2	A		√	
	E	√		
	I	√		
3	A		√	
	I	√ (x2)		

(x2) denotes that there were two teachers in the respective schools teaching *Thinking Science 1* to their classes.

Implementation of *Thinking Science 1* programme

The lessons covered by each of the intervention classes during the first phase of the study are shown in Table 2.8.

Three intervention groups participated in the second phase of the study. There was a considerable drop-off in the number of groups implementing the programme as teachers from the first phase, while having an interest in running the intervention, were unable to continue as they had different classes (not 6th class) within their schools.

In the third phase of the study there were three intervention classes. These were in Schools A and I, with one class in school A and two classes in school I. In school I, the teacher who implemented the *Thinking Science 1* programme in Phase 1 was back teaching 6th class in the school and agreed to teach the intervention lessons. The *Thinking Science 1* lessons lessons taught during the second and third phases are shown in Table 2.9.

Table 2.8: **The *Thinking Science 1* lessons taught in each intervention class in Phase 1 (denoted by √)**

Lesson Number	School Code							
	A1	C1	Ei1	Eii1	G1	H1	Ii1	Iii1
1	√	√	√	√	√	√	√	√
2	√	√	√	√	√	√	√	√
3	√	√	√	√	√	√	√	√
4	√	√	√	√		√	√	√
5	√		√	√	√	√		√
6	√			√	√		√	√
7	√	√	√	√	√	√	√	
7a		√	√	√		√	√	√
7b		√	√	√		√	√	√
8	√	√	√	√	√	√	√	√
13	√	√	√	√	√	√	√	√
15	√		√	√	√	√	√	√
16	√	√	√	√			√	√
17	√	√			√		√	√
18		√	√	√	√	√		√
19	√	√	√	√	√	√		√
20	√		√	√	√	√	√	
27	√	√			√		√	√
Total (18)	15	14	15	16	14	14	15	16

(A1= School A in Phase 1, C1= School C in Phase 1, etc.)

Table 2.9: **The *Thinking Science 1* lessons taught in each intervention class in Phase 2 and 3 (denoted by $\surd$)**

Lesson Number						School Code
	A2	E2	I2	A3	Ii3	Iii3
1	√	√	√	√	√	√
2	√	√	√	√	√	√
3	√	√	√	√	√	√
4	√	√	√	√	√	√
5	√	√	√	√		
6	√	√			√	√
7	√	√	√	√	√	√
7a	√		√	√	√	√
7b	√		√	√	√	√
8	√	√	√	√		
13		√	√	√	√	√
15	√	√	√	√	√	√
16	√	√	√	√	√	√
17		√	√	√	√	√
18	√	√				
19	√	√	√	√		
20	√	√	√	√	√	√
27	√	√	√	√	√	√
Fat in crisps	√		√	√	√	√
Germination challenge		√		√		
Clay boats	√					√
Total (21)	18	17	17	18	15	16

(A2=School A in Phase 2... A3=School A in Phase 3, etc.)

Evaluating the *Thinking Science 1* programme

Pupils' cognitive levels

Pupils' cognitive levels, in both the intervention and non-intervention groups, were tested on two occasions. The first test, the pre-test, was administered before the intervention began. The second test, the post-test, was administered after the implementation of the *Thinking Science 1* intervention, at the end of the primary school year. The schedules for testing in each phase of the study are shown in Figures 2.1 and 2.2 on page 112. The time-line for the third phase is not shown but it was the same as for the second phase of the study.

The tests of cognitive development used were the Science Reasoning Tasks (SRTs) [32], developed by the CSMS team. Their development was discussed in detail in Chapter 1. The details of the SRTs used as pre- and post-tests for the *Thinking Science 1* programme are discussed below.

- Pre-test

Task I, *Spatial Relations*, was used to determine the cognitive levels of all the students in the intervention and non-intervention groups, prior to the intervention. This task was also used to gauge the profile of cognitive levels of children in 6th class of primary school in Ireland.

This task was chosen specifically to cater for the potential range of concrete operational thought, typical of the average age in 6th class of primary school. It covers a range from pre-operational (1) to mature concrete (2B) operational thinking. The highest assessment possible is concrete generalisation (2B*) which is an indicator of fluency with concrete operations and the possibility of higher order thinking. The task tests the pupil's perception of spatial relations and co-ordination. The pupils demonstrate their perception of four different situations, via illustrations. Each scenario can be scored at a number of levels. The pupil's total score is then matched with a corresponding numerical value and Piagetian level. The key in the assessment of the illustrations was to mark, as far as possible, the pupil's intention, rather than their competence at the execution. An example of the scoring procedure is shown in Figure 2.7, where the child is asked to imagine that he or she is standing in the

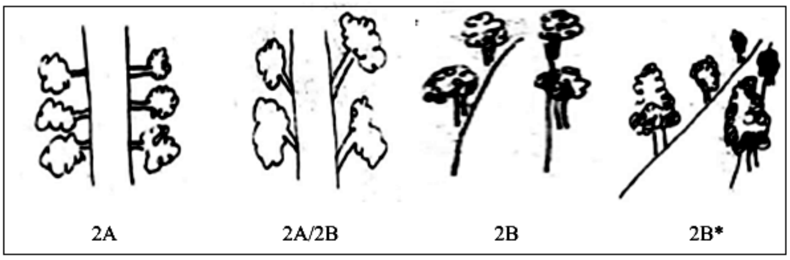


Figure 2.7: **Possible responses and corresponding Piagetian levels for Task I Question 4 (taken and adapted from [35])**

middle of a long straight road going away into the distance, and either side of the road are rows of trees. The child is asked to draw how they think it would look.

The 2A (early concrete) drawing displays no grasp of perspective and would achieve a score of 2 out of a possible 6. The second picture, typical of a mid-concrete response, would be awarded a score of 3, while the third picture would achieve a score of 4 and would be typical of a mature concrete response. The final picture displays full perspective, inclination of edges into the distance and trees graded in size and is typical of a concrete generalisation (2B*) response. A maximum award of 6 would be given if a 3-D view is generated.

The Cronbach Alpha co-efficient for Task I in this study was found to be 0.7, deeming it to be a reliable and internally consistent instrument.

- Post-test

Volume and Heaviness (Appendix A), the second task in the series of the SRTs, was used as a post-test. This task is hierarchically constructed and assesses between the range of pre-operational (1) and early formal (3A) operations. The task comprises of fourteen items which are central to the concept of 'size' and they test the child's ability to differentiate mass, weight, volume and density from each other. The task requires demonstration and students respond to questions via a worksheet. The responses are given scores of either '1' if correct or adequate, and '0' if incorrect. The answers were marked only in relation to the level specified for the question. For example, if a student answered a '2B' question with an excellent '2A' reply they do not get awarded a mark for the question. The total score at the end is matched with a numerical value and Piagetian level.

Question 1 of this task, as shown in Figure 2.8, involves the administrator filling container A to the top with water, then pouring the contents into X and refilling A. The containers should be placed next to each other and the student must record whether they think there is more, less or the same amount of water in containers A and X. This question demands an early concrete (2A) type of reasoning and tests the conservation of mass.

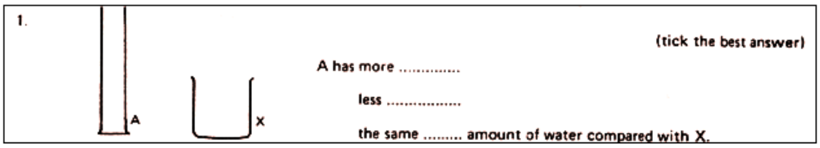


Figure 2.8: **Question 2 from *Volume and Heaviness* (taken from [32])**

Question 13 of this task is comprised of 2 parts, a and b, as shown in Figure 2.9. This task is introduced by the story of Archimedes and the King's new crown. The King asked Archimedes to find out if his new crown was pure gold, as he suspected that the goldsmith had stolen some of the gold while making up his new crown. The first question put to the students is classified as a transitional (2B/3A) question, while the second part involves an understanding of volume to weight ratios, an early formal (3A) thought process.

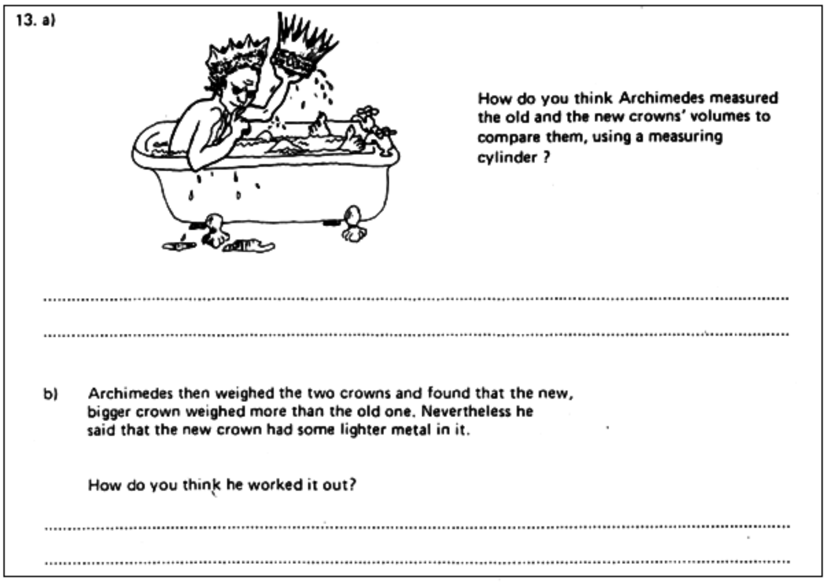


Figure 2.9: **Question 13 from *Volume and Heaviness* (taken from [32])**

The Cronbach Alpha co-efficient for Task II was found to be 0.7 in this study.

The administration of these SRTs, the correction and the analysis of the results were performed by the researcher, according to the instructions given by the test developers [35].

Teachers' evaluation

In order to gauge the 6th class teachers' opinions of the CASE programme and the effects of the programme on their pupils, interviews were conducted at the end of the school year with a sample of the class teachers. The researcher conducted the interviews using set questions which are included in the Appendix C. The data from the interviews were transcribed for the purpose of analysis.

In addition evaluation forms were filled out by the teachers. These forms were designed to gather information on the logistics of running the class, the attainment of learning outcomes and provided an opportunity for the teachers to compare this CASE methodology to their normal teaching practice. A template of the evaluation form is included in the Appendix C.

2.1.4 Adaptation and Implementation of CASE in 1st year at second level - *Thinking Science 2*

The aim of this programme was to promote and enhance formal operational thought of science students, in their 1st year at second level. As with *Thinking Science 1*, this programme also had to be adapted to suit the Irish second level system. These adaptions are discussed below.

1. **Fitting with the Junior Certificate science curriculum**

   When the 1st year teachers in the intervention schools were approached about teaching the *Thinking Science 2* programme, their commitment very much relied on the connectivity of the CASE programme to the aims and objectives of the Junior Certificate science curriculum. According to teachers' opinions the Junior Certificate science curriculum is very packed, with little time allocated for addressing topics not featured in the curriculum. The Department of Education recommends between 240 and 270 hours of class contact time over three years (equivalent to four class periods a week) in the junior cycle, in order to achieve the aims, objectives and learning outcomes of the science syllabus [149]. However anecdotal evidence showed that in the schools that participated in this study, the majority allocated on average only three forty-minute classes per week for 1st year science. In order to encourage the participation, and in the hope of the long-term use of the CASE programme, it was necessary to make the lessons as applicable to the curriculum as possible. Adey, Shayer and Yates [68] recommend that the *Thinking Science* lessons are kept separate from the content curriculum and they are referred to as 'something special', 'a *Thinking Science* lesson' or 'brain training'. However desirable that this may be, it was not possible within the constraints of the Junior Certificate science programme or even as a separate subject on the timetable. Due to these restrictions it was decided to relate the content of the CASE lessons as much as possible to the curriculum objectives, without altering the context of the lessons. Each activity was matched with its corresponding aim on the Junior Certificate science curriculum. In addition, the lessons were ordered in accordance with *Thinking Science* - 2nd edition - in order to comply with the spiral 'staircase' of development of the programme. The teachers were encouraged to sequence their scheme of work around the *Thinking Science 2* programme as much as possible. The *Thinking Science 2* lessons and the corresponding discipline and section are shown in Table 2.10.

Part of the revised Junior Certificate science curriculum [141] is Coursework A. This comprises of thirty mandatory student activities - ten each from biology, chemistry and physics - that are envisaged to be completed over the course of the three year Junior Certificate science programme. It is recommended that the activities are conducted in small groups of students and each student is required to complete reports on these activities, for assessment purposes. The second level teachers involved in the intervention phase of the project all had planned to do ten of the mandatory experiments in each of the three respective years. In order to accommodate the intervention schools' participation, it was suggested that the content of a selection of these mandatory experiments be integrated into the *Thinking Science 2* programme. The lessons required little change but the commitment from the teachers to embark on the new methodology whilst implementing the Coursework A component was necessary. The above lessons that combined this Coursework A component are marked with an asterisk (*) in Table 2.10.

Table 2.10: **The *Thinking Science 2* lessons, their related discipline (denoted by $\surd$) and the section they feature in on the Junior Certificate science curriculum [149] (* corresponds to mandatory experiments)**

Lesson Number	***Thinking Science 2* lesson**	**Biology**	**Physics**	**Chemistry**	**Section on Junior Certificate Science syllabus**
1/2	What varies?/ Variables	√	√	√	
3	The 'fair' test	√	√	√	
4	What sort of relationship?*	√	√	√	
7	Scaling: pictures and microscopes*	√			1C2 The microscope
10	The balance beam		√		3A3 Force and moments
11	Current, length and thickness		√		3C3 Current electricity; voltage
12	Voltage, amps and watts		√		3C3 Current electricity; voltage
16a	Interaction-Rusting nails*			√	2C3 Rusting and corrosion
16b	Interaction-Respiring yeast	√			1A4 Aerobic respiration
16c	Interaction- Germination of seeds*	√			1C6 Reproduction and germination in plants
21	Making groups*	√			1C1 Living things
22	More classifying: birds	√			1C1 Living things
23	Explaining states of matter*			√	2A1 Materials
24	Explaining solutions			√	2A7 Water and solutions
25	Explaining chemical reactions*			√	2C4 Metals
26	Pressure		√		3A4 Pressure
27	Floating and sinking*		√		3A2 Density and flotation
28	Up hill and down dale		√		3A3 Force and moments
29	Equilibrium in the balance		√		3A3 Force and moments
30	Divers*		√		3A2 Density and flotation

2. **Class-time**

   Unlike the primary system, where there is more flexibility on the time one could spend on a *Thinking Science* lesson, at second level the *Thinking Science 2* lessons had to be implemented within set class periods. In order to accommodate this often the bridging exercises/worksheets had to be scaled down or given as homework. Coming back to this exercise in the next science class was not ideal for the optimum effectiveness of the activity, but where there was little choice this had to be done. A selection of the lessons were more suitable for shorter class periods, i.e., 40 minutes. Overall, a double class was required to complete the *Thinking Science 2* lessons in full.

3. **Technicians**

   Currently, four percent of second level schools in the Republic of Ireland have laboratory technicians employed. This is in stark contrast with Northern Ireland and the United Kingdom, where all second level schools employ technicians [150]. In Ireland, the technical issues are handled by the teachers. In every *Thinking Science 2* lesson some amount of technical preparation was necessary, albeit to varying degrees. For example, Lesson 10 requires the manufacture of a class set of wooden laths with specially drilled holes, while Lesson 22 requires the photocopying of sets of work-cards and individual worksheets. To ensure that teachers were not troubled with this technical preparation, each intervention class was provided with the full range of materials (equipment, chemicals, etc.) and worksheets needed for each of the *Thinking Science 2* lessons. Any preparation that the teacher had to do for the class was solely on the delivery of the cognitive acceleration lesson.

The complete set of lessons in the *Thinking Science 2* programme and their corresponding schema in the *Thinking Science 2* programme are shown in Table 2.11.

Table 2.11: **The *Thinking Science 2* lessons and their corresponding formal schema (denoted by $\surd$)**

Lesson Number	***Thinking Science 2* lessons**	**Variables**	**Proportionality**	**Probability**	**Compensation**	**Correlations**	**Equilibrium**	**Classification**	**Formal Models**
1 and 2	What varies?/ Variables	$\surd$							
3	The ‘fair’ test	$\surd$							
4	What sort of relationship?	$\surd$							
7	Scaling: pictures and microscopes		$\surd$						
10	The balance beam				$\surd$				
11	Current, length and thickness				$\surd$				
12	Voltage, amps and watts				$\surd$				
16a	Interaction-Rusting nails	$\surd$							
16b	Interaction- Respiring Yeast	$\surd$							
16c	Interaction- Germination of seeds	$\surd$							
21	Making groups							$\surd$	
22	More classifying birds							$\surd$	
23	Explaining states of matter								$\surd$
24	Explaining solutions	$\surd$							$\surd$
25	Explaining chemical reactions								$\surd$
26	Pressure	$\surd$							
27	Floating and sinking	$\surd$							
28	Up hill and down dale						$\surd$		
29	Equilibrium in the balance						$\surd$		
30	Divers	$\surd$							

Selection of schools

The selection of second level schools was carried out at the very beginning of Phase 1, in order to aid in the selection of feeder primary schools.

The details of the 1st year classes in Phase 1 and 2 of the study are shown in Tables 2.12 and 2.13. The identity of the school and class, both denoted by numbers are shown, as well as the number of students in each class and whether the class was an intervention (E) or non-intervention class (C).

Table 2.12: **Profile of 1st year intervention (E) and non-intervention (C) classes in Phase 1**

Phase	School Code	Class Code	Number of students	Group
1	1	1.1.1	26	C
		1.2.1	23	C
	2	2.1.1	27	C
		2.2.1	28	C
		2.3.1	26	C
	3	3.1.1	27	C
		3.2.1	28	C
		3.3.1	27	C
		3.4.1	27	C
	4	4.1.1	23	C
		4.2.1	24	C
		4.3.1	24	C
		4.4.1	24	C
	5	5.1.1	17	E
		5.2.1	20	E
		5.3.1	20	C
	6	6.1.1	21	E
		6.2.1	16	E

The number of students that transferred from each of the primary schools to the second level schools, as part of the study in Phase 1 are shown in Figure 2.10. The number of students are shown in the circles. Figure 2.11 shows the number of students that transferred from each of the primary schools to the second level schools in Phase 2.

Table 2.13: **Profile of 1st year intervention (E) and non-intervention (C) classes in Phase 2**

Phase	**School Code**	**Class Code**	**Number of students**	**Group**
2	1	1.1.2	25	C
		1.2.2	26	C
	3	3.1.2	30	C
		3.2.2	31	C
		3.3.2	29	C
	4	4.1.2	22	C
		4.2.2	23	C
		4.3.2	22	C
		4.4.2	24	C
	5	5.1.2	19	E
		5.2.2	18	E
		5.3.2	19	E
	6	6.1.2	20	E
		6.2.2	20	C
		6.3.2	27	C

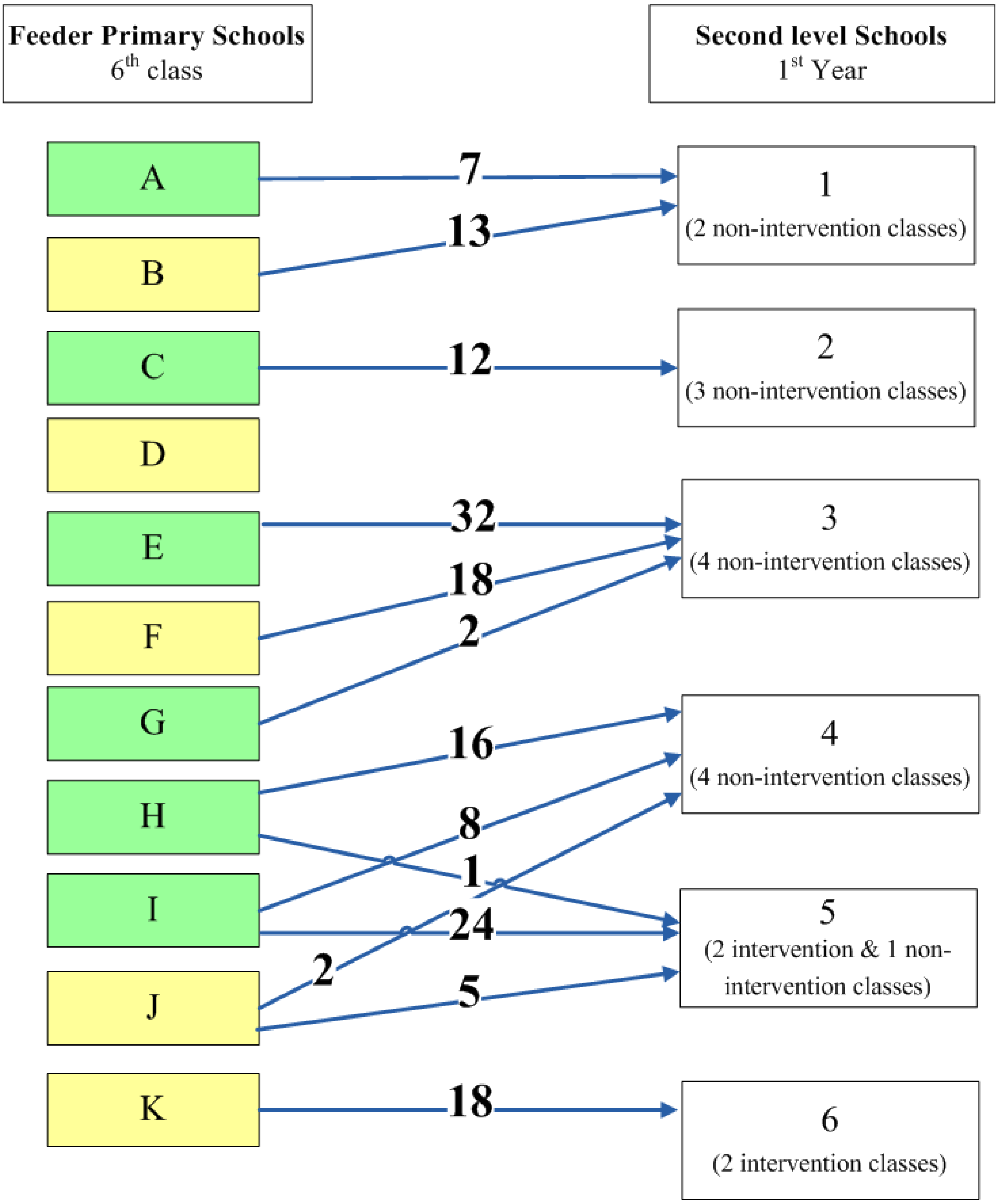


Figure 2.10: **Feeder numbers from primary to second level schools in Phase 1**

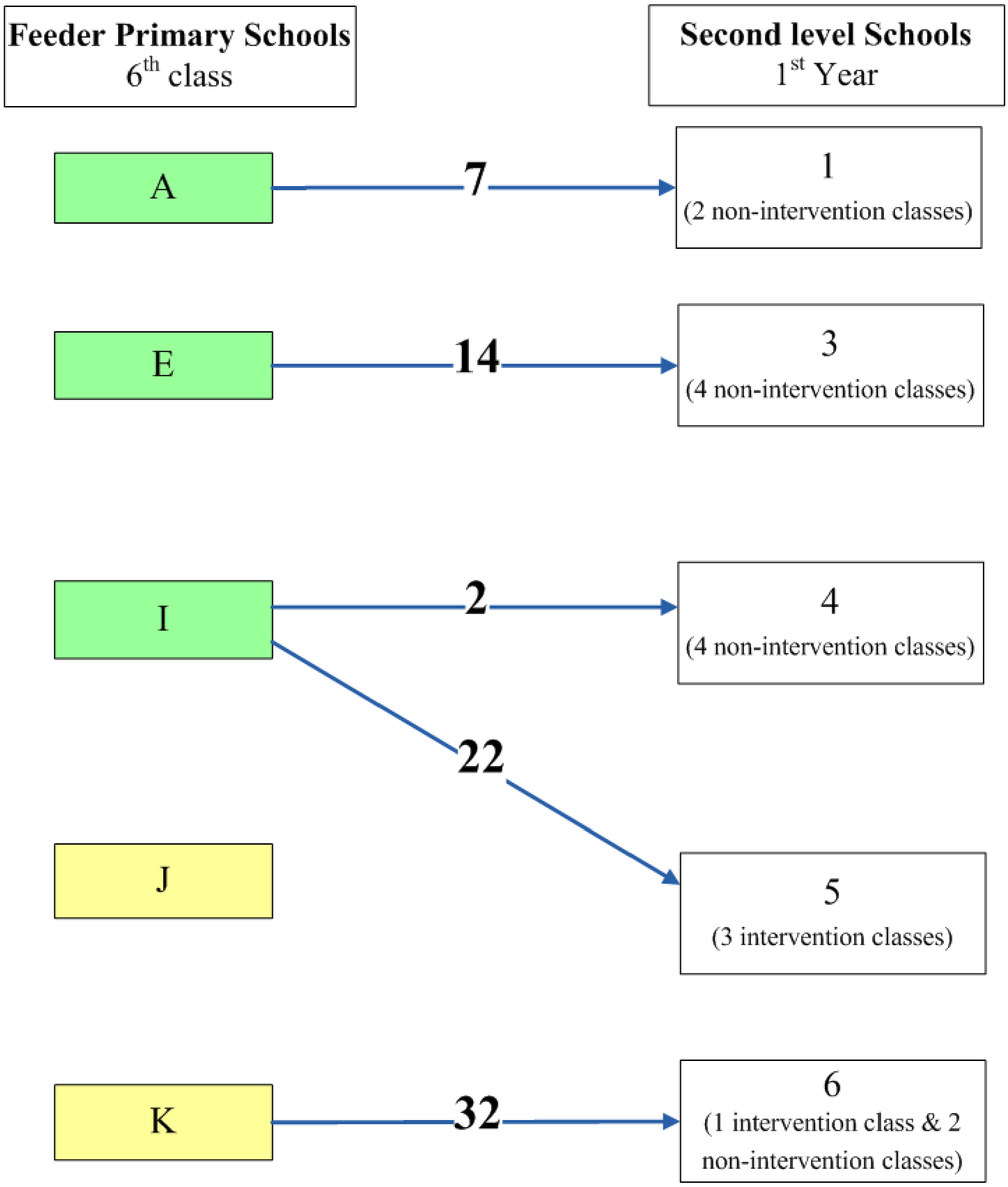


Figure 2.11: **Feeder numbers from primary to second level schools in Phase 2**

Teacher training

The preparation of teachers at second level was based on a similar ideology as for the primary school teachers, however some adaptions were necessary. The science teachers were specialised in science and therefore there was no time required for coverage of content knowledge. This extra time was spent addressing practical issues in the implementation of the programme such as planning and organisation of the term plan to suit the needs of the *Thinking Science 2* programme. There was a chance that if this time was not spent doing this that lessons would have been selected to suit the agenda of the school rather than the needs of the programme. In addition, some of the training was devoted to managing the time spent on the lessons, to ensure that the maximum value was obtained from the lessons. Three workshops were held with the teachers of the intervention classes. The first workshop involved briefing on the methodology, its purpose, background on Piaget's schemata of formal operations and a brief review of results that have been obtained in previous studies. Also the details of the *Thinking Science 1* programme were explained to the teachers and the content covered in the programme at primary level. The teachers were given two weeks to work through some lessons and the second workshop was spent addressing problems that arose and queries that emerged. A final workshop at this introductory stage followed some weeks after the teacher had begun implementing the programme. As well as a feedback session there was particular attention paid to the CASE methodology and the teachers' views and experience of using the five 'pillars'. The details of the teaching arrangements for the *Thinking Science 2* programme in Phase 1 and 2 are shown in Table 2.14.

Table 2.14: **Teaching arrangements for *Thinking Science 2* intervention programme-Phase 1 and 2**

Phase	Class Code	Class Teacher	Team-teachers	Researcher
1	5.1.1	√		
	5.2.1		√	
	6.1.1	√		
	6.2.1	√		
2	5.1.2			√
	5.2.2			√
	5.3.2			√
	6.1.2	√		

Evaluating the *Thinking Science 2* programme

Students' cognitive levels

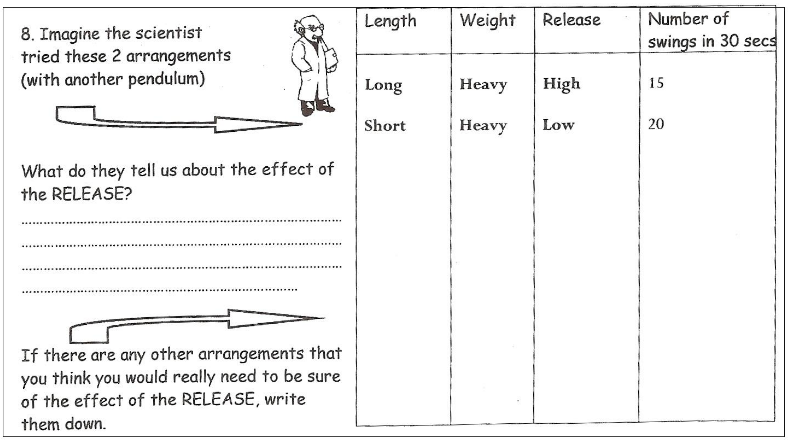
Students' cognitive levels, in both the intervention and non-intervention groups, were tested on two occasions. The first task, the pre-test was administered before the intervention began, in September of the respective phases. This test acted as a pre-test to the students that were new to the cohort, i.e., those who were not part of either the intervention or non-intervention group at primary level. It was also a delayed post-test for the students that were in the intervention and non-intervention groups at primary level. The post-test was administered at the end of the school year, after the completion of *Thinking Science 2* intervention programme. The schedules for testing in each of the phases of the study were shown in Figure 2.1 and Figure 2.2 on page 112.

As in the *Thinking Science 1* programme, the SRTs [32] were used as tests of cognitive development. They were part of the same series as the tasks used in the testing of *Thinking Science 1*, but were developed to assess a greater range of formal operational thought. A student's total score is calibrated to a scale and a level of cognitive development is ascribed, as discussed earlier in Section 1.1.2 and detailed in Appendix A. The details of the tasks used at pre- and post-test are discussed below.

- Pre-test/ Delayed post-test

Task III, *The Pendulum* (Appendix A), was used to determine the cognitive levels of all the second level students. This task was also used to determine a profile of 1st year second level students' cognitive levels. This task covers a range of cognitive levels from mature concrete (2B) to formal generalisation (3B). The task investigates students' ability to sort the effects of three variables -length, weight and release height of a pendulum- and figure out their effect on the period of oscillation. To master this task the student must be able to design experiments which control appropriate variables and make deductions from experimental evidence obtained during the task. In total, there are thirteen items. A question from Task III is shown in Figure 2.12.

The Cronbach Alpha co-efficient for Task III in this study was 0.7, indicated that it



8. Imagine the scientist tried these 2 arrangements (with another pendulum)

Length	Weight	Release	Number of swings in 30 secs
Long	Heavy	High	15
Short	Heavy	Low	20

What do they tell us about the effect of the RELEASE?

....

If there are any other arrangements that you think you would really need to be sure of the effect of the RELEASE, write them down.

Figure 2.12: **Question 8, Task III *The Pendulum* [32]**

had good internal consistency.

- Post-test

The post-test, *Equilibrium in the Balance* (Appendix A), is the fourth in the series of the SRTs. This task is hierarchically constructed and assesses between the ranges of mature concrete (2B) and formal generalisation (3B). The task contains thirteen items and investigates the student's ability to recognise and use inverse proportions in a balance beam. Figure 2.13 shows the apparatus used in this task. The majority of the questions are at the concrete and early formal levels. Towards the end of the task, proportions and the work principle are introduced, only accurately conceptualised by a late formal thinker. The task requires demonstration, and students respond to questions via a worksheet. The responses are given scores of either '1' if correct or adequate and '0' if incorrect. The answers were marked only in relation to the level specified for the question. The final score each student obtained was matched with a corresponding numerical scale and Piagetian level, representative of the student's stage of cognitive development.

Question 5 of SRT III, as shown in Figure 2.14, involves the administrator talking through the question with reference to the diagram. This is classified as a mature concrete operational (2B) question.

Question 10 on this task is comprised of 2 parts, a and b, as shown in Figure 2.15. The demonstrator explains the picture, that two different shapes are balanced at distances of two and three arbitrary units on the beam. Part (a) requires the

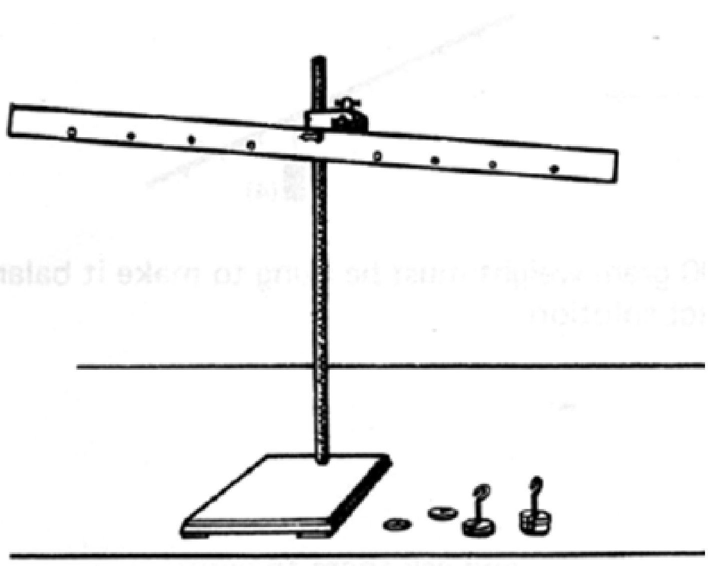


Figure 2.13: **Equipment needed for Task IV, *Equilibrium in the balance* [32]**

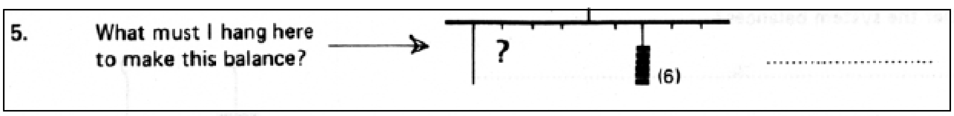


Figure 2.14: **Question 5 of Task IV *Equilibrium in the balance* (taken from [32])**

student to determine which one they think is heavier, while part (b) asks by 'How much heavier is the one you have chosen, than the other one?'. This item requires late formal operational reasoning (3B).

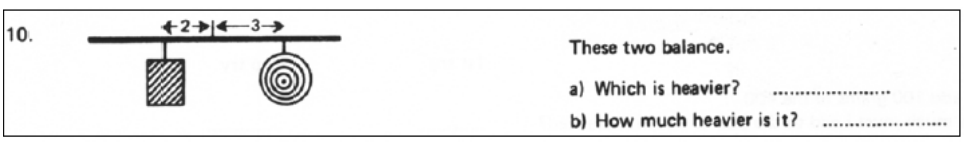


Figure 2.15: **Question 10 of Task IV *Equilibrium in the balance* (taken from[32])**

Teachers' evaluation

In order to qualitatively evaluate the effects of the programme on students' development and the general success of it, interviews were conducted with teachers. The researcher conducted the interview and the questions used to lead the interview are shown in Appendix C. Some of the feedback is reported in Section 2.2.3.

Implementation

In Phase 1 of the study the *Thinking Science 2* programme was implemented with four intervention classes in 1st year at second level. Over the nine month period it was aimed that between 14 and 20 lessons would be taught, at a rate of about one every two weeks. Table 2.15 shows the lessons covered by each of the intervention classes during Phase 1 and Phase 2 of the study. Yet again in the second phase of the study there were four intervention classes. The intervention schools did not change but there were some changes in teachers from the first phase. In School 5, the 1st year science teacher, who was involved in the team-teaching arrangement of the CASE lessons in Phase 1, got re-assigned new classes, which did not include 1st year science. The new 1st year teacher in this school however was willing to become involved if all three of the classes could be taught the *Thinking Science 2* lessons by the researcher. In School 6, the 1st year teacher, trained in the use of CASE, had only one 1st year science class in Phase 2 and agreed to implement the programme again with this class.

Conclusions

The original CASE materials, *Thinking Science* were successfully implemented across two levels in the Irish education system. The needs at both levels were assessed and the programme was adapted accordingly. The results of the programmes, namely *Thinking Science 1* at primary level and *Thinking Science 2* at second level are discussed in the next section.

Table 2.15: **The *Thinking Science 2* lessons covered in each intervention class in Phase 1 and 2 of the study**
(5.1.1=School 5, Class 1 in Phase 1, 5.2.1=School 5, Class 2 in Phase 1, etc.)

	School Code							
Lesson Number	5.1.1	5.2.1	6.1.1	6.2.1	5.1.2	5.2.2	5.3.2	6.1.2
1 and 2	√	√	√	√	√	√	√	√
3	√	√	√	√	√	√	√	√
4	√	√	√	√	√	√	√	√
7	√	√			√	√	√	
10			√	√	√	√	√	√
11		√	√	√				√
12		√	√	√				√
16a	√	√	√	√	√	√	√	√
16b	√	√			√	√	√	
16c	√	√	√	√	√	√	√	√
21	√	√	√	√	√	√	√	√
22	√	√	√	√				√
23	√	√	√	√	√	√	√	√
24	√	√	√	√				√
25	√	√			√	√	√	
26			√	√	√	√	√	√
27	√	√	√	√	√	√	√	√
28			√	√				√
29			√	√	√	√	√	√
30	√	√			√	√	√	
Total (20)	14	16	16	16	15	15	15	16

2.2 Results of the *Thinking Science 1* and *Thinking Science 2* programmes

Introduction

In order to evaluate the effectiveness of the intervention programme on cognitive development, rigorous analysis was performed on student responses to the Science Reasoning Tasks, used to assess the students' cognitive levels. Due to the quasi-experimental manner in which the study was carried out, the results section is comprised of three parts. The first part reports the effectiveness of the *Thinking Science 1* programme on 6th class primary school pupils' cognitive development. The second section reports the findings from the intervention in 1st year at second level-*Thinking Science 2*. Finally, the third part details the results of the students who did both interventions and the effectiveness of the overall *Thinking Science* programme, i.e., *Thinking Science 1 and 2*, on cognitive development. A number of students missed either the pre- or post tests and these have been excluded from the analysis, as it was not possible to measure the change in their Piagetian level over the duration of the intervention.

As discussed in Section 2.1, the study was carried out with several cohorts of students, namely three 6th class cohorts and two 1st year cohorts. For the purpose of the analysis the results for the three phases were combined, unless otherwise stated. First the method of result analysis and reporting is outlined.

2.2.1 Method of Analysing Results

The results were analysed using the Microsoft Excel programme and the Statistical Package for the Social Sciences (SPSS) (Version 15) programmes.

In this report, the output of all t-tests are reported in the following format; (t(df)=x, p=y), where x and y are the out-putted t-value and significance. The symbols t and df, denote the t-value and degrees of freedom, respectively. The p denotes the statistical significance of the t-value. In all tests 'Levene's Test for Equality of Variances' was analysed first. If the results from this test were not significant, it was assumed that the variances were equal. If the test was significant, the null hypothesis, that the validity of the two groups is equal, was rejected, implying that the variances were not equal.

Throughout the results section the letter N is used to represent sample number, M represents mean, SE stands for Standard Error and the Greek letter, σ, represents standard deviation.

The results were presented as follows; Initially the profile of Piagetian levels of the 6th class pupils in this study is presented. Following this the pre-test scores of the intervention and non-intervention groups are compared to assess if there were any initial differences between both groups at the start of the study. The effects of the intervention are discussed in terms of change in cognitive levels and the difference in mean scores in cognitive tasks between the time of pre- and post-test. However, a basic comparison of means was not seen as a sufficient way to compare these groups due to students' natural cognitive development. To combat this Residual Gain Score analysis was carried out. The method of this analysis is discussed below. In addition the results are reported in terms of effect sizes, a technique which reports the difference between the mean post-test scores of the intervention and non-intervention groups, in terms of the standard deviation of the non-intervention group. This analysis is also reported for the 1st year group and the combined group that did both programmes over the two levels.

Residual Gain Score (RGS) analysis

Residual Gain Score (RGS) analysis was used to predict post-test scores of the intervention group, based on the actual pre- and post-test scores of the non-intervention group. If there is any difference between the actual scores obtained by the intervention group, compared with that predicted from the non-intervention group, it can be associated with the intervention. This technique of analysis was used by Adey and Shayer [25]. The RGS method works by using the regression line drawn from the plot of the pre- and post-test results of the non-intervention group, as shown in Figure 2.16. Using the equation of the line, the predicted post-test scores for the intervention group can be computed. When the predicted post-test scores are subtracted from the actual scores, the RGS is found. In theory, the RGS of the non-intervention group should distribute around a mean of zero. The RGS of the intervention class will also group around a mean. If the mean is zero, this implies that the intervention had little or no effect on the parameter being measured. A positive mean implies that the intervention has been beneficial, while a negative mean suggests a harmful effect. Embretson [151] recommends this method, as a means to compare groups, as it is *'the best measure of gain because it is uncorrelated with initial status'*.

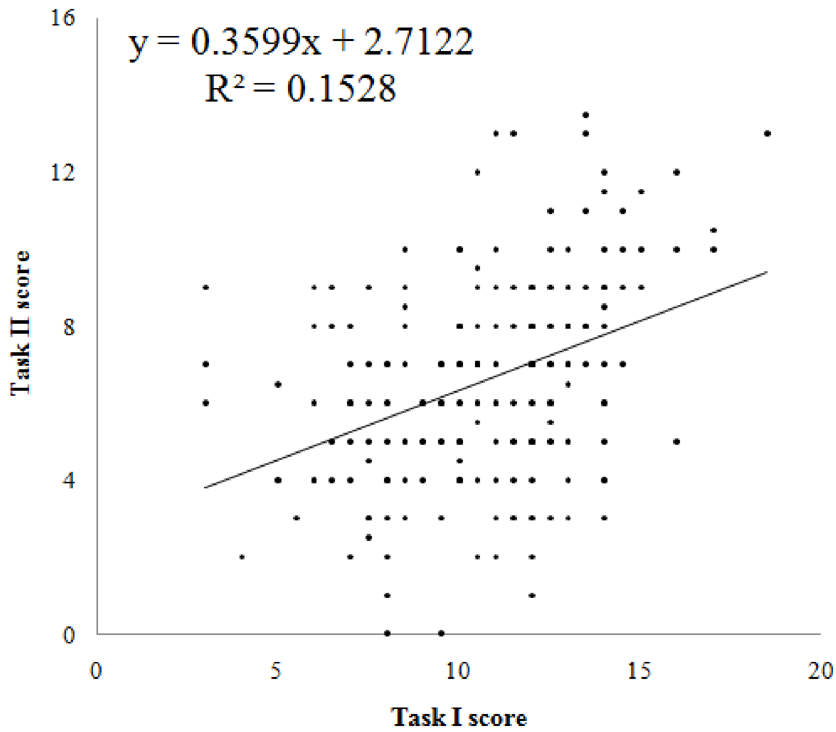


Figure 2.16: **RGS plot of 6th class non-intervention groups pre- and post-test scores**

Sample numbers

As this study was conducted over a period of three years and over two levels in the Irish education system, there were many students involved, on both an intervention and non-intervention basis. Figure 2.17 and Figure 2.18 display the number of students that participated as part of the intervention and non-intervention group for the *Thinking Science 1* (6th class) programme, the *Thinking Science 2* programme and both programmes consecutively. The number of students that were part of the intervention group over the three phases is shown in Figure 2.17. There were 343 students who were taught through the *Thinking Science 1* programme only, 119 who were taught through the *Thinking Science 2* programme only and 32 who were taught through both.

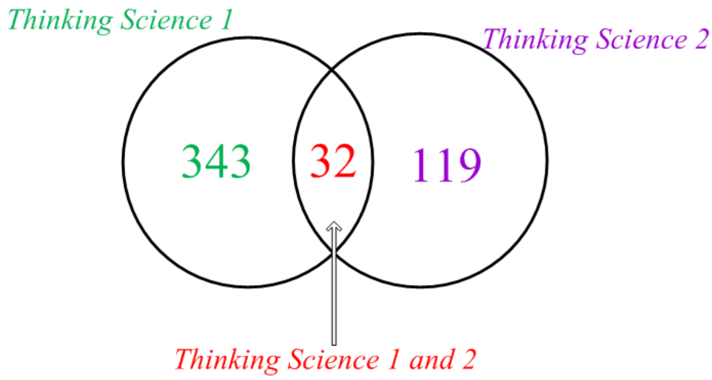


Figure 2.17: **Total number of students in the intervention group of the *Thinking Science* programmes over the three phases (for further clarification see Figure2.25)**

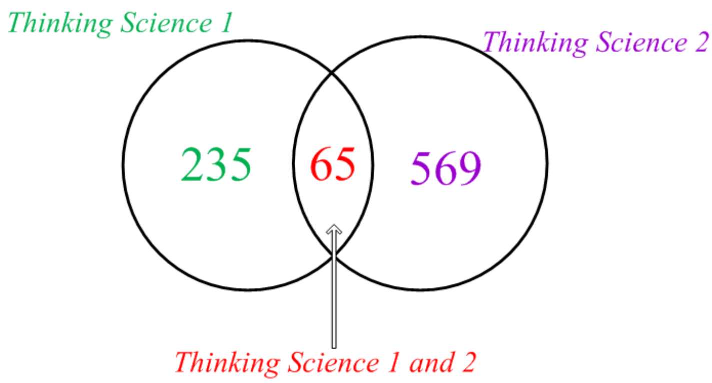


Figure 2.18: **Total number of students in the non-intervention group of the *Thinking Science* programmes over the two phases (for further clarification see Figure2.24)**

As Figure 2.18 shows there were 235 students who were part of the non-intervention group in 6th class, 569 in 1st year and 65 who were part of the non-intervention group between 6th class and 1st year.

2.2.2 Results of the *Thinking Science 1* programme

In this section the effectiveness of the *Thinking Science 1* programme, implemented in the final year of primary school, is reported. There were 14 intervention classes and 10 non-intervention 6th classes part of this study, over the three phases. To begin the profile of the Piagetian levels of the 6th class pupils are reported and discussed.

Profile of Piagetian levels of 6th class primary school pupils

The pre- test, Task I, was carried with all the 6th class pupils. The average age of the pupils at the time of pre-test was 12 years and 4 months. The Piagetian levels of the total cohort of pupils that completed Task I (N=621), determined from their pictorial responses to the task, are displayed in Figure 2.19. These levels represent a stage of cognitive development characteristic of certain age-groups, as shown in Table 2.16.

Table 2.16: **Age/stage picture**

Piagetian level	**Symbol**	**Age**
Early concrete	2A	5/6
Mid concrete	2A/2B	7/9
Late concrete	2B	10/11
Early formal	3A	11/13
Late formal	3A/3B	14/15
Formal generalisation	3B	15/16

By the age of 12 years, it is assumed by the Piagetian model that pupils display early formal (3A) operational thought. However, as Figure 2.19 shows there were no pupils at this level in the Irish sample. The majority of the sample (44 percent) were at the 2B level, typical of 10/11 year olds. Even more alarming was the percentage at the early concrete (2A) and mid concrete (2A/2B) levels, typical thought of 5/6 and 7/9 year olds, respectively. The Piagetian levels of the male and female groups are shown in Figure 2.20. There was no statistical significant difference in the Piagetian levels between the female and male cohorts at this stage, (t(619)=-0.64, $p < 0.05$).

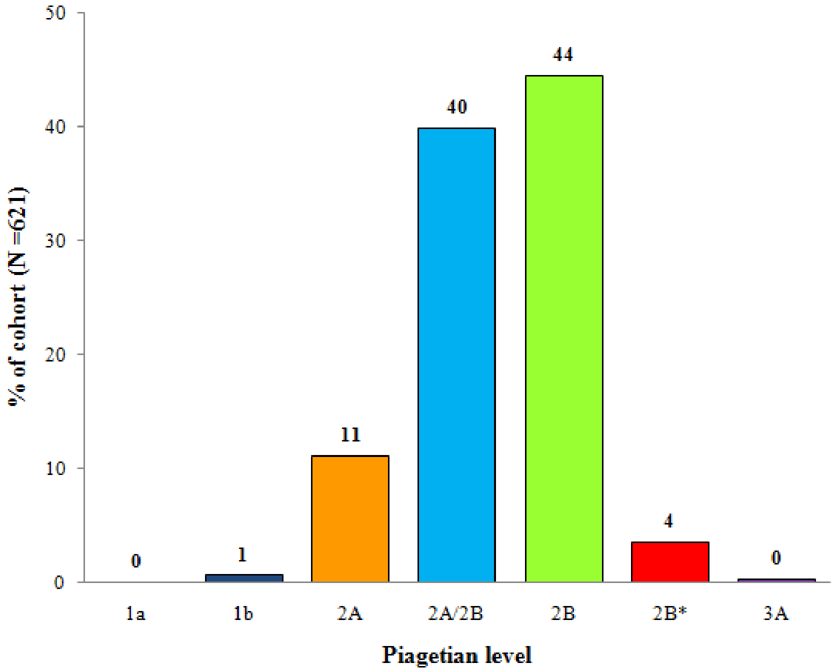


Figure 2.19: **Pre-test Piagetian levels of 6th class pupils; Results from Task I**

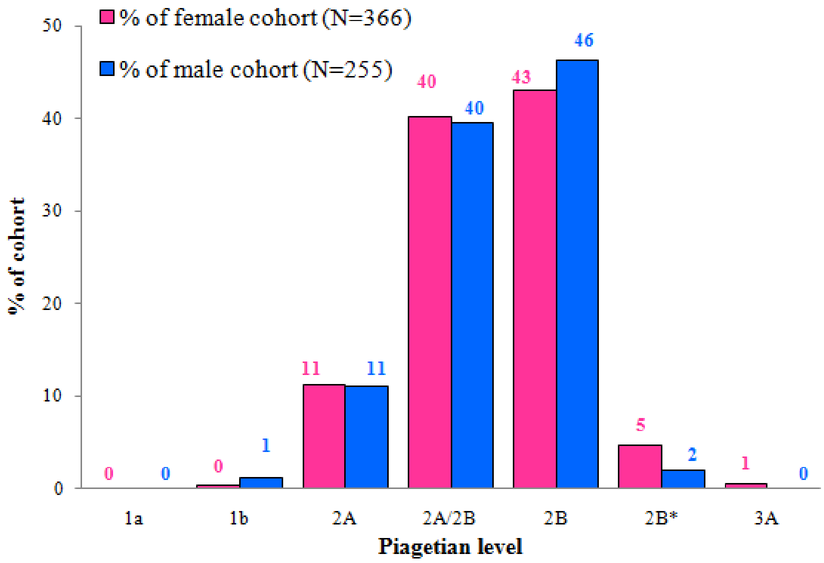


Figure 2.20: **Pre-test Piagetian levels of 6th class male and female groups; Results from Task I**

In the second and third phases of the study, the pupils' ages were obtained. The ages were divided into three categories, namely less than 11.5 years, between 11.5 and 12.5 years and between 12.5 and 13.5 years. The distribution of the Piagetian levels, based on age, is shown in Figure 2.21. As the chart shows the pupils in the older age category (between 12.5 and 13.5 years) were distributed towards the higher Piagetian levels, despite being in the same class as the other pupils. However, at the 2A level there were approximately equal percentages over the three age groups.

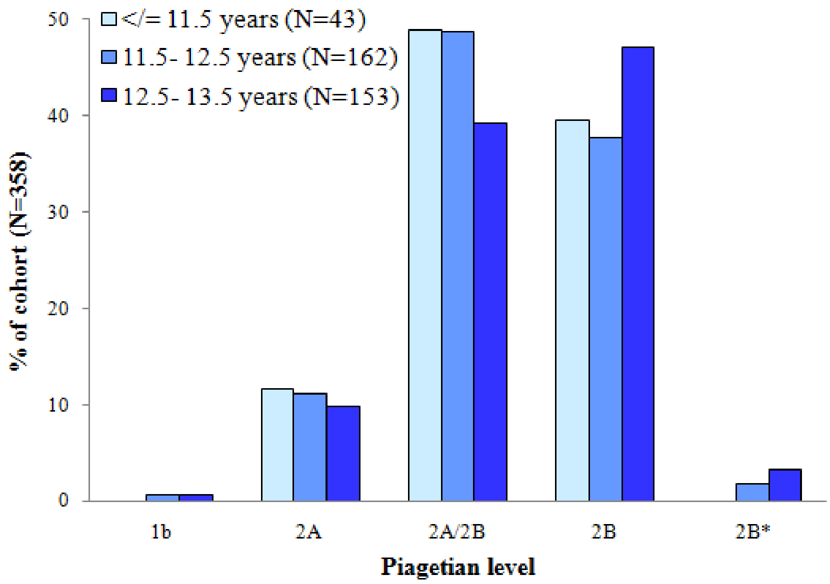


Figure 2.21: **Pre-test Piagetian levels of 6th class groups based on age; Results from Task I**

The data obtained from the students in this study were compared to their comparable age group in the British population. Figure 2.22 was used to match the Irish and UK sample cohorts. The proportions of the children, at age 12.3 years, at the different Piagetian stages in the British and Irish sample are shown in Table 2.17.

It can be seen that the sample in this study had levels at the pre-test stage that were comparable, but lower than the British population. Furthermore, the average age of the sample was 12 years and 4 months. At this age, according to Piagetian stage theory, the majority of the children should have been at the early formal (3A) stage, the start of formal operational thinking. In complete contrast nearly none of the students in this Irish sample are at this stage, compared with 13 percent of the British population.

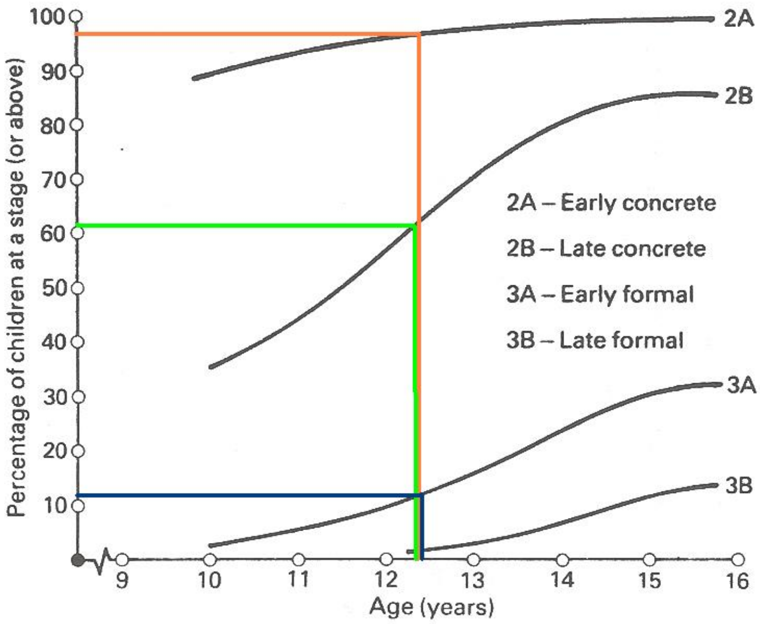


Figure 2.22: **Proportion of children at different Piagetian stages in the representative British (England and Wales) child proportion (taken and adapted from [1])**

Table 2.17: **Approximate proportion of British (English and Welsh) and Irish children (* based on data from this study) at respective Piagetian levels**

Piagetian level	**Approximate proportion at stage in British child population (12.3 years) [1]**	**Extrapolated proportion of Irish children at stage* (12.3 years)**
At 2A or above	95 percent	99 percent
At 2B or above	60 percent	48 percent
At 3A or above	11 percent	0.3 percent
At 3B or above	2 percent	0 percent

Comparing the non-intervention and intervention groups, at pre-test stage

Before the effectiveness of the *Thinking Science 1* programme was analysed, it was first necessary to compare the intervention and non-intervention groups to assess if there was any underlying difference in cognitive developmental levels between the groups, prior to the intervention. The cognitive levels of both groups, determined by the pre-test (Task I) are shown in Figure 2.23. The figure shows that a slightly higher proportion of the intervention group appear to be at the 2B and 2B* levels.

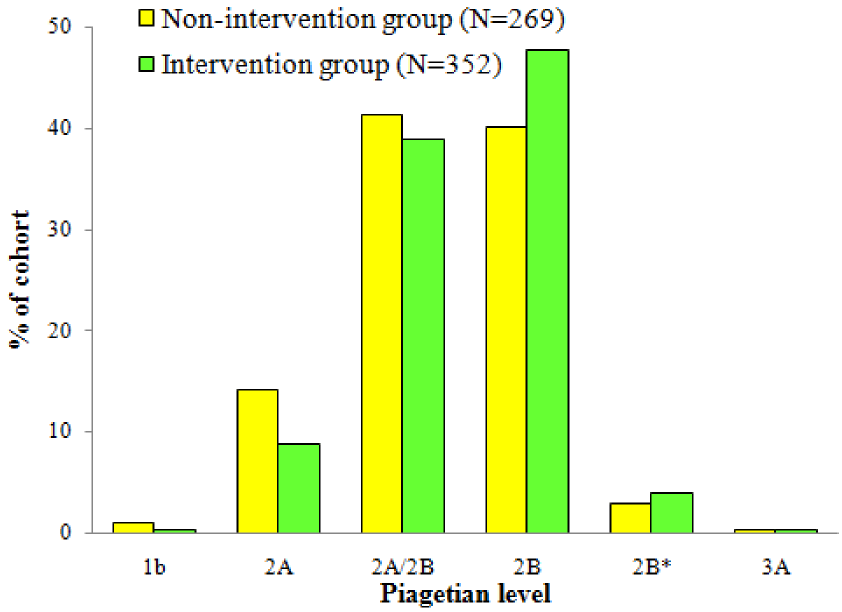


Figure 2.23: **Pre-test Piagetian levels of intervention and non-intervention groups; Results from Task I**

In order to assess this difference further, it was necessary to analyse the difference in the mean scores. To check if there was an initial statistical significant difference between the non-intervention and intervention groups, an independent t-test was performed on the samples. As can be seen in the Table 2.18 the mean for the intervention group (M=11.39, SE=0.14) was higher than that of the non-intervention group (M=10.72, SE=0.17). This difference was significant (t(619)=3.14, p=0.00).

Table 2.18: **Sample numbers, pre-test means and standard deviations of non-intervention and intervention groups**

Group	**N**	**Pre-test mean**	σ
Non-intervention	269	10.72	2.75
Intervention	352	11.39	2.59

In order to indicate the magnitude of the initial differences between the intervention and non-intervention groups, it was necessary to calculate the effect size. This was done by computing an eta squared (η^2) value, using Equation 2.1;

$$\eta^2 = \left[\frac{t^2}{t^2 + (N1 + N2 - 2)}\right] \tag{2.1}$$

where, t represents the t-value, and N1 and N2 represents the sample number in the two groups. Eta squared values range from 0 to 1 and they represent the proportion of variance in the dependent variable that is explained by the independent variable. The guidelines that Cohen [152] proposed for interpreting the strength of the eta squared value are shown in Table 2.19.

Table 2.19: **Strength of eta squared (η^2) values, proposed by Cohen [152]**

η^2 **value**	**Meaning**
0	no effect
0.01	small effect
0.06	moderate effect
0.14	large effect

The eta squared (η^2) value for the difference in the pre-test mean for the intervention and non-intervention groups was 0.02. This corresponds to a small effect. This implies that although there was a significant difference between the two groups at the pre-test stage, this difference was relatively small. It can be said that the two groups were more or less at equal cognitive levels, at the beginning of the intervention.

Pre- and post-test cognitive levels

In order to evaluate the effect of the *Thinking Science 1* programme on pupils' cognitive development, subsequent analysis required the pupils to complete both the pre- and post-tests. Figures 2.24 and 2.25 show the numbers of the pupils in the non-intervention and intervention groups and the numbers of those eliminated from the analysis. In total, sixty-two pupils in the non-intervention group and seventy-three in the intervention group did not complete both tasks and so their data was eliminated. This elimination resulted in an intervention group of 304 and a non-intervention group of 238 pupils.

Table 2.20 shows the mean post-test (Task II) scores for the intervention and non-intervention groups. The intervention groups had a greater mean post-score (M=7.84, SE=0.14) compared to the non-intervention group (M=6.57, SE=0.16).

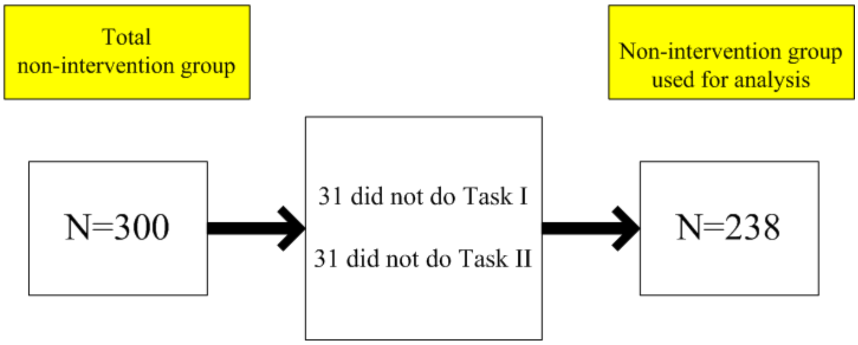


Figure 2.24: **Total numbers of pupils in 6th class non-intervention group, and selected for further analysis**

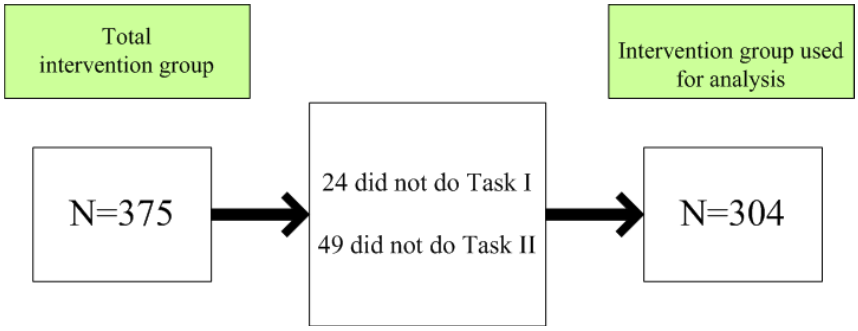


Figure 2.25: **Total numbers of pupils in 6th class intervention group, and selected for further analysis**

There was a statistically significant difference between the two groups (t(540)=5.84, $p < 0.01$). The magnitude of the differences in the means was moderate (η^2= 0.06).

Table 2.20: **Post-test mean score of non-intervention and intervention groups**

Group	**N**	**Post-test mean**	σ
Non-intervention	238	6.57	2.50
Intervention	304	7.84	2.51

It can be seen that the intervention group had higher scores in both the pre- and post-test, both of which were significantly different from the non-intervention group. However, as outlined before the magnitude of the difference between the post-test scores was greater than that of the difference between the pre-test scores so it can be implied that the *Thinking Science 1* programme may have contributed to the greater post-test score of the intervention group.

Piagetian level analysis

Initial analysis involved comparison of the Piagetian levels, determined from the pre- and post-tests, of the intervention and non-intervention groups. Figure 2.26 and 2.27 shows the Piagetian levels for both intervention and non-intervention groups respectively. As one would have expected, from the previous analysis that highlighted the difference between the non-intervention and intervention groups, it is clear from both figures that there was a marginally higher percentage of the intervention group at higher cognitive levels at the pre-test stage. For example, 49 percent of the intervention group were at the late concrete level (2B) compared with 41 percent of the non-intervention group. However, the differences between each group at the pre-test stage were slight. At the post-test stage, both groups followed a similar trend, with there being a shift towards the right-hand side of the chart, towards more formal operational thought. However, one of the more interesting findings, which suggests the success of the *Thinking Science 1* programme on cognitive development, was at the late concrete (2B) and concrete generalisation (2B*) levels. In the case of the intervention group, 49 percent were at this level at the time of pre-test, compared with 41 percent of the non-intervention group. At the post-test this percentage decreased in the intervention group, but stayed the same in the non-intervention group. It could be suggested from the figure that the pupils in the intervention group moved to the concrete generalisation (2B*) group, with an increase in 20 percent of the group at this level from pre- to post-test. In the case of the non-intervention group, the increase at this concrete generalisation (2B*) level is only 6 percent from the time of pre-test to post-test.

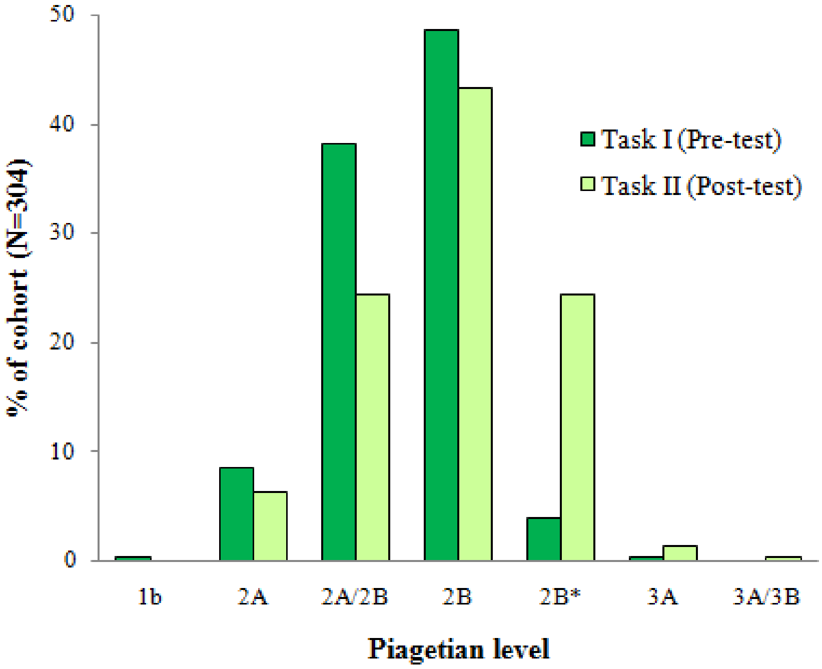


Figure 2.26: **Piagetian levels of intervention group at pre- and post-test**

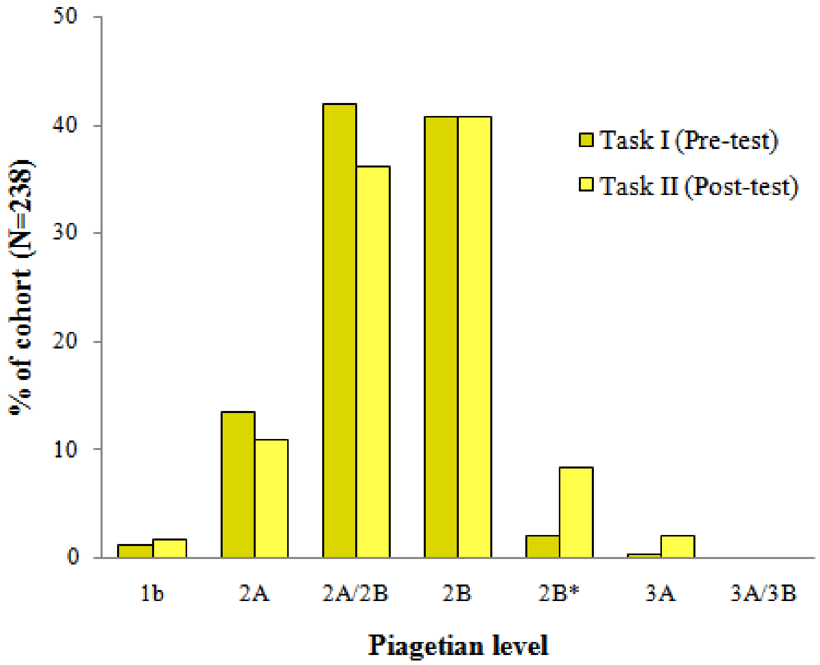


Figure 2.27: **Piagetian levels of non-intervention group at pre- and post-test**

The degree of change in levels can be seen in Figure 2.28. This was done by counting each pupil's change from the pre-test to the post-test, in terms of their Piagetian sub-level. If, for example, a pupil attained a 2B level in Task I and a 2B* in Task II, they were ascribed +1, representing a gain of one sub-level. If a pupil was at the 2B* level at pre-test and 3A/3B at post-test there were ascribed as +2, i.e., gaining two levels, and so on.

Figure 2.28 further amplifies the point made previously. 47 percent of the non-intervention group made no change in Piagetian level, compared with 38 percent of the intervention group. The chart implies that approximately 47 percent of the intervention group made gains of one and two Piagetian sub-levels, compared with 31 percent of the non-intervention group. A greater percentage of the non-intervention group did not change in Piagetian level over the course of the intervention, compared with the intervention group.

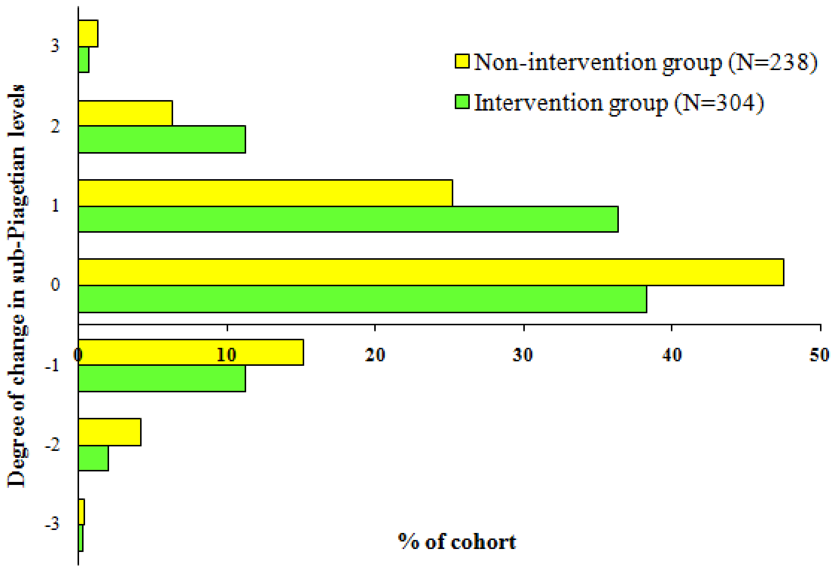


Figure 2.28: **Degree of change in Piagetian sub-levels of non-intervention and intervention groups**

Effect sizes

Adey and Shayer [25] discuss the effects of interventions in terms of their *effect sizes*. When an intervention group has been exposed to some intervention or treatment and then subsequentially compared at post-test, with a comparable non-intervention group, the effect size is the difference between the mean post-test scores of the experimental (M_e) and control groups (M_c), given in units of the standard deviation of the control group (σ_c). Equation 2.2 was used.

$$Effectsize = \frac{M_e - M_c}{\sigma_c} \tag{2.2}$$

An effect size of 0.5 σ, is a modest effect size and will move the mean score from 'average' (the 50th percentile) to that of the top 30 percent (the 69th percentile) of the ability range. An effect size of 1 σ is considered substantial, and moves the mean score up to that of the 84th percentile. Figure 2.29 shows the shifts for students starting at age 11 years.

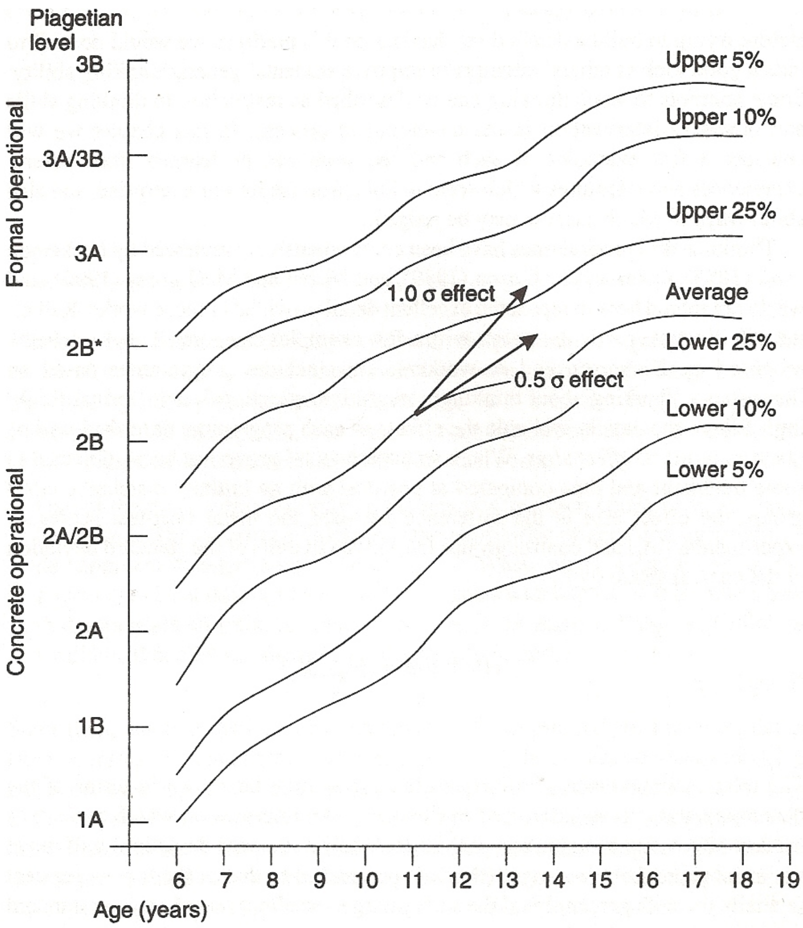


Figure 2.29: **Cognitive development: effect sizes on 11 year old (taken from [25])**

The data from Table 2.20 was used to calculate the effect size. The *Thinking Science 1* programme had an effect size of 0.51 σ, which corresponds to a modest effect size.

Residual Gain Score (RGS) analysis

The mean RGS of the intervention and non-intervention groups are shown in Table 2.21. The intervention group had the greatest mean RGS (M=1.00, SE=0.14) compared with the non-intervention group (M=0.03, SE=0.15). The difference between the two groups, in terms of mean RGS, was significant (t(540)=4.78, p=0.00) and corresponds to an eta squared (η^2) value of 0.04, which equates to a small to moderate difference.

Table 2.21: **Task I, II and RGS means for non-intervention and intervention groups**

Group	**N**	**Task I mean**	**Task II mean**	**Mean RGS**
Non-intervention	238	10.72	6.57	0.03
Intervention	304	11.46	7.84	1.00

In order to gain more insight into the groups that gained the most from the intervention programme, it was necessary to first inspect the mean RGS values within the two gender groups, based on the plot shown in Figure 2.16. Table 2.22 shows the mean RGS values of the male and female groups, in both the intervention and non-intervention groups.

Table 2.22: **RGS means for non-intervention and intervention groups, based on gender**

Group	**Gender**	**N**	**Mean RGS**	σ
Non-intervention	Male	129	0.14	2.44
	Female	109	-0.09	2.10
Intervention	Male	94	1.23	2.16
	Female	210	0.90	2.45

Within both gender groupings, the intervention group attained greater mean RGSs than the non-intervention groups, both significant to the 99 percent confidence level. In order to assess if the *Thinking Science 1* programme had a greater effect on the male or female cohort we must take a closer look at the data in Table 2.22. The male group attained a higher mean RGS (M=1.23, SE=0.22) than the female group (M=0.90, SE=0.17). However, this difference was not significant (t(302)=1.13, p=0.26). In conclusion, it can be said that there was no difference in the mean

RGS of the male and female groups in the intervention cohort. It is also worth noting that there was statistically no difference between the male (M=11.36, SE=0.24) and female group (M=11.40, SE=0.17) in their pre-test (Task I) scores (t(350)=-0.14, p=0.89). There was also no statistical difference in the mean RGS of the male and females, in the non-intervention groups (t(236)=-0.77, p=0.44).

The *Thinking Science 1* programme was implemented in fourteen classes over the three phases of the study. Ten non-intervention classes were also part of this study. In order to gauge if there was a 'class-effect' to the programme it was necessary to analyse the RGS values within different class groups. Table 2.23 outlines the mean RGS for each of the class groups and their corresponding standard deviation (σ). In the column, called Mean RGS, the data from the non-intervention groups over two phases was used to predict the scores of the intervention group. In the column, called Mean RGS (individual year), all the non-intervention and intervention groups', data over the two phases were analysed separately. There is no data for the third phase as there was no non-intervention group in this part of the study.

The mean RGS value for the class groups are shown in Figure 2.30. The green bars show the mean RGS for the intervention group, while the non-intervention means are displayed in yellow. It can be seen from the figure that the majority of the intervention groups attained positive RGS values.

In general from the class RGS values, it can be said that the intervention group made the most positive gains. In total, three class groups had mean gain scores greater than 2, three classes had a mean score greater than 1, and four had mean gain scores greater than zero. In one class group, H1, there was a outlier with a negative mean RGS of -0.18. However, when this class group was analysed in terms of the RGS, using just the Phase 1 data, the mean RGS had a positive value of approximately 0.08. However, it is clear from the distributions of the gain scores that some classes made great gains in achievement, i.e., C1, while other class groups made little or no gain compared with the non-intervention groups, i.e., class group E2.

Table 2.23: **Mean RGS for 6th class intervention (E) and non-intervention (C) groups in Phase 1, 2 and 3**

Phase	**School**	**Class code**	**Group (E/C)**	**N**	**Mean RGS**	σ	**Mean RGS (individual year)**	σ
1	A	A1	E	23	0.13	2.40	0.36	2.41
	B	B1	C	29	-0.18	2.32	0.15	2.36
	C	C1	E	27	2.05	2.10	2.16	2.14
	D	D1	C	23	0.38	2.52	0.56	2.37
	E	E1(i)+E1(ii)	E	31	1.49	2.49	1.77	2.59
	F	F1(i)+F1(ii)	C	49	-0.15	2.77	0.14	2.73
	G	G1	E	22	1.61	2.49	1.61	2.44
	H	H1	E	29	-0.18	2.21	0.08	2.31
	I	I1(i)+I1(ii)	E	52	0.32	2.38	0.47	2.46
	J	J1(i)+J1(ii)	C	33	-1.18	2.09	-0.70	2.21
	K	K1	C	17	0.04	1.95	-0.10	1.82
2	A	A2	E	21	2.44	2.01	2.08	1.95
	E	E2	E	18	0.28	1.37	-0.29	1.45
	I	I2(i)	E	24	2.33	2.09	1.73	2.12
		I2(ii)	C	28	1.01	1.78	0.48	1.77
	J	J2	E	17	-0.02	1.15	-0.45	1.17
	K	K2(i)+K2(ii)	C	42	0.59	2.14	-0.11	2.14
3	A	A3	E	17	1.60	1.74	n/a	n/a
	I	I3(i)+I3(ii)	E	40	0.31	2.28	n/a	n/a

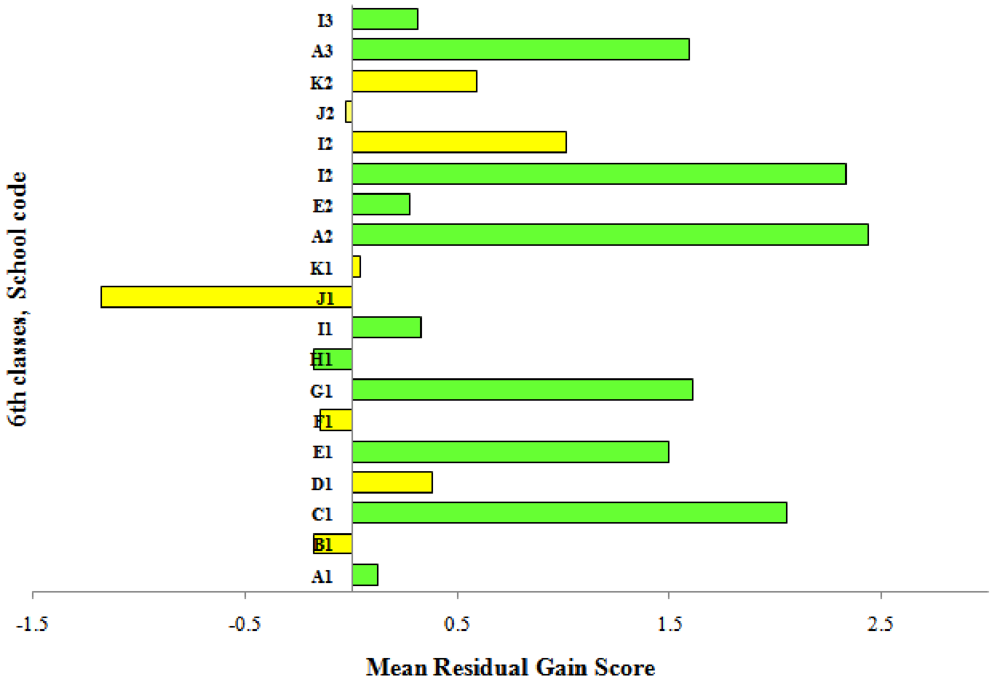


Figure 2.30: **Chart of mean RGS for 6th class intervention (green) and non-intervention (yellow) groups**

In the case of class group C1, the mean RGS was approximately 2.1. Figure 2.31 shows the distribution of the mean RGS within this group alone and it can be seen that there was an element of bimodality within the data. Approximately 22 percent of the class group attained RGS values between -1 and 1, while 60 percent of the group made gains over 2 RGS. In class group H1, there is a mean RGS of -0.2 approximately. However, Figure 2.32 shows that this RGS for the class also follows a bimodal distribution.

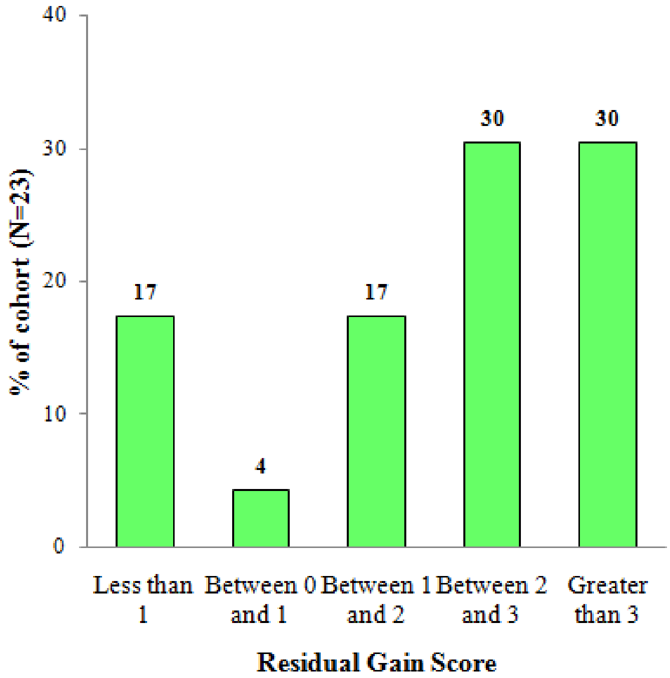


Figure 2.31: **Details of RGS values in class group C1**

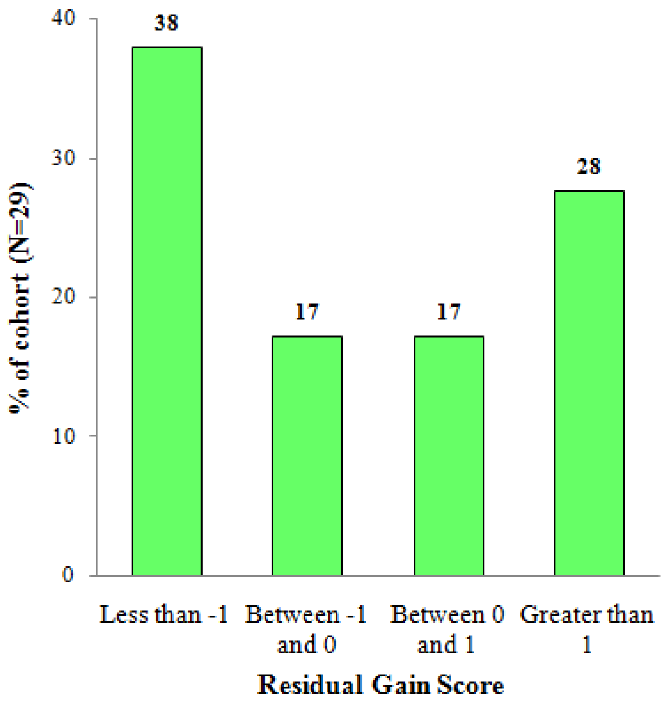


Figure 2.32: **Details of RGS values in class group H1**

Teacher effect

As described in the previous section, the *Thinking Science 1* programme was implemented via three different methods of instruction, namely with the class teacher themselves, the researcher and by team-teaching, which involved a combination of both. This added an interesting dynamic to the study and the analysis of all the different teaching methods was necessary to see if the method of implementation effected the success of the intervention.

The mean RGS values for the different teaching arrangements are shown in Table 2.24. The team-teaching implementation method had the highest RGS (M=1.33), which was the method that combined the class teacher and the researcher. This method was the most ideal, in a theoretical sense, as it combined the researcher, who was trained in the CASE methodology, and the class teacher who was most familiar with the abilities of the individual pupils within the class. The mean of the researcher was the second highest (M=1.10). Perhaps the 'novelty' factor was the reason for this high value. This was followed by the class teacher (M=0.83). However, it must be noted that there was no significant difference between the mean RGS values in any of these teaching arrangements. Bimodality was also a feature of these results.

Table 2.24: **Mean RGS values for different teaching arrangements**

Teaching arrangement	**N**	**Mean RGS**	σ
Class teacher	165	0.83	2.35
Researcher	78	1.10	2.44
Team teachers	61	1.33	2.29

An extra variable in this study was the type of school that the pupils received the intervention in. There were two types of schools: single-sex and co-educational. Table 2.25 shows the mean RGS of the intervention male and female groups in both of these types of schools. The males in the co-educational school had a higher mean (M=1.42) than the males in the single-sex school (M=1.05). However, this difference was not significant (t(94)=-0.84, $p > 0.01$). The results of the female group were similar. The females in the co-educational school had a greater mean RGS (M=1.38) compared with the females in the single-sex school (M=0.79). However, this difference was also not significant (t(208)=-1.35, p=0.18).

Table 2.25: **RGS means for males and females in the intervention group, in different school types**

School type	Gender	N	Mean RGS
Co-educational	Male	45	1.42
	Female	38	1.38
Single-sex	Male	49	1.05
	Female	172	0.79

Teachers' evaluation

As discussed in Section 2.1 interviews were conducted with teachers to gather qualitative data about the effect of the programme on their students' thinking and learning. The feedback was extremely positive in terms of the effect of lessons on pupils' thinking as can be interpreted from some of the following quotations;

> *My overall impression of the programme is very positive. There is no doubt that children's power of reasoning developed.* (Teacher from School G)

> *You can nearly see the cogs going around in their head.* (Teacher from School I)

One of the advantages of implementing the CASE programme at primary school is that teachers can aid the bridging process of the lessons into other areas as they teach all subjects to their pupils. In terms of evaluation, primary school teachers provided valuable information about their pupils' progress in other areas of the curriculum. Some teachers interviewed commented on the noted improvement of their students in other areas of the curriculum.

> *The reasoning developed was positive for maths, English comprehension and even history.* (Teacher from School G)

> *Great benefit for pupils, especially in maths.* (Teacher in School I)

> *They (the pupils) benefited from the great links between maths and science in the lessons.* (Teacher from School A)

All of the teachers that were interviewed said that they would use the intervention programme in their teaching again. Some of the teachers commented on how valuable the programme was from the point-of-view of their professional development.

> *I couldn't fault the programme. It has been a great experience and I've learned so much.* (Teacher from School I)

> *I've learned an awful lot myself and I think that's nearly more important than what they (the pupils) have learned because I know how to go about it now.* (Teacher from School A)

2.2.3 Results of the *Thinking Science 2* programme

In this section the effectiveness of the *Thinking Science 2* programme, implemented in the first year at second level, is reported. The students included for analysis in this part of the study are those that were in 1st year at second level and did not receive the *Thinking Science 1* intervention at primary level. The average age of the students at pre-test was 12 years and 9 months. To begin the profile of the Piagetian levels of the 1st year students that were part of this study are reported.

Profile of Piagetian levels of 1st year second level students

The aim of the pre-test in this part of the study was to gauge the cognitive levels of those students that were involved in the study for the first time, i.e., they were not part of the cohort in 6th class. In addition, the pre-test gauged the cognitive level of the 6th class pupils after their summer break and at the beginning of their second level education. The pre-test Piagetian levels of the whole group, with the exception of those who received the intervention in 6th class are shown in Figure 2.33.

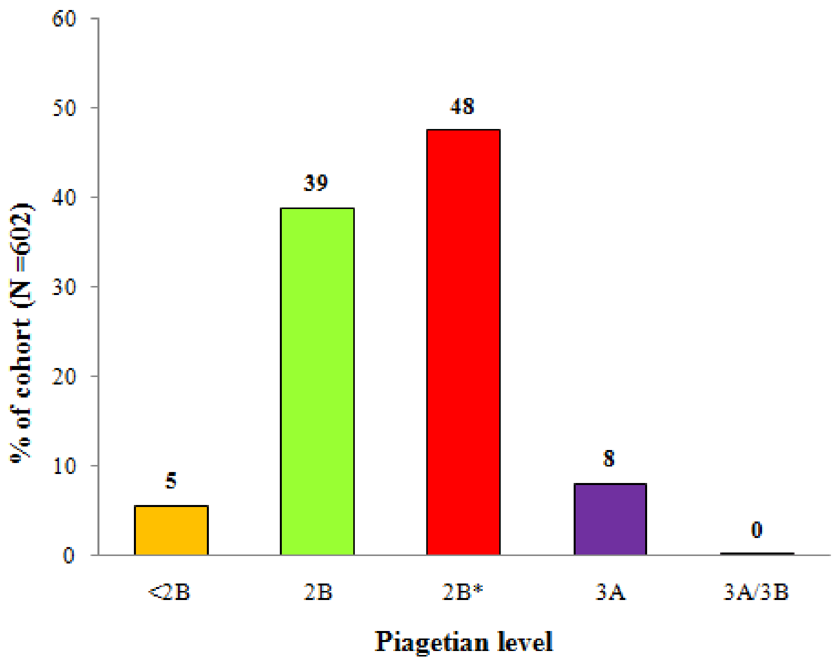


Figure 2.33: **Pre-test Piagetian levels of 1st year group (without the 6th class intervention group)**

Table 2.26: **Approximate proportion of British (English and Welsh) and Irish children (* based on data from this study) at respective Piagetian levels**

Piagetian level	Approximate proportion at stage in British child population (12.75 years) [1]	Extrapolated proportion of Irish children at stage* (12.75 years)
At 2A or above	97 percent	-
At 2B or above	68 percent	94.5 percent
At 3A or above	15 percent	8.14 percent
At 3B or above	4 percent	0 percent

It can be seen that the majority of the cohort of 1st year students were at the concrete generalisation (2B*) level. Less than 8 percent of the first year cohort were at the early formal (3A) level. To make comparisons with the British population from the CSMS study, at the same age, nearly 15 percent of the students were at the 3A level. Considering that many of the concepts in Junior Certificate science require competence in formal operation thought, it leads to concerns about the potential of their progress.

Table 2.26 shows the proportions of the British and Irish groups at the different levels of cognitive development. The table shows that although there are glaring similarities, the Irish cohort have attained less of the formal level thinking compared with the British group, at the same age.

In order to assess if there was a gender difference in this profile shown in Figure 2.33, comparisons were made between the male and female cohorts. Figure 2.34 shows the Piagetian level profile in terms of gender groupings. Over half of the female population were at the concrete generalisation (2B*) stage, with just over 11 percent at the early formal (3A) level of cognitive development. There is a larger cohort of the female group to the right-hand side of the chart compared with the male grouping, where the majority (45 percent) are at the late concrete (2B) level. This difference in cognitive level, between the male and female groups, at this pre-test stage was statistically significant; ($t(600)=-5.61$, $p=0.00$) and corresponded to an eta squared value of 0.05, equivalent to a small to moderate effect. From this it can be said that the female group were at slightly higher cognitive levels of development, at this pre-test stage.

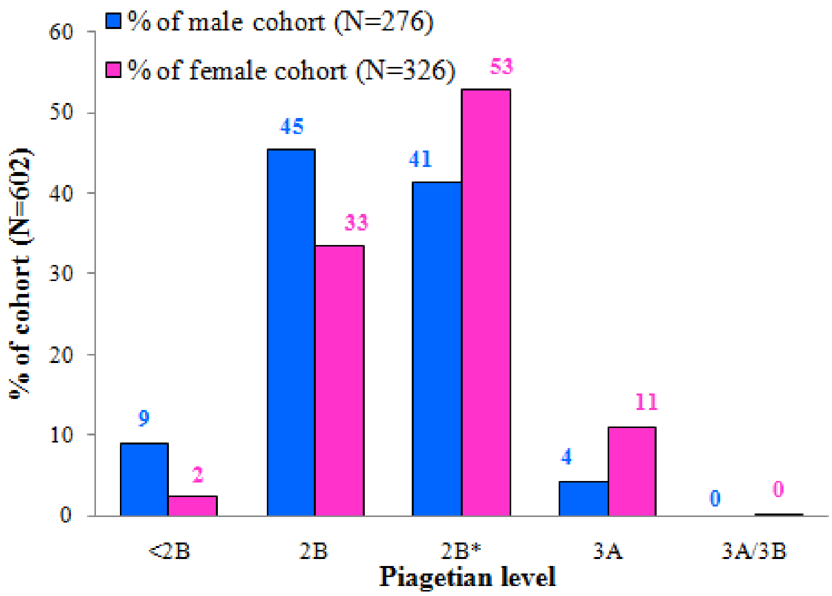


Figure 2.34: **Pre-test Piagetian levels of 1st year students based on gender groupings (without the 6th class intervention group)**

Comparing the non-intervention and intervention groups, at pre-test stage

Before embarking on the analysis of any changes in cognitive level of the intervention and non-intervention groups, it was first necessary to find out if there is a statistically significant difference between both groups, at the time of pre-test. The pre-test means for both groups are shown in Table 2.27. The mean for the non-intervention group (M=3.09, SE=0.08) was greater than that of the intervention group (M=2.63, SE=0.17). This difference was significant (t(600)=-2.38, p=0.02), but the magnitude of the difference was small (η^2=0.01).

Table 2.27: **Pre-test means of intervention and non-intervention groups**

Group	**N**	**Pre-test mean**	σ
Non-intervention	496	3.09	1.82
Intervention	106	2.63	1.72

Pre- and post-test cognitive levels

This analysis required the 1st year students to complete both the pre- and post-tests. Figure 2.35 and 2.36 show the numbers of the students in the non-intervention and intervention groups and the numbers of those eliminated. In total 15 percent of the non-intervention group and 25 percent of the intervention group were eliminated due to students not having completed both tests. This elimination resulted in a intervention group of 94 students, and a non-intervention group of 449.

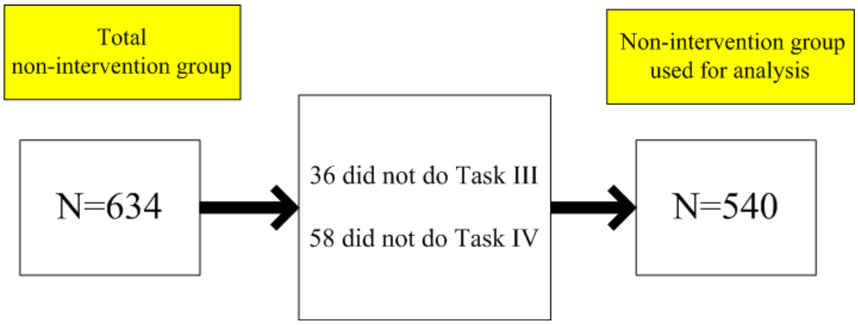


Figure 2.35: **Total numbers of 1st year students in non-intervention group, and selected for further analysis**

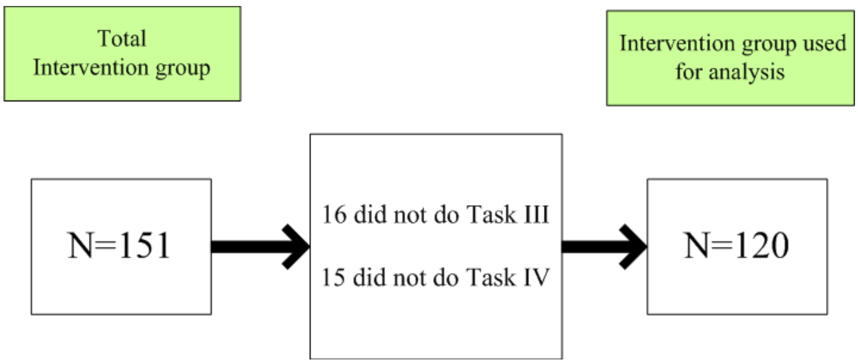


Figure 2.36: **Total numbers of 1st year students in intervention group, and selected for further analysis**

Figure 2.37 displays the pre- and post-test scores for the intervention and non-intervention groups and Table 2.28 shows the post-test results for both groups.

The post-test mean of the intervention group was higher (M=4.33, SE=0.19) than the non-intervention group (M=3.50, SE=0.08). There was a significant difference between the two scores (t(541)=4.51, $p < 0.01$) and the magnitude of the difference in the post-test means was small to moderate ($\eta^2 = 0.04$).

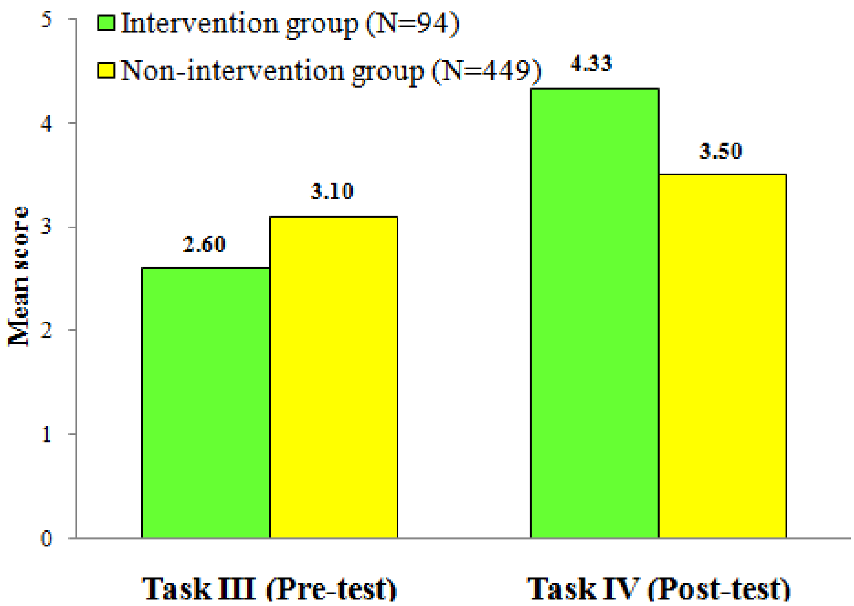


Figure 2.37: **Pre- and post-test mean scores of 1st year intervention and non-intervention groups (those who did both pre- and post-test)**

Table 2.28: **Post-test mean scores of non-intervention and intervention groups**

Group	**N**	**Post-test mean**	σ
Non-intervention	449	3.50	1.60
Intervention	94	4.33	1.81

Piagetian level analysis

The change in Piagetian levels for the intervention group over the period of the *Thinking Science 2* programme is shown in Figure 2.38. It can be seen that while the majority of the students (51 percent) at the time of pre-test, were at the late concrete level (2B), at the time of post-test this majority (56 percent) were at the concrete generalisation (2B*) stage. The chart shows a general shift towards the right-hand side, indicative of more formal reasoning. There was an increase of 20 percent in the number of students at the 2B* stage between the period of pre- and post-test. At the 3A level, there was an increase in 5 percent of the cohort, between the pre- and post-test.

In order to gauge if this change was due to the *Thinking Science 2* programme or other factors it was necessary to inspect the change in cognitive levels for the non-intervention group, shown in Figure 2.39. The majority of the non-intervention students, 50 percent, at the time of pre-test were at the concrete generalisation (2B*) stage. However, at post-test stage this majority of students, 51 percent, were at the late concrete stage (2B). This shows a decrease in the number of students at the 2B* and 3A stages. Overall, this paints a picture of slight regression for the non-intervention group. It can be said when comparing both Figures 2.38 and 2.39 that the intervention group made more progress in terms of cognitive development, between the period of pre- to post-test.

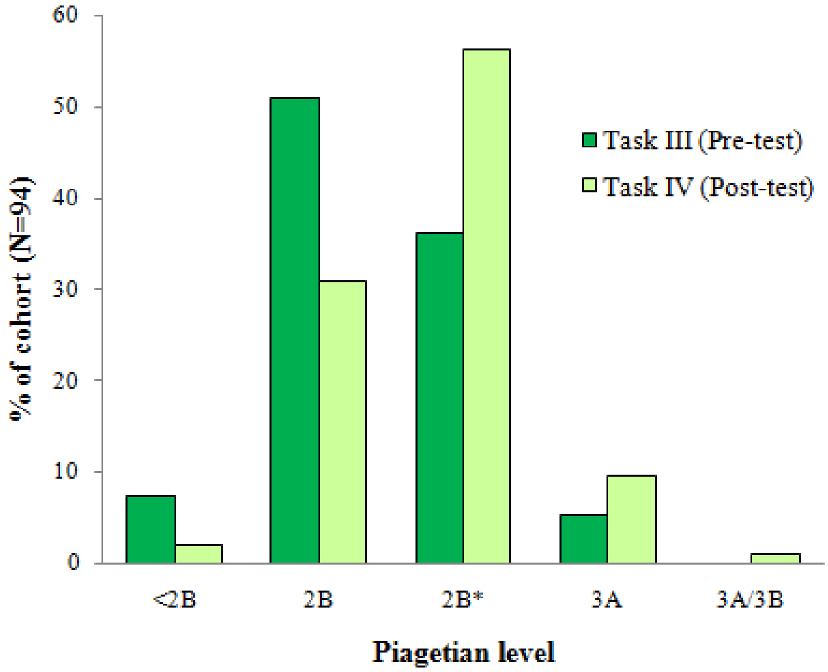


Figure 2.38: **Piagetian levels of intervention group at pre- and post-test**

The degree of change in levels of the non-intervention and intervention groups is shown in Figure 2.40. It can be seen that approximately the same number of each group did not change in sub-level over the period from pre-test to post-test. The most stark contrast between the two groups is for those that increased one Piagetian sub-level. 35 percent of the intervention group increased by one sub-level, compared with less than half of that in the non-intervention group, 16.5 percent. Twenty-eight percent of the non-intervention group decreased by one Piagetian level compared with 7 percent of the intervention cohort.

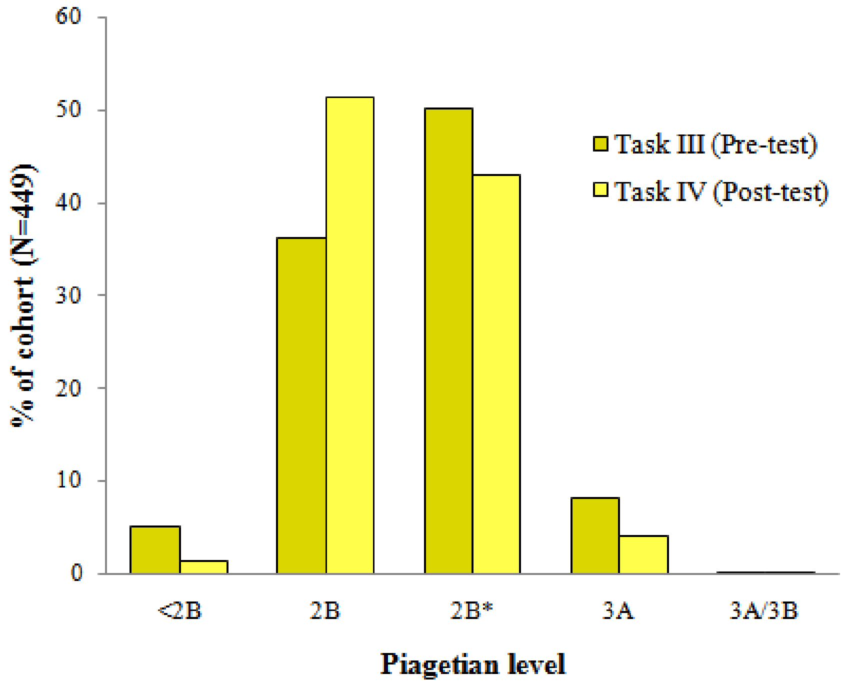


Figure 2.39: **Piagetian levels of non-intervention group at pre- and post-test**

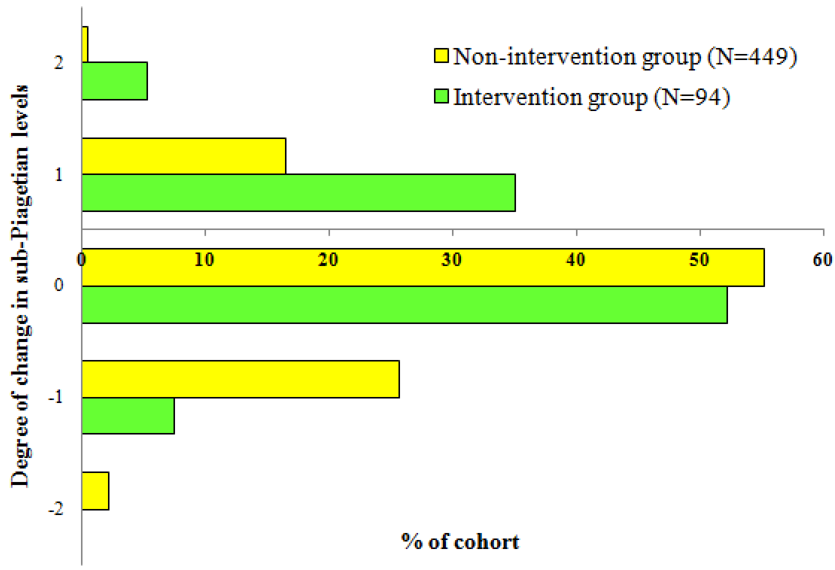


Figure 2.40: **Degree of change in Piagetian sub-levels of non-intervention and intervention groups**

Effect size

The effect size for the *Thinking Science 2* programme was computed using Equation 2.2, as shown on page 166. The data was calculated from the post-test score data in Table 2.28. The effect size was worked out to be 0.52 σ, equivalent to a moderate effect size.

Residual Gain Score (RGS) analysis

In order to gain deeper insight into the gains made by the intervention group, RGS analysis was carried out. Figure 2.41 shows the plot used in the RGS analysis for this group. From this the RGS values were computed.

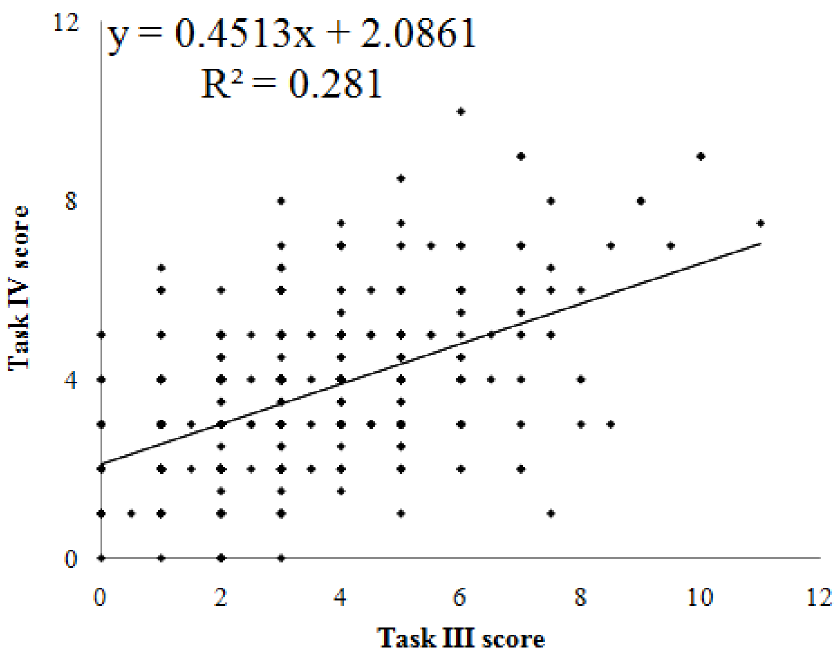


Figure 2.41: **Plot used in RGS analysis; Pre- and post-test scores of 1st year non-intervention group**

The mean RGS values of the intervention and non-intervention groups are shown in Table 2.29. The mean RGS of the intervention group (M=1.07) far exceeded that of the non-intervention group (M=0.01). The difference in the means was significant (t(541)=6.64, p=0.00) and corresponded to a magnitude of moderate size (η^2=0.08).

Table 2.29: **Mean RGS values of non-intervention and intervention group**

Group	**N**	**Mean RGS**	σ
Non-intervention	449	0.00	1.40
Intervention	94	1.07	1.47

Table 2.30 displays the mean RGS values for the male and female groups in the intervention and non-intervention cohorts. The males in the intervention group (M=0.84) had a higher RGS than the non-intervention group (M=-0.08). The difference between males in both groups was significant, (t(243)=4.55, p=0.00) and the magnitude of this difference was moderate (η^2=0.08). The situation was similar for the female group where the intervention group had a higher mean RGS (M=1.30), compared with the non-intervention group (M=0.07). This difference was also significant (t(296)=5.03, p=0.00), and corresponded to a magnitude of moderate size (η^2= 0.08).

Table 2.30: **RGS means for non-intervention and intervention groups, based on gender**

Group	Gender	N	Mean RGS	σ
Non-intervention	Male	198	-0.08	1.26
	Female	251	0.07	1.72
Intervention	Male	47	0.84	1.15
	Female	47	1.30	1.51

The effect of the *Thinking Science 2* intervention programme on the male and female groups was carried out to assess if the programme at this level worked best for either of the genders. At pre-test there was a significant difference between the genders in the intervention group. The female cohort had a higher pre-test score (M=3.05, SE=0.29) compared with the male cohort (M=2.14, SE=0.20), and the difference was significant (t(92)=-2.59, $p < 0.05$). At the time of post-test there was also a significant difference between the two groups, with the female group attaining a higher mean post-test score (M=4.77, SE=0.31) than the male group (M=3.89, SE=0.19),(t(92)=-2.40, $p < 0.05$).

Figure 2.42 shows the RGS values for male and female cohorts in the intervention and non-intervention groups. It can be seen that the female cohort made greater gains compared with the male intervention group. However, in the case of RGSs, the difference was not significant (t(92)=-1.54, p=0.13), and corresponds to a magnitude of relatively small size (η^2=0.03).

Over the two phases of implementation of *Thinking Science 2*, eight classes were taught the intervention as a supplement to their normal science class. There were twenty-five 1st year science classes that did not receive the *Thinking Science 2*

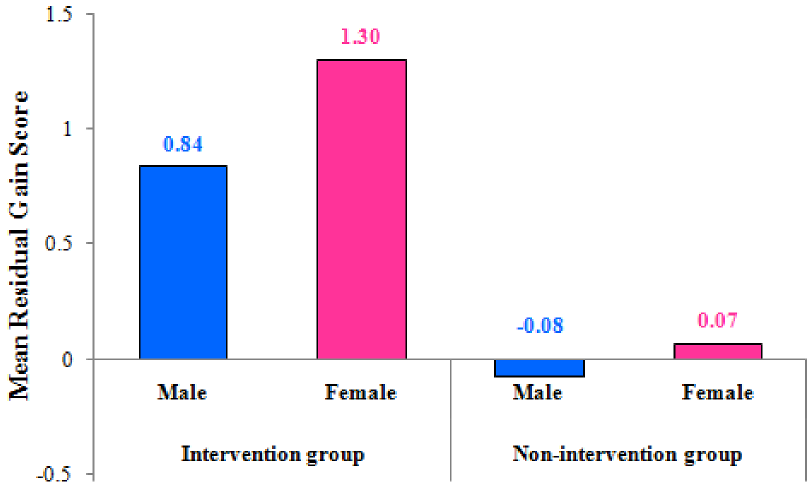


Figure 2.42: **Chart of mean RGS values of male and female groups**

intervention. Two RGS analyses were performed on the pre- and post-test data of the groups. One involved the data from the individual phases of study (i.e., data from Phase 1 and 2 were analysed separately) and the other was for the entire group together (i.e., data from Phase 1 and 2 were analysed together). The results from both analyses, for each individual class in Phase 1 are shown in Table 2.31 and the Phase 2 data is shown in Table 2.32. Figure 2.43 shows a breakdown of the RGS for the individual 1st year classes, both intervention (indicated in green) and non-intervention (indicated in yellow).

Figure 2.44 and Figure 2.45 show the RGS for the first and second phases of the study. These charts show the RGS, computed from the individual year data.

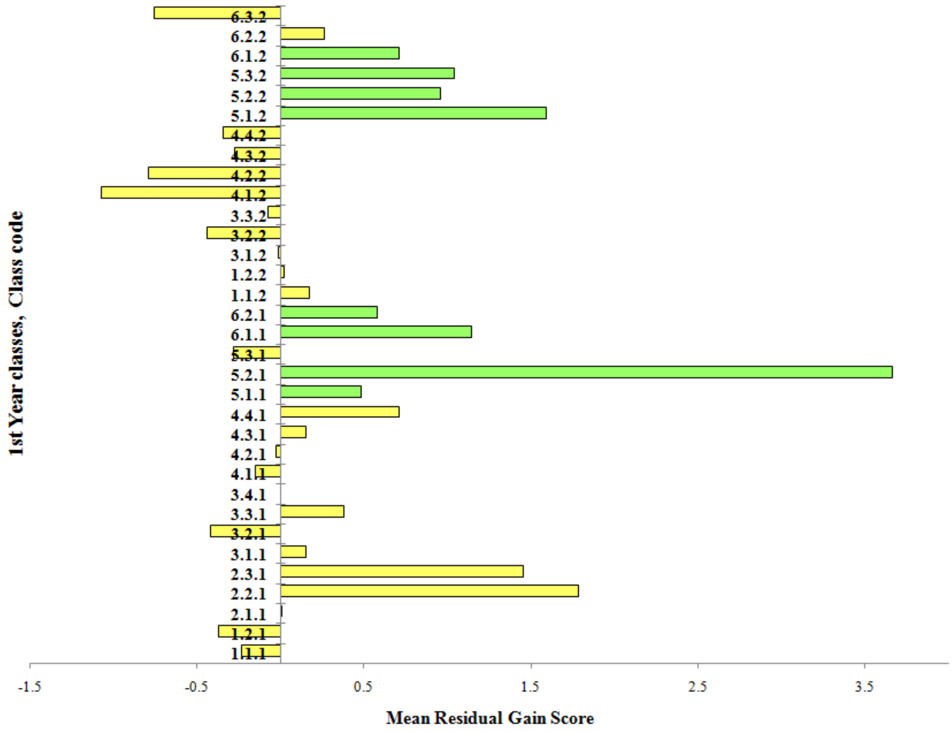


Figure 2.43: **Mean RGS for individual 1st year classes, using entire data**

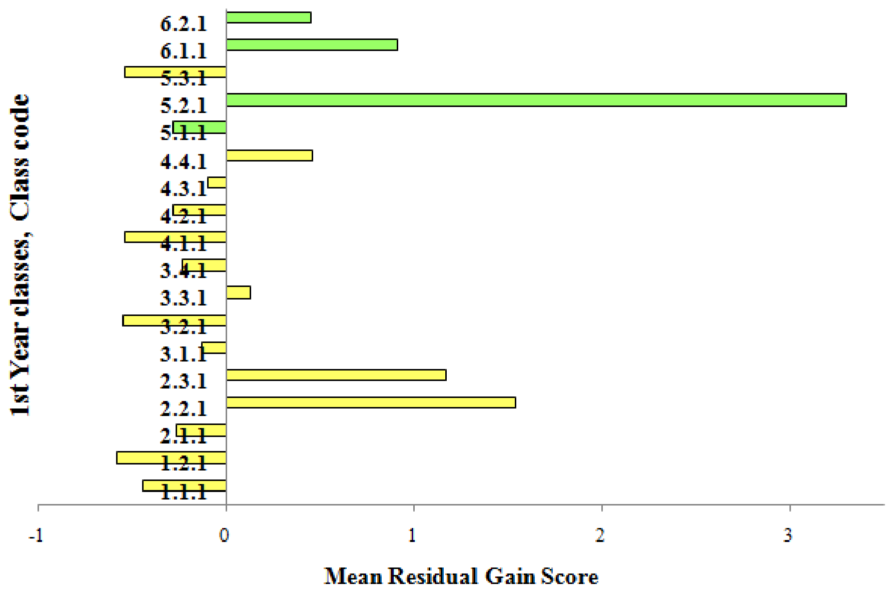


Figure 2.44: **Mean RGS (individual) for intervention (green) and non-intervention (yellow) class groups in Phase 1 of the study**

Table 2.31: **Mean RGS of 1st year classes in Phase 1, both intervention (E) and non-intervention (C) (excluding students who were in the 6th class intervention group)**

Phase	**School**	**Class code**	**Group (E/C)**	**N**	**Mean RGS**	σ	**Mean RGS (individual year)**	σ
1	1	1.1.1	C	18	-0.23	0.80	-0.44	0.79
		1.2.1	C	17	-0.37	0.75	-0.58	0.73
	2	2.1.1	C	23	0.01	1.18	-0.27	1.21
		2.2.1	C	20	1.79	1.69	1.54	1.68
		2.3.1	C	19	1.45	1.29	1.17	1.28
	3	3.1.1	C	15	0.15	1.56	-0.13	1.54
		3.2.1	C	11	-0.42	0.86	-0.55	0.86
		3.3.1	C	17	0.38	1.36	0.13	1.38
		3.4.1	C	17	0.00	0.96	-0.23	0.95
	4	4.1.1	C	13	-0.15	0.87	-0.54	0.87
		4.2.1	C	14	-0.03	1.11	-0.28	1.12
		4.3.1	C	17	0.15	1.17	-0.10	1.12
		4.4.1	C	17	0.71	1.13	0.46	1.19
	5	5.1.1	E	8	0.48	0.85	0.28	0.81
		5.2.1	E	4	3.66	1.74	3.30	1.73
		5.3.1	C	11	-0.28	0.92	-0.54	0.96
	6	6.1.1	E	18	1.14	1.26	0.91	1.26
		6.2.1	E	14	0.58	0.95	0.45	0.95

Table 2.32: **Mean RGS of 1st year classes in Phase 2, both intervention (E) and non-intervention (C) (excluding students who were in the 6th class intervention group)**

Phase	School	Class code	Group (E/C)	N	Mean RGS	σ	Mean RGS (individual year)	σ
2	1	1.1.2	C	17	0.17	2.04	0.62	1.97
		1.2.2	C	20	0.02	1.19	0.32	1.16
	3	3.1.2	C	22	-0.01	1.10	0.19	1.16
		3.2.2	C	22	-0.44	0.85	-0.23	0.94
		3.3.2	C	21	-0.08	1.10	0.14	1.06
	4	4.1.2	C	19	-1.07	1.46	-0.56	1.42
		4.2.2	C	22	-0.79	1.37	-0.35	1.31
		4.3.2	C	19	-0.28	1.44	0.06	1.38
		4.4.2	C	22	-0.34	1.76	0.05	1.69
	5	5.1.2	E	13	1.59	1.29	2.07	1.29
		5.2.2	E	12	0.96	2.22	1.28	2.31
		5.3.2	E	10	1.04	1.36	1.26	1.41
	6	6.1.2	E	15	0.71	1.16	0.85	1.08
		6.2.2	C	22	0.26	1.57	0.61	1.56
		6.3.2	C	14	-0.76	1.25	-0.54	1.21

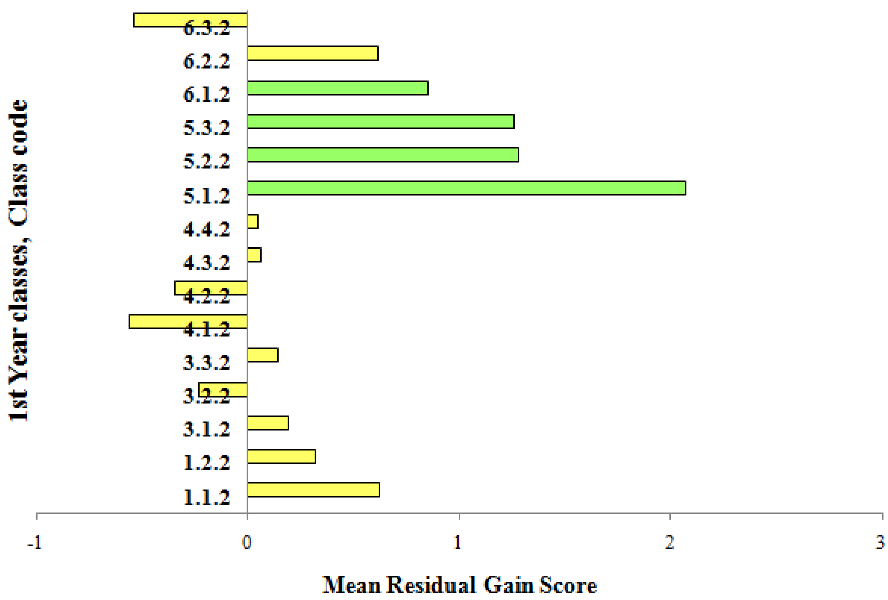


Figure 2.45: **Mean RGS (individual) for intervention (green) and non-intervention (yellow) class groups in Phase 2 of the study**

Teacher effect

Similar to the primary school intervention programme, *Thinking Science 2* was also taught in a variety of ways. The three arrangements involved the science teacher implementing the intervention, the researcher, and a combination of both, team-teaching. Table 2.33 shows the mean RGS for each of the teaching arrangements. It is can be noted that the highest mean was for the team-teaching combination (M=3.66). The sample number was quite small due to the exclusion of the students who did the *Thinking Science 1* programme. However, even when the *Thinking Science 1* students were included in the analysis, the mean was considerably greater than the other groups (M=3.26). The second highest mean RGS was for the group taught by the researcher (M=1.22) and this was followed by the science teacher (M=0.79). There was no statistically significant difference between the group taught the programme by the science teacher or by the researcher (t(88)=-1.49, p=0.14). However, there was a significant difference between the class teacher and the team-teaching arrangement (t(3.18)=3.26, p=0.04) and the magnitude of this difference was large (η^2=0.16). When the groups that were taught the programme by the researcher and the team-teaching arrangement were compared there was no significant difference, (t(3.66)=2.67, p=0.06). However, when the students that completed the *Thinking Science 1* programme, at primary level, were included in the test the difference was significant (t(25.99)= -4.88, p=0.00).

Table 2.33: **Mean RGS values of different teaching arrangements in Phase 1 and 2**

Teaching arrangement	**N**	**Mean RGS**	σ
Class teacher	55	0.79	1.11
Researcher	35	1.22	1.66
Team teachers	4	3.66	1.74

Teachers' evaluation

Interviews were conducted with the 1st year teachers to gauge their opinion on the effects of the programme on their students' cognitive development and to appraise their general perception of the programme. The second level teachers were very positive about the *Thinking Science 2* intervention programme and its effects on students' thinking.

> *It (CASE) is a great methodology and it encourages students to think.* (Teacher from School 5-Phase 2)

> *Students responded well, some found it heavy going as we were teasing out at a more intense level than students are used to.* (Teacher from School 5-Phase 1)

When teachers were asked for their feedback on whether they would use the programme again there was a general consensus that the programme was time-consuming and in some cases could be better fit to the existing curriculum.

> *Students could do with it (the intervention programme) on a continuous basis but the activities need to be linked to course content.* (Teacher from School 5-Phase 1)

> *The programme demands more time and needs to be altered to fit better with the curriculum.* (Teacher from School 6)

Teachers also commented that they themselves learned alot from been part of the implementation of the CASE programme at second level. None of the second level teachers in this study had taught through the CASE methodology before and so they benefited from exposure to a new methodology and the training and support provided.

> *It has been a huge profitable learning curve.* (Teacher from School 5-Phase 1)

All of the teachers claimed that the training provided was satisfactory and the materials and resources provided were excellent.

2.2.4 Results of the combined *Thinking Science 1* and *2* programmes

Introduction

In this section, the term intervention group describes the students that received the *Thinking Science 1* and *Thinking Science 2* intervention programmes. The non-intervention group did not receive any of these programmes, but their cognitive levels were tracked over the two years in 6th class and 1st year. In this section, the task completed by the students prior to the *Thinking Science 1* programme, Task I, is referred to as the pre-test and the post-test was Task IV, completed at the end of the *Thinking Science 2* programme. Task II and III were completed at the end of the first part of the intervention and at the beginning of the second part, respectively. Just under 20 percent of the entire cohort from Phase 1 and 2 in this study were tracked over the two levels. Figure 2.46 shows the exact number of these students that were tracked and into what groups they belonged to over the two years.

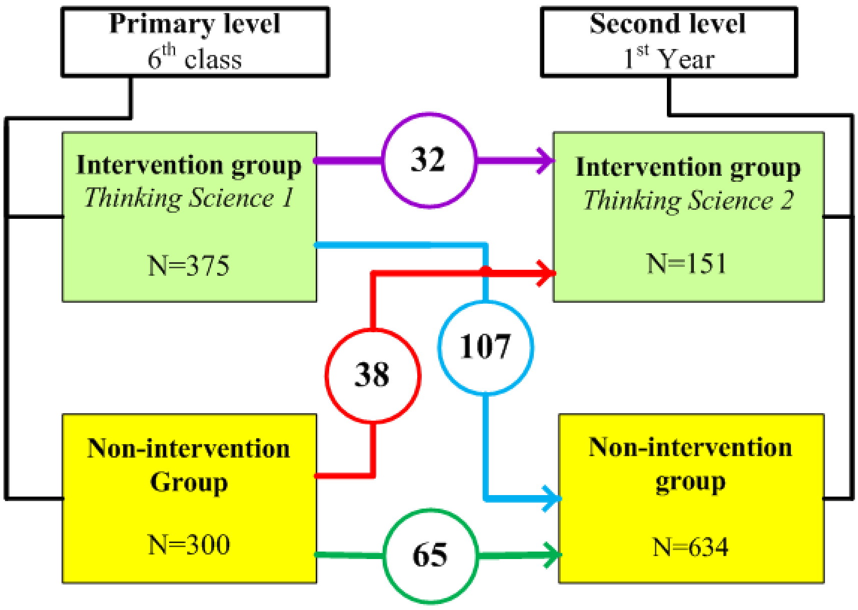


Figure 2.46: **Number of students in the intervention and non-intervention groups tracked over two years**

It must be noted that out of the large intervention group at primary and second level, discussed in the previous sections, the group that did both programmes was relatively small (N=32). Some reasons were identified for this. To begin, the information that was obtained about feeder primary schools was anecdotal evidence from second level schools. In some cases primary schools that were identified as potentially having a large cohort of pupils transferring to selected second level schools did not have such numbers in the particular years that the study was carried out. In addition to this it was more difficult to encourage second level teachers to become involved in the intervention programme compared with primary teachers. Some second level science teachers were reluctant to commit due to being already involved in other programmes or unable to dedicate the time to implement the programme over the period of the school year.

Pre-test cognitive levels

In order to gauge if there was any difference between the groups prior to the intervention, the pre-test (Task I) means were analysed. Table 2.34 shows the pre-test means. The mean score of the non-intervention group (M=10.71) on the pre-test was slightly higher than that of the intervention group (M=10.60). However, there was no statistically significant difference between the groups at pre-test, either in their task scores (t(88)=-0.20,p=0.84) or their directly related, Piagetian level (t(88)=-0.53, p=0.60).

Table 2.34: **Pre-test mean for intervention and non-intervention groups**

Group	**N**	**Pre-test mean**	σ
Non-intervention	59	10.71	2.42
Intervention	31	10.60	2.97

Effect size

The effect size of the *Thinking Science 1 and 2* programme was calculated using Equation 2.2 and the post-test scores shown in Table 2.35. The computed value was 1.06 σ, which corresponded to a large effect size.

Table 2.35: **Post-test mean score of non-intervention and intervention groups**

Group	**N**	**Post-test mean**	σ
Non-intervention	54	3.37	1.52
Intervention	29	4.98	2.52

Analysis of post-test scores

In order to assess the continuous progress of the non-intervention and intervention groups, only those who have completed all four tasks over the two years were included in the subsequent analysis. Table 2.36 and Figure 2.47 display the mean task scores for each of the groups.

It can be seen that there was no significant difference between the two groups at pre-test, Task I; (t(62)=-0.12, p=0.91). However, at the post-test, after *Thinking Science 1* the means differed significantly. The intervention group had the highest mean (M=8.08, SE=0.49) compared with the non-intervention group (M=6.74, SE=0.31) and this difference was statistically significant; (t(40.80)=2.34, p=0.03). The *Thinking Science 1* part of the programme had a moderate effect on the cognitive development of the intervention group and this corresponded to an eta squared value of 0.08.

Task III had two purposes essentially. The first was to gauge the cognitive levels of the non-intervention and intervention groups before the second part of the programme, *Thinking Science 2*. The second purpose of the task was to act as a delayed post-test for the *Thinking Science 1* programme, as it was carried out three months after the completion of the programme. The results of this were interesting. Although the mean Task III score of the intervention group was higher (M=3.35, SE=0.51) than that of the non-intervention group (M=2.93, SE=0.28) the difference was not significant, (t(36.79)=0.74, p=0.47). RGS analysis was performed on the Task II (post-test in 6th class) and Task III (pre-test in 1st year) scores. The mean RGS of the non-intervention group computed was 0.00, compared with a mean RGS of 0.15, for the intervention group. This shows that the intervention group made a slightly greater gain over the summer months (when no intervention took place), when compared with the non-intervention group.

The final post-test, Task IV was used to gauge the effectiveness of the entire *Thinking Science 1 and 2* programmes. The mean of the intervention group (M=5.27, SE=0.52) was higher than that of the comparable non-intervention group (M=3.38, SE=1.60) yet again. This difference was significant (t(33.97)=3.27, p=0.00), and corresponded to a large eta squared value of 0.15. This result implies that the completion of both programmes had a greater effect over that of just one.

Table 2.36: **Mean scores of intervention and non-intervention groups in Tasks I, II, III and IV**

Group	N	**Task I mean**	σ	**Task II mean**	σ	**Task III mean**	σ	**Task IV mean**	σ
Non-intervention	40	10.81	2.49	6.74*	1.93	2.93	1.76	3.38**	1.60
Intervention	24	10.73	3.22	8.08*	2.39	3.35	2.50	5.27**	2.56

*= 95 percent significant

**= 99 percent significant

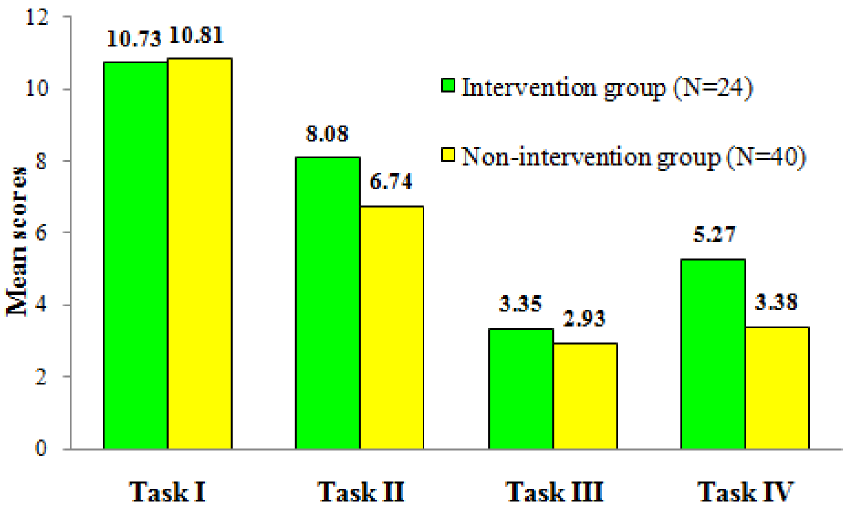


Figure 2.47: **Task I-IV scores for intervention and non-intervention groups**

Piagetian level analysis

In terms of Piagetian levels over the four tasks for the non-intervention and intervention groups, Figure 2.49 and Figure 2.48 show them, respectively. One of the most interesting and perhaps expected observations is the shift towards the right-hand side of the charts, as the tasks progress. However, one of the things that is most notable is the greater number of students in the intervention group who have entered the formal operational stage compared to that of the non-intervention group.

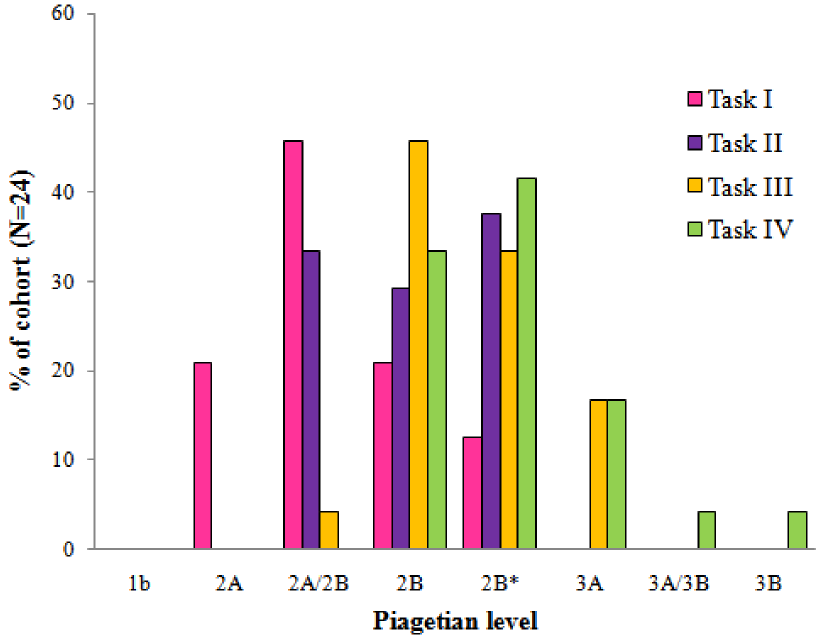


Figure 2.48: **Piagetian levels of intervention group over Tasks I-IV**

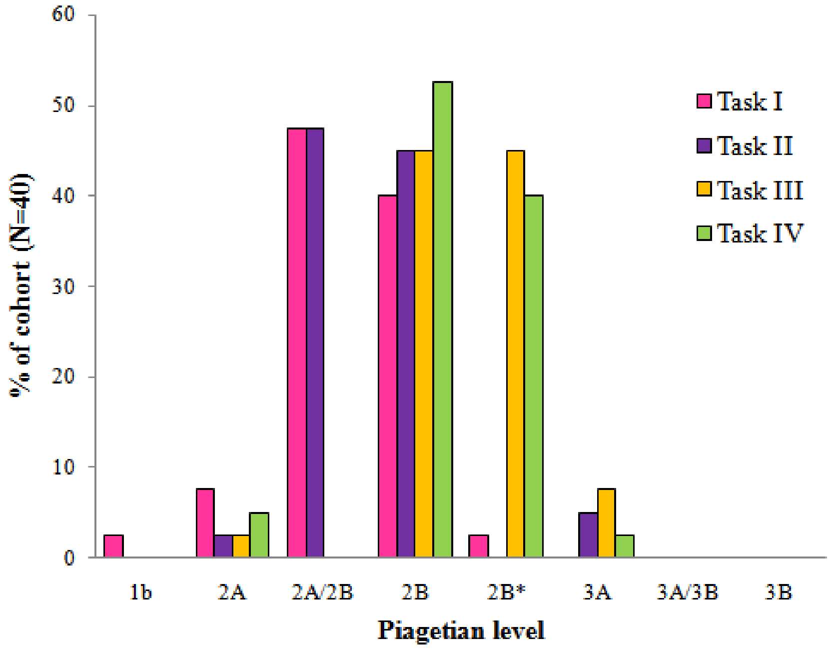


Figure 2.49: **Piagetian levels of non-intervention group over Tasks I-IV**

Figure 2.50 shows the degree of change in Piagetian sub-levels from pre-test (Task I) to post-test (Task IV) for the non-intervention and intervention groups. The majority of students in both the intervention and non-intervention groups gained at least one Piagetian sub-level over the course of the *Thinking Science 1* and *Thinking Science 2* programmes, over a time-frame of two years approximately. However, the degree by which they changed sub-level is quite different. To begin with, 23 percent of the non-intervention group made no change in level over the period of the four tasks. This can be compared with just 4 percent of the intervention group that made no change. More of the non-intervention group changed just one sub-level, with 45 percent of the non-intervention group compared with 37.5 percent of the intervention group. This same percentage (37.5 percent) of the intervention group increased by two sub-levels, compared with 25 percent of the non-intervention group. Yet again more of the intervention group increased by three sub-levels (17 percent) compared with the non-intervention group (5 percent). 4 percent of the intervention group increased greatly by four Piagetian sub-levels. This chart shows that overall the intervention group made greater gains in cognitive development over the course of the two programmes, compared to the comparable non-intervention group.

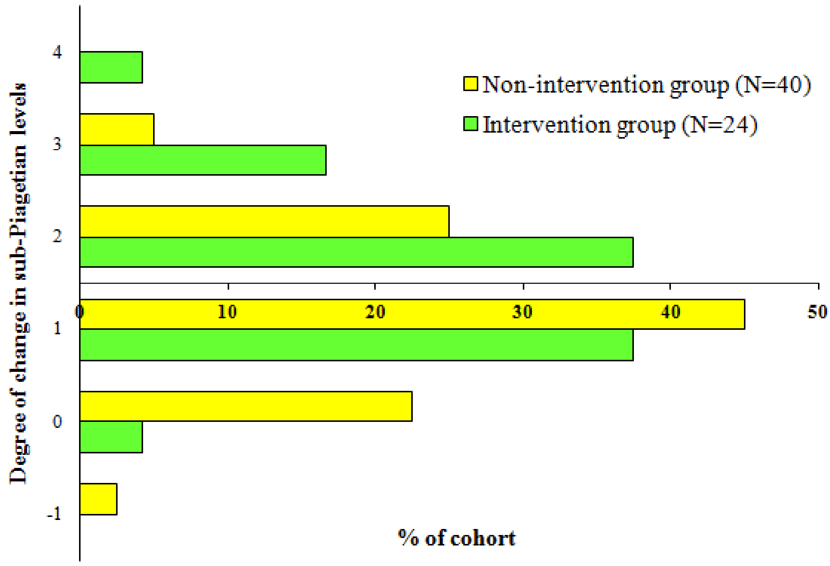


Figure 2.50: **Degree of change in Piagetian sub-levels for intervention and non-intervention groups, from Task I to Task IV**

Residual Gain Score (RGS) analysis

RGS analysis was carried out on the pre-test (Task I) and post-test (Task IV) scores, to evaluate the effectiveness of the *Thinking Science 1* and *Thinking Science 2* programmes. The mean RGS values for the intervention and non-intervention groups are shown in Table 2.37. The mean RGS was higher for the intervention group (M=1.53, SE=0.44), compared with the non-intervention group (M=0.00, SE=0.22). This difference between the groups was significant (t(75)=3.48, p=0.00) and the magnitude of the difference was large (η^2= 0.13)

Table 2.37: **Mean RGS value (from Task I and IV) of non-intervention and intervention group (those who did Task I and IV)**

Group	**N**	**Mean RGS(using Task I and IV)**	σ
Non-intervention	49	0.00	1.54
Intervention	28	1.53	2.33

Figure 2.51 shows, over the period of *Thinking Science 1* (RGS 1), *Thinking Science 2* (RGS 2) and both programmes (RGS), how the intervention group did compared with the non-intervention group. RGS 1 was computed from the data from Tasks I and II, before and after the *Thinking Science 1* programme. RGS 2 was computed from the data from Tasks III and IV, before and after the *Thinking Science 2* programme and finally RGS was calculated from the data from the pre-test at the very beginning (Task I) and the post-test at the very end of the programmes (Task IV). The greatest gains, as expected, were over the two programmes. The mean of the intervention group (M=1.86, SE=0.47) was greater than that of the non-intervention group (M=-0.04, SE=0.25). The difference was significant (t(35.82)=3.62, p=0.00) and corresponded to large magnitude of difference (η^2=0.17).

In the case of RGS 1, the intervention group had the highest mean (M=1.50) compared with that of the non-intervention group (M=0.25). The difference between the means was statistically significant; (t(62)=2.58, $p < 0.05$) and the magnitude of this difference was moderate (η^2=0.1).

In the case of the RGS 2 analysis, the mean of the intervention group was also greater (M=1.67) than that of the non-intervention group (M=-0.03). This difference was also significant (t(37.60)=4.09, p=0.00) and the magnitude of this difference was very large (η^2= 0.21). An interesting feature that can be seen from this chart is the RGS values of the non-intervention group. It can be seen that over the period of the *Thinking Science 1* programme, the final year at primary level, the non-intervention group made gains of 0.25 RGS. However, the gains made at second level were negligible in comparison. This analysis does not have a large enough sample to be able to make conclusive deductions, but this result suggests that the sample in the non-intervention group made greater cognitive gains at primary level than in 1st year at second level.

The analysis of the effect of gender is shown in Table 2.38. The cohort that did both programmes was all female and so no gender comparisons can be made about the effect of programmes on the respective genders. As can be seen from the table the mean RGS for the male cohort is higher than that of the female cohort in the non-intervention group, but this difference is not significant (t(47)=0.81, p=0.43).

No conclusions can be made about the gender effect of the entire programme on students' cognitive development. However, as will be discussed in the following section, the Learning and Study Strategies Inventory- High School version (LASSI-HS) was used to gauge values for motivation for students in both the intervention and non-intervention group in first year at second level. There was no statistically significant difference between the motivation values for the male and females in both groups.

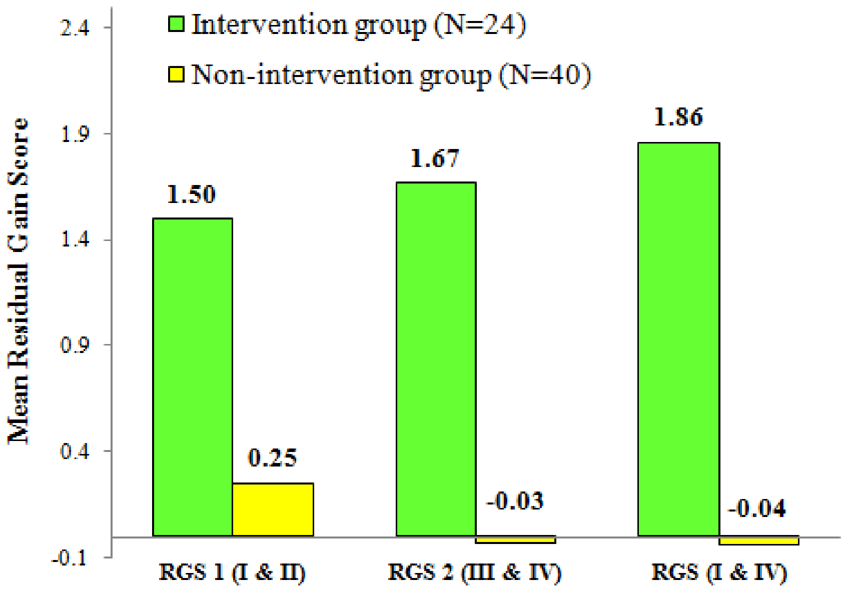


Figure 2.51: **Mean RGS values for non-intervention and intervention group from analysis of Tasks I, II, III and IV (those who did all four tasks)**

Table 2.38: **Mean RGS for gender groups**

Group	**Gender**	**N**	**Mean RGS(using Task I and IV)**	σ
Non-intervention	Male	40	0.08	1.61
	Female	9	-0.38	1.21
Intervention	Male	n/a	n/a	n/a
	Female	28	1.53	2.33

The mean RGS values on the two sets of data for the different cohorts of students is shown in Figure 2.52. The first set of data on the chart shows the mean RGSs computed from Tasks I and II. The second set is the mean RGSs from Tasks III and IV. The four groups are those who did the *Thinking Science 1* programme only, those who did the *Thinking Science 2* programme only, those who did both *Thinking Science 1 and 2*, and finally those who did neither. All of the students in each of the groups completed all four tasks. The mean RGS was calculated using the pre- and post-test scores of the whole non-intervention group as predictors.

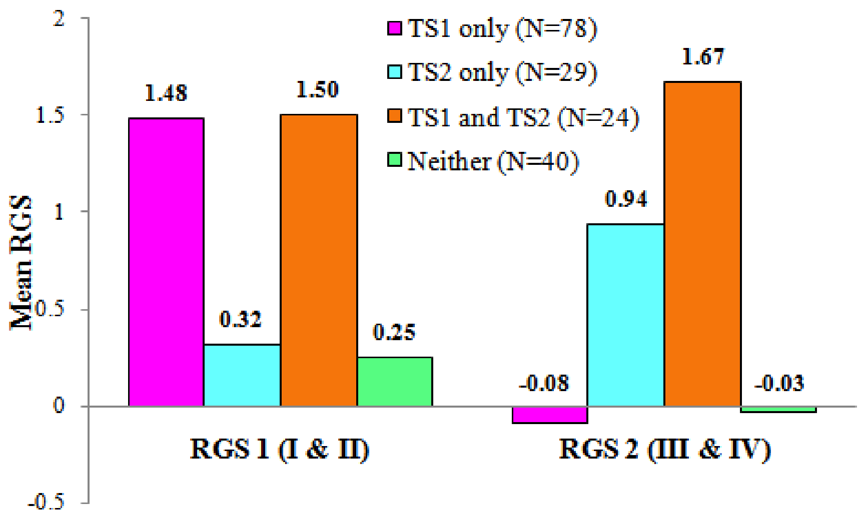


Figure 2.52: **All mean RGS scores for intervention and non-intervention group**

To begin, the group who did the *Thinking Science 1* programme only, had a mean RGS of 1.48. However, when the group were tracked into second level, their RGS from Task III and IV was -0.1 approximately, even lower than those students who had done neither programme. A possible explanation for this is that the absence of the CASE methodology in their second level science teaching inhibited their development, even more so than if they had been part of the non-intervention group from the beginning.

The RGS 1 data (data from Task I and II) for the *Thinking Science 2* only group and the group that did neither programme are similar, as would be expected since neither did the *Thinking Science 1* programme. The means in the RGS 1 analysis were highest and for the *Thinking Science 1* only group and the group that did both programmes. This was also expected at this stage as both groups were only taught through the *Thinking Science 1* programme at this time.

In the RGS 2 analysis, the highest mean was for the group that did both *Thinking Science 1* and *Thinking Science 2* programmes (M=1.67). The mean for the group that did just the *Thinking Science 2* programme was 0.94. This clearly shows that the group that did both programmes made more significant gains that those who just did one of the programmes. The non-intervention group, that did neither *Thinking Science 1* nor *Thinking Science 2*, had a mean RGS of 0.25 at primary level and a negative value of -0.03 at second level. This implies that the students in that group gained more in terms of cognitive development at 6th class in primary school than in 1st year at second level. Also the chart shows that the group that did *Thinking Science 1* only did not do make any more gains in cognitive development that the non-intervention group in the RGS 2 analysis.

2.2.5 Correlations with cognitive development and motivation

In order to try to account for why the CASE intervention programme was particularly successful in enhancing some students' cognitive development an additional study was conducted. The main aim of the study reported in this section was to determine if students' intrinsic qualities affected the success of the programme on their cognitive development. Leo and Galloway [97] proposed that the varying degrees of success of the programme on different students could be attributed to their different motivational styles. In this study the LASSI-HS (Appendix B) was used to try to determine if students' intrinsic qualities affected the success of the CASE programme on their cognitive development.

The Learning and Study Strategies Inventory- High School version (LASSI-HS) [153] is an assessment tool designed to measure students' use of learning and studying strategies and methods in second level education. The original LASSI-HS was a 76-item self-scoring instrument that assessed ten scales. These ten scales were; Attitude, Motivation, Time management, Anxiety, Concentration, Information Processing, Selecting Main Ideas, Study Aids, Self-Testing and Test Strategies.

The purpose of using this tool was to explore if there was a correlation between student motivation and their cognitive developmental gains or otherwise, due to the intervention. In addition, the survey was adapted to assess student attitude, anxiety and concentration. There were time-constraints as to how long students could spend filling out the survey, and so the number of items was reduced. As our interest was in students' motivation, attitude, anxiety and concentration, the questions relating to time management, information processing, selecting main ideas, study aids, self-testing and test strategies were deleted. The Cronbach Alpha value for the adapted LASSI-HS, used in this study was 0.78, deeming it to be a reliable and internally consistent instrument.

The results on Table 2.39 show medium (0.3-0.5) significant correlations between RGS score and attitude and concentration. However, contradictory to Leo and Galloway's postulate there was no significant correlation between student motivation and RGS.

Table 2.39: **Correlation with mean RGS and LASSI values (* denotes significance at the 95 percent confidence level)**

N=23	**Anxiety**	**Attitude**	**Concentration**	**Motivation**
RGS (Task I and IV)	-0.06	0.48*	0.50*	0.40

2.2.6 Conclusions

The results of the *Thinking Science 1* and *Thinking Science 2* programmes showed positive effects, in terms of cognitive development. The *Thinking Science 1* programme, implemented at primary level had a modest effect size of 0.51 σ. In terms of RGS values, the intervention group had a mean of 1 RGS, compared with a mean of zero for the non-intervention group. The difference in these means was significant, and was of a small to moderate magnitude. The programme had effects on both the male and female cohorts, with no significant difference between the genders at this level. The mean RGS of class groups varied from 0 to 2.3, implying that the *Thinking Science 1* programme had a very positive effect on some classes, while it had a negligible effect on others. This bimodality was also observed in classes were the gains were high, with some students making great cognitive gains, while other classes' gains were comparable with the non-intervention students. This bimodality was also a feature of the original CASE experiment. The programme was taught through three different arrangements. Although, there was a mean difference in the gains for the three arrangements, none of these were significant. The male and female groups who were taught through the *Thinking Science 1* programme in co-educational schools also made slightly higher gains than those in single-sex schools, but similarly these differences were not significant.

The *Thinking Science 2* programme was implemented in 1st year at second level. Initially, prior to this intervention there was a significant difference in the cognitive levels of both genders. A greater proportion of females were at higher cognitive levels than the males in the group. There were also negligible differences in the pre-test means of the intervention and non-intervention groups, with the non-intervention group having a slightly higher pre-test mean to start with. However, this had changed by the time of the post-test. By then the intervention group had a significantly higher mean. The effect size of the *Thinking Science 2* programme was 0.52 σ, similar to that of the *Thinking Science 1* programme. The mean RGS of the intervention group was 1 and was significantly different from that of the non-intervention group, with a mean RGS of 0. There was a significant difference in the post-test scores of the male and female groups in the intervention cohort. However, in terms of RGS this difference was not significant. In terms of individual classes, the mean RGS ranged from a negligible 0.5, to a high value of 3, with the majority of the classes having an RGS of 1. There also appeared to be a 'teacher effect' in the results for this part of the programme. There was a great difference in the mean RGS, with the highest been for the team-teaching arrangement. There was a significant difference between this arrangement and the class teacher.

In terms of the students who did both the *Thinking Science 1* and *Thinking Science 2* programmes, their results were analysed separately from the previous groups. The sample included in this analyses was much smaller, due to the difficulty in tracking students across the transition as outlined in Section 2.2.4. The effect size of the combined programmes was 1.06 σ, corresponding to a large effect. These results were in accordance with results reported by Shayer [60] on the original *Thinking Science* programme. The RGS means for the intervention and non-intervention groups were 1.5 and 0, respectively. These means were significantly different and the magnitude of this difference was large.

Arising from recommendations from second level teachers, as detailed in Section 2.2.3, it was decided to incorporate the CASE methodology into Junior Certificate science topics. The method by which this was done and details of its implementation are discussed in Chapter 3.

2.3 A snap-shot of 1st year university students' cognitive levels

In light of the 6th class and 1st year profiles of cognitive development it was decided to conduct a small-scale survey of 1st year university students' cognitive levels, to determine the proportions at the concrete and formal operational levels in 3rd level education. The sample of students were from 1st year science courses and the average age of the cohort was 18 years and 10 months. The fourth task in the series of SRTs, *Equilibrium in the balance* (Appendix A), was used to assess the cognitive levels at the beginning of the academic year. In this study, the Cronbach's Alpha co-efficient for the task was 0.7, deeming it as internally consistent.

The Piagetian levels of the cohort (N=162) are displayed in Figure 2.53. It can be seen that 57 percent of the students are at the formal operational levels, with the majority (40 percent) at the early formal (3A) level. According to Piagetian theory, by the age of 14/15 years children should be at the late formal (3B) operational level. However, in this sample only 2 percent were at the 3B level. 43 percent of this university sample were at the concrete levels of cognitive development.

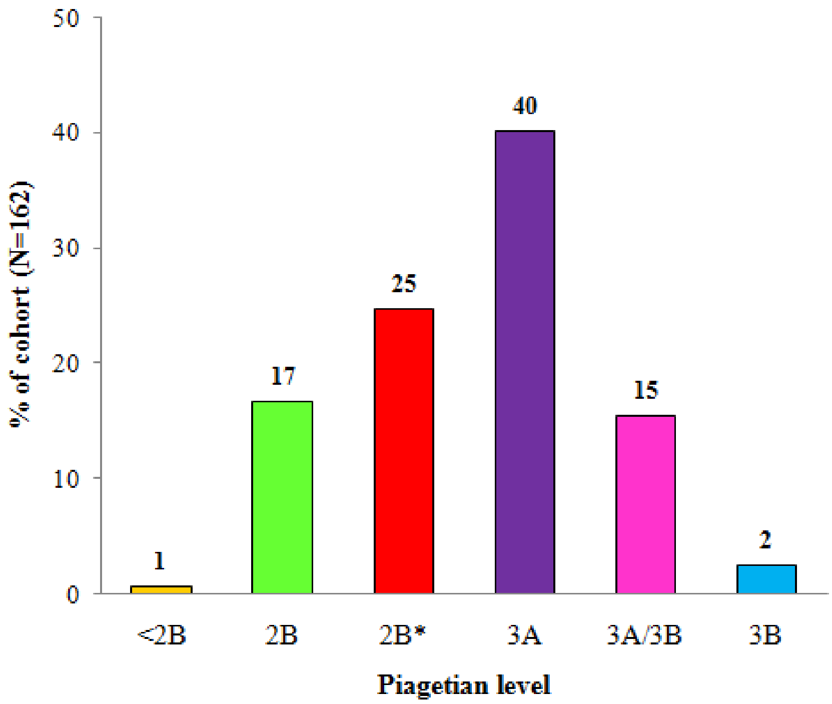


Figure 2.53: **Piagetian levels of 1st year university science students (Average age 18.8 years)**

In terms of gender there was a statistical significant difference between the male and female groups, with the males at the higher levels of development. Figure 2.54 shows the profile of Piagetian levels for the gender groups. 47 percent of the female group, compared with 73 percent of the male group, displayed formal operational thought. The greatest difference between the groups was at the late concrete level, with 24 percent of females at this level compared with 7 percent of the males.

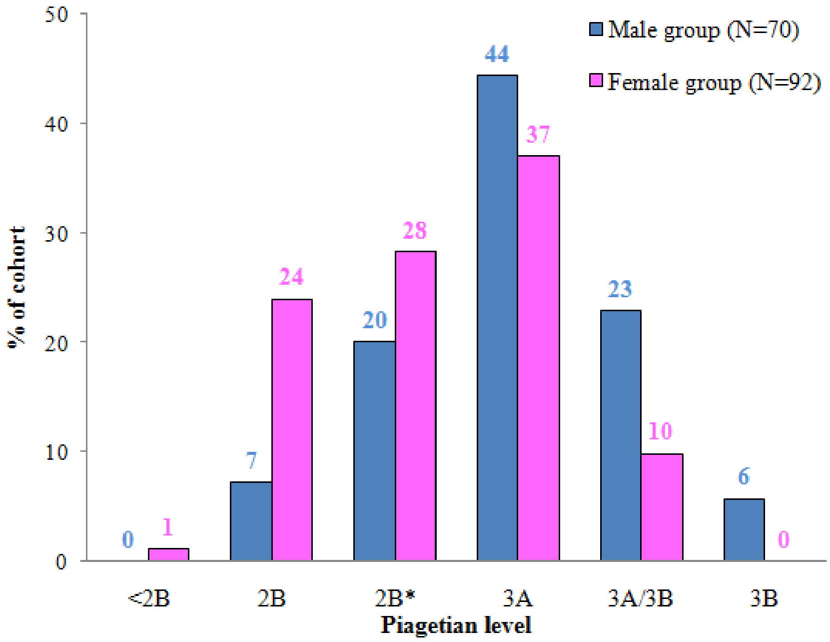


Figure 2.54: **Piagetian levels of 1st year university science students, based on gender**

Some of the 1st year cohort (N=53) studied physics for the Leaving Certificate course, the final two years in second level education. Assuming that these students studied the concept of equilibrium in detail, it was decided to remove these students from the sample. Figure 2.55 shows the the profile of the 1st year students, when this group was removed. This profile is comparable to that of the entire cohort. 45 percent of this sample display formal operational thought, with the great majority (33 percent) of these at the early formal (3A) level.

An analysis of the gender differences show that there was a significant difference between the genders, with the male group displaying more competence in formal operational thought than the female group. The profile, according to gender, can be seen in Figure 2.56. It can be seen that there was a much greater proportion of the female group at the concrete operational (63 percent) levels, compared with the males (42 percent).

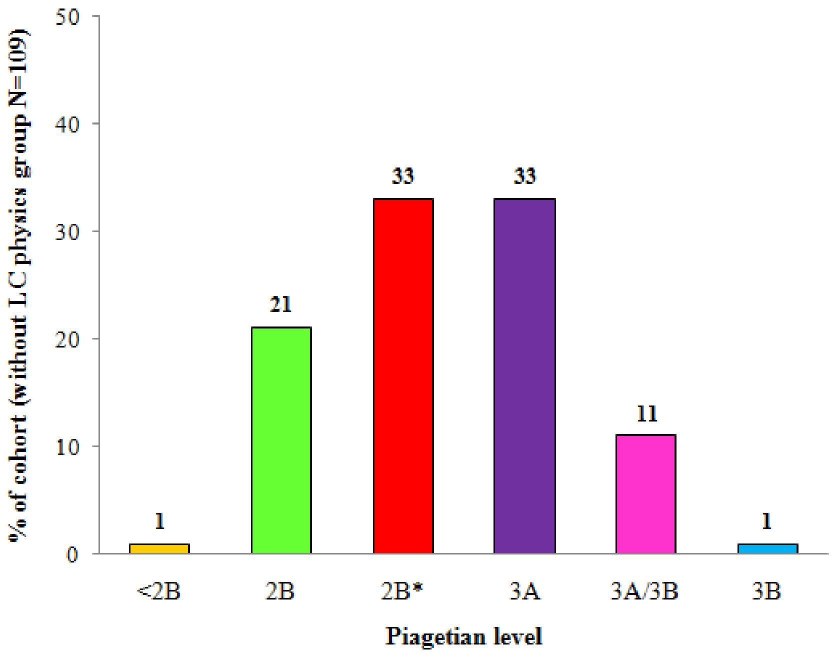


Figure 2.55: **Piagetian levels of 1st year university science students (without the Leaving Certificate physics cohort)**

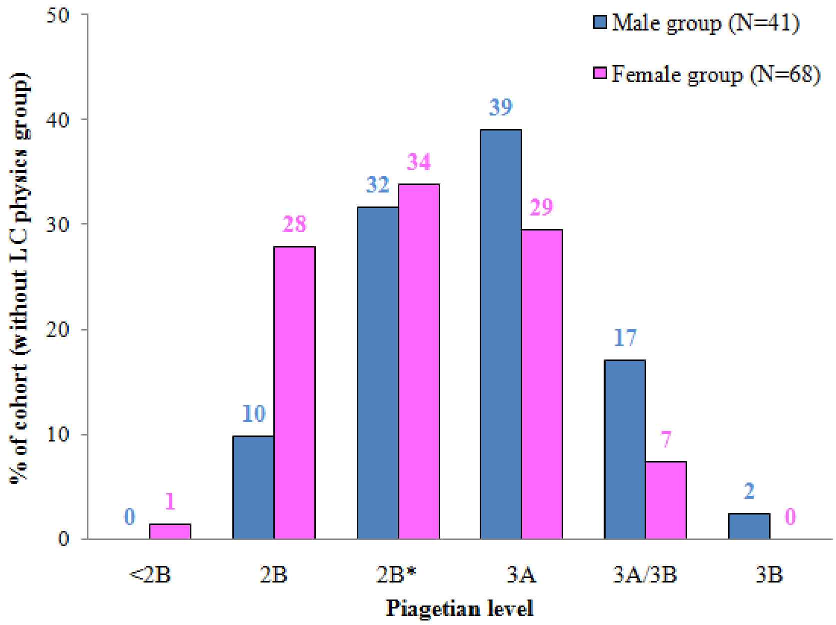


Figure 2.56: **Piagetian levels of 1st year university science students, based on gender (without the Leaving Certificate physics cohort)**

To conclude, this small scale survey yielded a profile of cognitive levels of students that choose to study science at university level. A very small proportion displayed late formal operational thought, necessary for competence in operations such as proportionality, equilibrium and formal modeling.

Chapter 3

The Development and Implementation of the *Thinking through Science* programme for use at Second Level

Introduction

This chapter is comprised of three sections. The first section details how the lessons were developed for use in 2nd year at second level, while the second and third sections review how the lessons were implemented and evaluated, respectively.

3.1 Development of lessons

3.1.1 Background

Following the improvement of the CASE programme, as reported in Chapter 2, on students' cognitive development in this study, it was decided to extend the use of the CASE methodology for suitability for use in the Irish context. The purpose of this part of the study was to develop, implement and assess the effectiveness of lessons, developed for Junior Certificate topics, based on the CASE methodology.

Feedback from interviews with second level teachers about the *Thinking Science 2* intervention programme was very positive, as reported in Section 2.2.3. The teachers who were involved in the implementation called for more opportunities and more direction on how they could incorporate this CASE methodology into their science teaching. However, one concern was the time-frame in which the methodology had to be incorporated and the already existing demands of the curriculum on time and teaching resources. The *Thinking Science 2* programme, although considered valuable by teachers, was also considered as an extra add-on that they could manage without. Also, not all the CASE activities fitted directly into the Irish Junior Certificate science curriculum. Metacognition and bridging were often the pillars that were allocated the least amount of time in the *Thinking Science* intervention, due to the time constraints of single classes. Due to their importance in the process of cognitive acceleration, these pillars had to be allocated more time. As it may have been overly ambitious and unrealistic for us to ask for the curriculum to be cut down for certain teachers who choose to use *Thinking Science*, it seemed more appropriate and possible to incorporate the CASE methodology into the existing topics on the curriculum, and so *Thinking through Science* was developed. The main reasons for the development of the *Thinking through Science* material include attempts to make the programme more practical for use at second level, to increase the frequency of use of the CASE methodology, to cater for a broader range of topics and overall to increase the sustainability of CASE in Irish second level classes. Some of these reasons are discussed below;

- Frequency of use

The CASE methodology must be used frequently if it is to have any beneficial effect on cognitive development. In the original CASE materials the recommended implementation involved using one lesson every two weeks, over a period of two years. This time frame stemmed from work by Lipman [54] and Feuerstein [48]. Their extensive research suggested that in order to have a permanent effect on student's thinking processes the programme must be implemented over a sufficiently long period of time to make a permanent difference. This was based on the premise that student's mental processes would connect concepts over a long period of time, rather than lessons which would require only short-term working memory [154]. The *Thinking through Science* programme was also hoped to increase the frequency of the use of the methodology in Irish classrooms. It was decided to incorporate the methodology into entire topics taught over several class periods. Essentially the frequency of the lessons was shifted from one lesson every two weeks to a much more concentrated 3-4 lessons per week, for a period of 2-3 weeks per topic, over a school term. In addition, the amount of time spent on each of the pillars in CASE would be increased, especially on metacognition and bridging, the pillars which all to often teachers had to rush towards the end of the lesson.

- Broader range of topics

In total, the original 32 *Thinking Science* [59] activities directly cover 9 topics on the Junior Certificate science syllabus, namely three biology, four physics and two chemistry. Although some of the topics covered in the intervention programme are present on the Irish science curriculum, many are not. Although the CASE materials are irrelevant of content and more crucial is the underlying schema of formal operational thought, it was the relatedness of these topics to the curriculum that encouraged their use in the schools. To combat this, lessons for second level science topics, based on the CASE methodology, were developed. The topics to be developed were chosen by teachers as the topics that were left to cover in the time allocated to implement them. The other advantage was that teachers could donate time to metacognition and bridging on a less restricted timescale than in previous CASE lessons.

In response to these needs a series of lessons, based on the CASE methodology were developed for use in the Junior Certificate science course. The next section describes how the materials were designed and developed.

3.1.2 Development of *Thinking through Science* materials

Topics that were chosen for *Thinking through Science*

Five second year classes in second level schools were chosen to be part of this phase of the study. Two of the schools had implemented the *Thinking Science 2* programme in Phase 1 of the study. In order to suit the needs of the school and to ensure that the materials developed would be used, the schools were asked to suggest topics that they would be teaching in the time-frame of the study and topics that they would be prepared to teach through the CASE methodology. Two chemistry and four physics topics on the Junior Certificate science course were chosen. Each class group would be taught either two or three of the topics over the period of one term. The topics chosen are shown in Table 3.1.

Table 3.1: **Topics chosen for *Thinking through Science***

Topic	**Discipline**
Acids and Bases	Chemistry
Chemical Reactions	Chemistry
Pressure	Physics
Density	Physics
Force	Physics
Moments	Physics

Method for developing the *Thinking through Science* materials

The method by which the materials and topics were developed was similar to that of the Moran and Vaughan model [155] used in their development of CASE materials for atomic structure and bonding activities for use at Key Stage 4 in the United Kingdom. The phases of development for their materials are summarised in Figure 3.1. Their first phase, interpreting the CASE style, involved embedding their reasoning patterns (formal models and classification) for their lessons in the pillars of CASE. The second phase involved the physical preparation of materials needed for the lessons. Writing the accompanying 'Action worksheets' was the third phase. Each worksheet was written with the aim of moving pupils on in their thinking and understanding. The materials were then piloted with groups of pupils and CASE teachers. The worksheets were altered, after comments from users, in order to improve wording and diagrams.

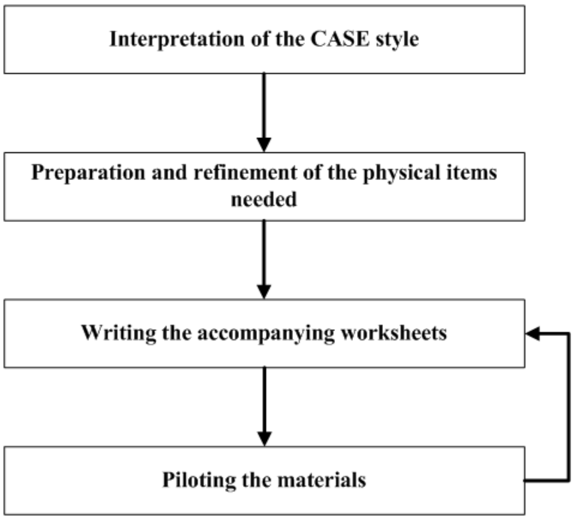


Figure 3.1: **Moran and Vaughan's model for developing CASE activities on atomic structure and bonding [155]**

There were four main features which provided the backdrop for the development of the *Thinking through Science* materials. These are listed and discussed below;

1. Schemata of formal operational thought, according to Piaget [38]
2. The aims and objectives of the topics, in relation to the Junior Certificate science course [149]
3. Curriculum Analysis Taxonomy [1]
4. The pillars of CASE [59]

To begin, the underlying schema for each topic was identified, as shown in Table 3.2. In addition, the aims of the topic according to the Junior Certificate science syllabus were identified in order to build the topic around these aims and satisfy its use in schools. The curriculum analysis taxonomies were used to match the typical response or cognitive abilities with the respective cognitive levels. In general, the aim was to have the lessons increasing in complexity throughout each topic. The lessons were designed according to the CASE methodology and so the pillars were incorporated into each lesson. Clear and concise learning objectives were set out for each topic, and each class within the topic, so the aim of each lessons was clear. Some of the original *Thinking Science* activities were incorporated in the topics. For example in the pressure topic, Activity 26 was included as an introductory lesson. Also lesson 27, Floating and Sinking was included as an introductory lesson in the density topic.

1. Schemata of formal operational thought

   The lessons developed in the *Thinking through Science* programme and their corresponding schemata are shown in Table 3.2. In some topics there were multiple schemata covered.

Table 3.2: **The *Thinking through Science* topics and corresponding schema (denoted by $\surd$)**

Topic	**Variables**	**Proportionality**	**Probability**	**Compensation**	**Correlations**	**Equilibrium**	**Classification**	**Formal Models**
Acids and Bases		$\surd$						$\surd$
Chemical Reactions								$\surd$
Pressure	$\surd$					$\surd$		
Density	$\surd$							
Forces		$\surd$						$\surd$
Moments						$\surd$		

2. Junior Certificate science curriculum

   As detailed in the earlier chapters, the Junior Certificate science curriculum is quite rigid and there is little room, within the three year time-frame, to deviate from course work. The only incentive for schools to become involved in this study was the potential accelerated cognitive development of their students. Teachers were adamant that the materials should be directly related to the aims of the curriculum, in order to ensure coverage of the course, and so the students in the intervention group would be at no particular disadvantage to the other non-intervention students in the school. As a starting point, each of the topics had to be part of the curriculum and the learning objectives of the lessons should also incorporate aims of the curriculum. For each of the topics the aims of what was to be addressed by the lessons was set out clearly. The aims, in accordance with the Junior Certificate science course, for the chemistry and physics topics are shown in Tables 3.3 and 3.4. In addition, some mandatory experiments were included in the *Thinking through Science* materials. In as far as possible the experiments were conducted through the CASE methodology, incorporating the schemata of formal operations.

Table 3.3: ***Thinking through Science*** **chemistry topic aims and corresponding Junior Certificate syllabus aims**

Thinking Science **topic**	**Junior Certificate science topic**	**Curriculum objective [149]**
Acids and Bases	Acids and Bases (Chemistry)	Test a variety of solutions and classify, investigate the pH of a variety of materials using the pH scale, name everyday examples, state the names and formulae of common strong acids and bases, show the neutralisation of an acid with a base, understand that when an acid and base react, salt and water is formed, titrate HCl against NaOH, prepare NaCl
Chemical reactions	Rusting and Corrosion, Metals (Chemistry)	Understand that rusting is a chemical process, describe the reactions of alkali metals with air and water, investigate the reaction between zinc and HCl, investigate the relative reactivities of Ca, Mg, Zn and Cu based on their reactions with water and acid

3. Curriculum Analysis Taxonomy

As introduced in Chapter 1, detailed work by Shayer on the analysis of science curricula was conducted and published in the early seventies [44]. They devised two taxonomies, which altogether comprised of fifteen categories of thinking, and overall they provide an extensive description of concrete and formal operational thought, in terms of the typical behaviour at each stage.

Table 3.4: ***Thinking through Science* physics topic aims and corresponding Junior Certificate syllabus aims**

***Thinking Science* topic**	**Junior Certificate science topic**	**Curriculum objective [149]**
Pressure	Pressure (Physics)	understand the relationship between pressure, force and area, pressure and depth for a liquid, that atmosphere exerts pressure and that atmospheric pressure varies with height, examine weather charts to observe variations in atmospheric pressure and relate to weather conditions
Density	Density and flotation (Physics)	measure mass and volume of a variety of solids and liquids and determine their densities, investigate flotation of a variety of solids and liquids in water and other liquids, and relate the results of this to their densities
Force	Force and Moments (Physics)	understand the concept of force, recall newton as unit of force, describe forces and their effects, investigate examples of friction and effect of lubrication, investigate the relationship between extension of a spring and applied force, understand weight is a force of gravity and changes with location, investigate role of center of gravity in design for stability and equilibrium, investigate law of the lever

The first taxonomy, entitled ‘Different aspects of the development of the child’s interaction with the world’ [1], focuses on the mental activities of students. The taxonomy describes in detail the psychological characteristics of children’s thinking from the pre-operational to the late formal operational stage. Most of the characteristics described are directly relevant to the understanding of science, e.g., interest and investigation style, but some are broader in their scope. The aspects shown in Table 3.5 were analysed in terms of the interpretation by children at all the different levels, ranging from early concrete to late formal operational thought [1].

The second taxonomy compliments the first, but it concentrates on the mental schemata specific to different types of science activity. Taxonomy 2, 'The development of different 'schemas' required for the understanding of the sciences' [1], is described also in terms of typical pupil responses at varying levels of cognitive development from early concrete (2A) to late formal operational (3B).

Table 3.5: **Taxonomy 1; 'Different aspects of the development of the child's interaction with the world' and Taxonomy 2:'The development of different 'schemata' required for the understanding of the sciences' [1]**

Taxonomy 1 headings	**Taxonomy 2 headings**
Interest and Investigation style	Conservation
Reasons for events	Proportionality
Relationships	Equilibria of systems
Use of models	Mathematical operations
Type of Categorisation	Control of variables
Depth of Interpretation (of descriptive passages)	Exclusion of variables
	Probabilistic Thinking
	Correlation Reasoning
	Measurement Skills

Adey and Shayer developed their taxonomies further by applying the taxonomy to the traditional science disciplines; physics, chemistry and biology. Adey and Shayer compiled these tools in the hope of catering for the subject specialist and to broaden scope for class planning with a wider range of pupils. The topics for each of the disciplines are characterised by typical thought processes of the pupil at the various stages of cognitive development. Table 3.6 shows the extensive list of topics for which there are descriptives for [1].

Table 3.7 shows an example of the taxonomies applied to a topic from each of the disciplines; physics, chemistry and biology. The characteristics of thought for each of the levels from early concrete to late formal operational are shown for a selection of topics.

Table 3.6: **Taxonomy for physics, chemistry and biology topics**

Physics	**Chemistry**	**Biology**
Floating and Sinking	Solution	Living things: Classification and Differentiation
Force and pressure	Changes of state	Structure and Function
Equilibrium of physical systems	Speed of reaction	Growth
Momentum	Elements and particle theory	Respiration, Nutrition and Transport
Velocity and acceleration	Compounds, reactions and their chemical representation	Reproduction
Newton's Laws	Acids and alkali	Ecosystem
Electricity	Oxidation and reduction	Evolution and Genetics
Temperature and Heat	Chemical Equilibria	Chemical Processes
Kinetic theory	Chemicals and energy	Experimental Design
Energy and Power	Organic chemistry	Control and coordination
Thermodynamics		
Light		

In order to ensure that the *Thinking through Science* lessons were designed to promote cognitive development, it was necessary that they were mainly pitched towards the formal operational level. However, in each lesson it was necessary to have aspects of the lesson at the concrete operational level so as 90 percent of the class were at a level to understand the initial phase of the topic. As with the original CASE materials, as the course of lessons developed, the level at which the lesson operated rose gradually.

Each of the concepts to be taught in the lessons, that corresponded to the curriculum aims, were mapped onto the curriculum analysis taxonomy and matched with the level necessary to gain true understanding of the concept. Most of the concepts in each of the topics selected, start at the early concrete (2A) level, attainable to nearly all the students in every group. They then progress almost always in the following order from late concrete (2B) through to late formal operational (3B) thought. Essentially, as the time spent on the topic progresses so does the cognitive demand of the lessons. Figures 3.2, 3.3, 3.4, 3.5 and 3.6 show the sequencing and level of cognitive demand for the concepts taught in each of the six *Thinking through Science* topics, namely acids and bases, chemical reactions, density, pressure and force and equilibrium. On each of the diagrams the corresponding aim of the Junior Certificate science syllabus is marked in the circle beside where the concept features, e.g., OC18.

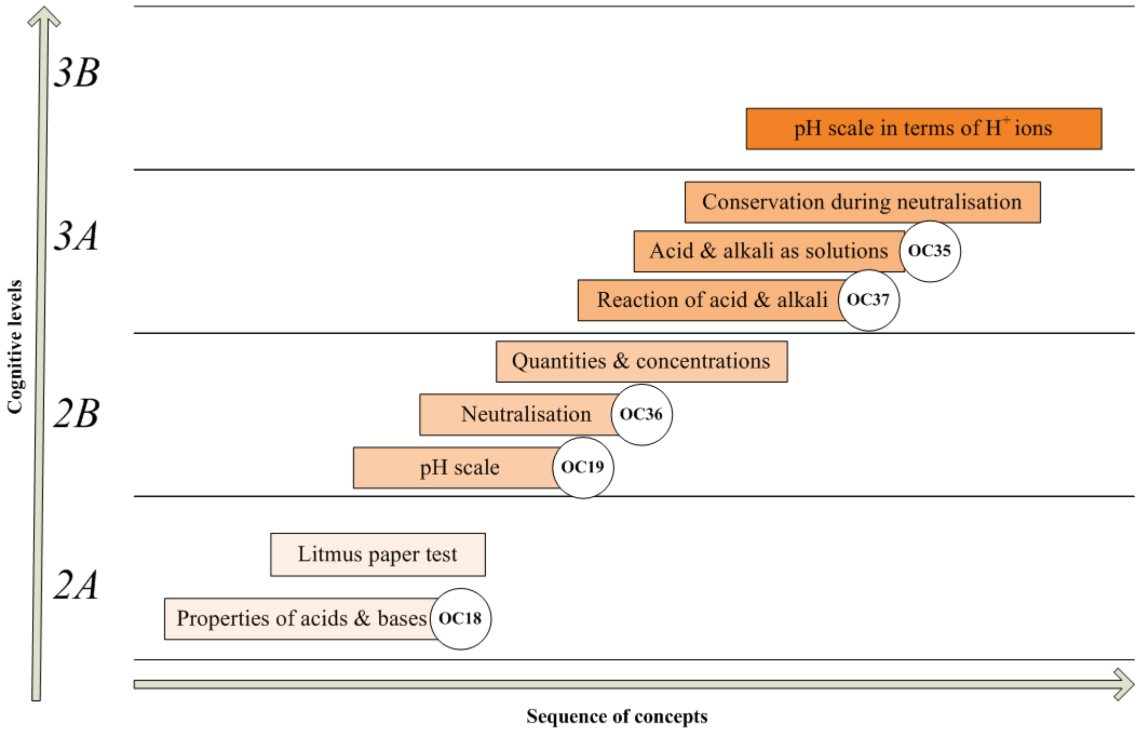


Figure 3.2: **Operating range and sequencing of concepts in *Thinking through Science*; Acids and Bases**

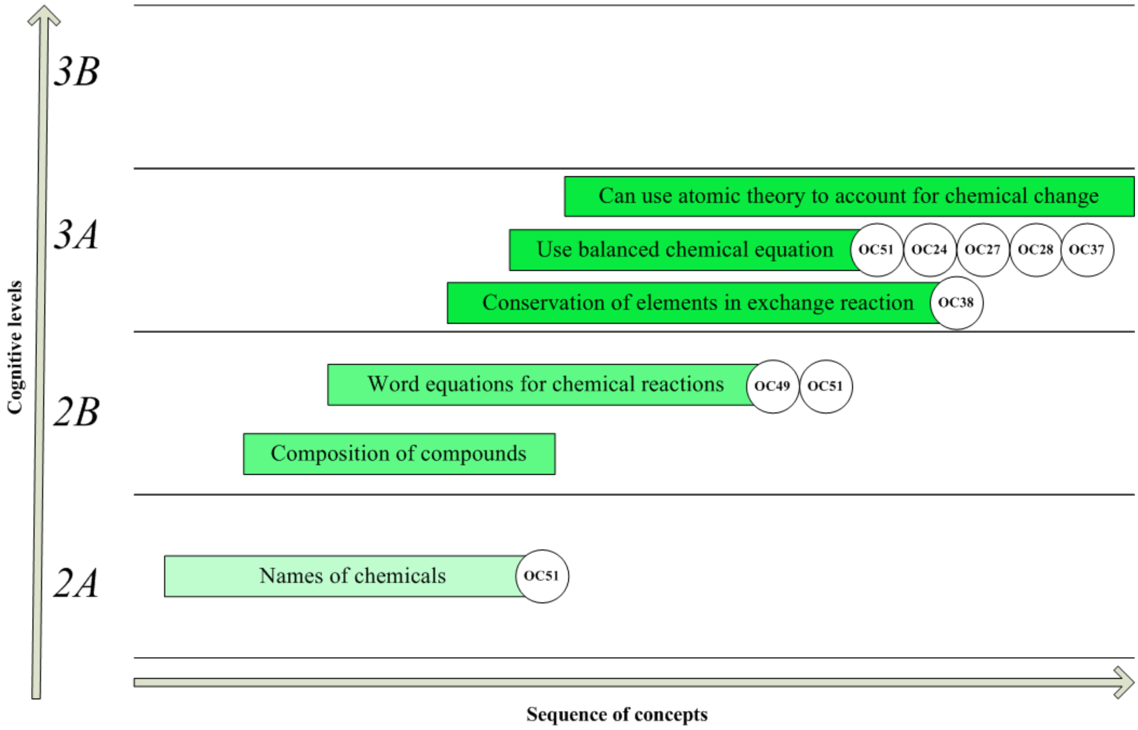


Figure 3.3: **Operating range and sequencing of concepts in *Thinking through Science*; Chemical Reactions**

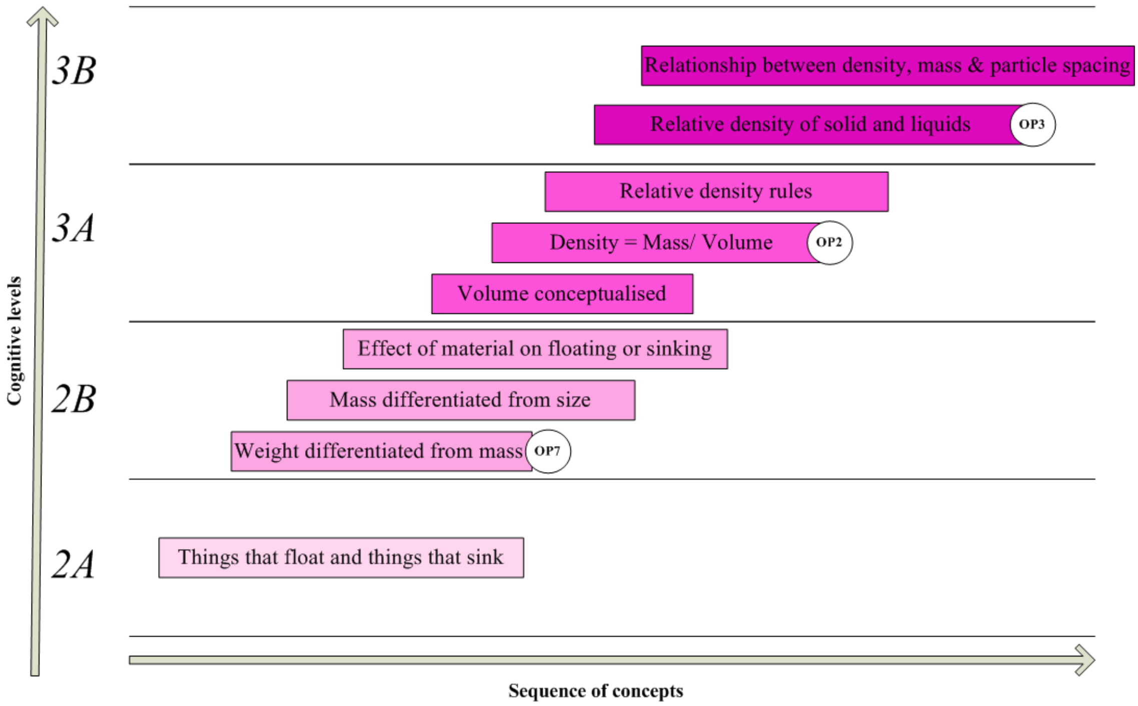


Figure 3.4: **Operating range and sequencing of concepts in *Thinking through Science*; Density**

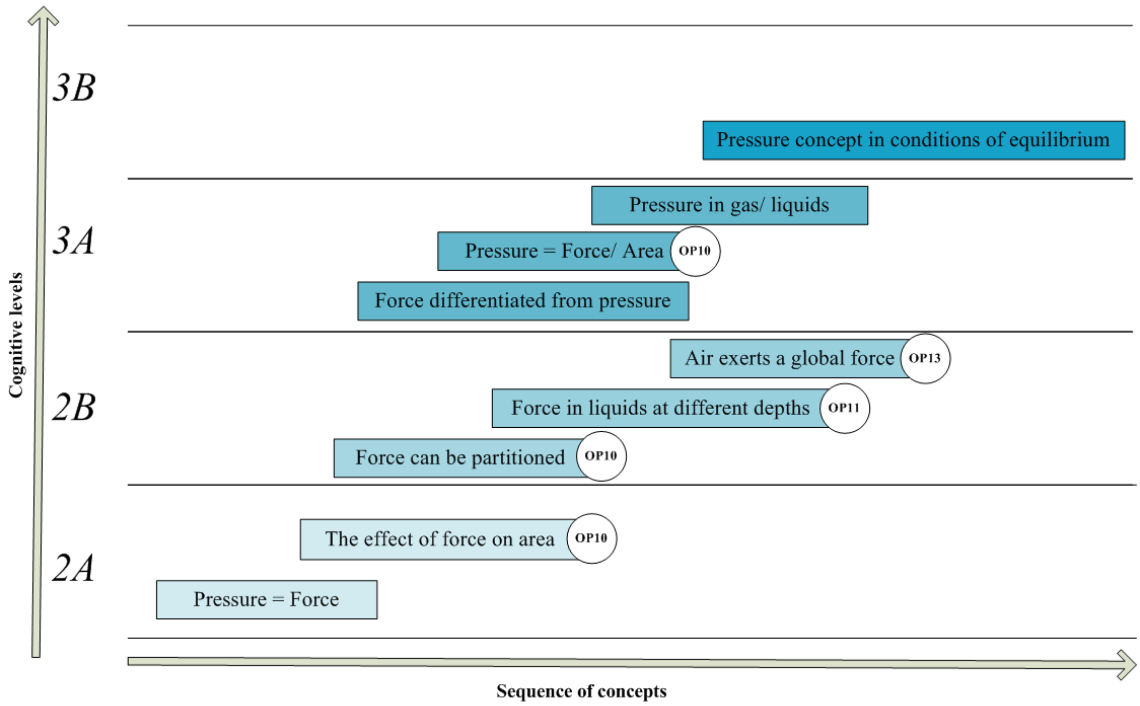


Figure 3.5: **Operating range and sequencing of concepts in *Thinking through Science*; Pressure**

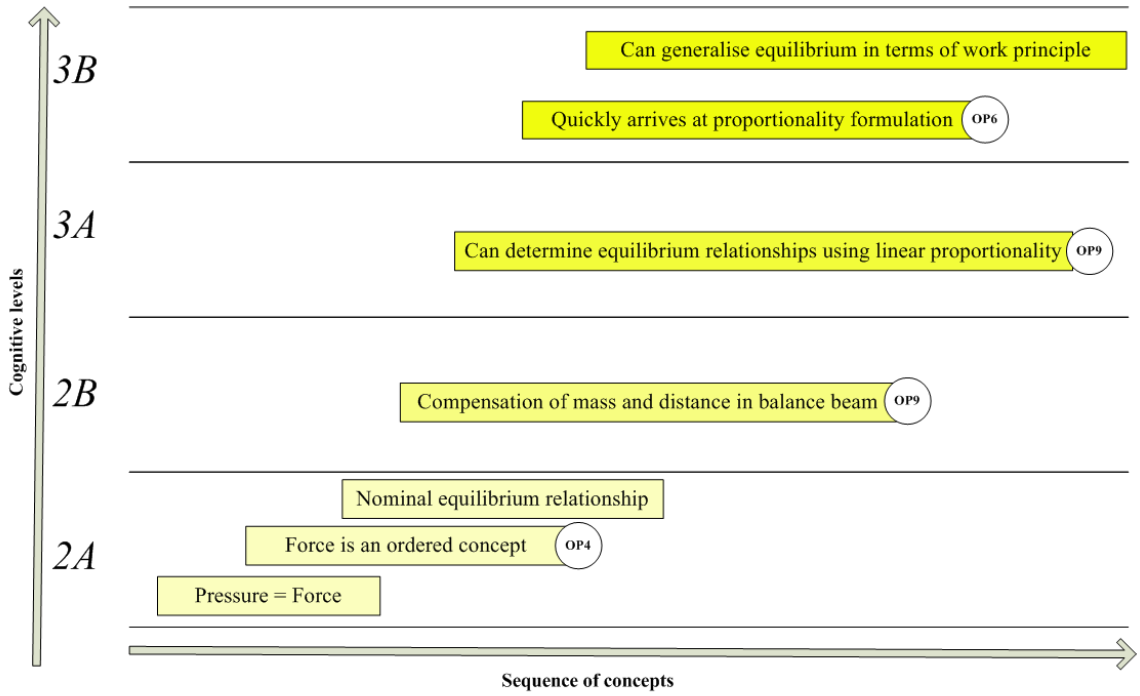


Figure 3.6: **Operating range and sequencing of concepts in *Thinking through Science*; Force and Equilibrium**

Table 3.7: **Cognitive levels of three physics, chemistry and biology topics [1]**

Topic (Discipline)	**2A early concrete**	**2B late concrete**	**3A early formal**	**3B late formal**
Force and pressure (Physics)	Pressure = Force. The effect of a force is greater if it acts through a thinner surface. 'Force' is a concept which is ordered.	Force increases with depth. Vacuum is treated as a negative force. Air exerts a global force. Force can be partitioned. The word pressure may be used but still gives a working definition of 'force'.	Distinguishes force from pressure. Pressure is treated as force per unit area. The pressure in a gas or liquid is the same in all directions.	Can apply the pressure concept to the general understanding of conditions of equilibrium.
Solution (Chemistry)	Salt/ sugar dissolve in water. Mass of solute is conserved but volume is not.	The process is reversible.	The particles intermingle, but stay 'the same', so that each conserves volume, weight, and chemical properties.	Saturation involves an equilibrium situation, with precipitation rate=solution rate.
Growth (Biology)	Growth as increase in size, as measured by height or weight. Growth not a constant phenomenon. Physical factors effect growth, e.g. poor nutrition.	Growth is a result of cellular division. Occurs in special areas in plants. In humans some parts grow faster than others. For humans appreciation that different measurements of growth are not necessarily related to one another, e.g. height and weight.	Different measurements of growth not necessarily related for other organisms e.g. height/ weight of plant in dark. Simultaneous processes of cellular enlargement and specialisation in animals and plants. Growth rates.	Process of nuclear division and energy transformations, multiple interactions of factors effecting growth. Cell-division in eggs as sequenced by genetic code for differentiation of organs.

4. Pillars of CASE

The pillars of CASE are taken from the original *Thinking Science* materials [59]. Below, each of the pillars are briefly outlined, how they were implemented and an example of them from a *Thinking through Science* lesson. As much as possible the time allocated to each pillar was proportioned in each lesson, but due to many classes being single ones there was not enough time to cover each pillar in each lesson, and so some single lessons would be dedicated to a single pillar, e.g. a metacognitive activity.

Concrete preparation

Most lessons in the *Thinking through Science* series began with the concrete preparation pillar. The main aim of this pillar was, as in the original materials, to set up and prepare the whole class for the thinking activities. An example of concrete preparation is taken from a lesson in the Acids and Bases series. Students spend a part of the first lesson classifying household products as a whole group exercise so as to get them engaged with the new topic and the idea that they must classify them according to their own criteria.

Another example can be taken from the Pressure series. Students are presented with four different shoe types, from stiletto heels to snow shoes (all the same shoe size) and students are asked to rank how the shoes would sink into sand if they were in them. As a group the class are invited to share their predictions and the reasoning behind them. Following this, four suitcases of varying masses are displayed and students once again predict in which situation will a person carrying the cases sink furthest into the sand. The findings from these two scenarios are the content for the investigation in the construction part of the lesson.

Construction and Cognitive conflict

This part of the lesson is that which features the main student activity or group work. It is drawn from the concept of Vygotsky's ZPD, where social exchange is encouraged. The CASE processes of cognitive conflict and social construction are the main elements of this pillar.

Cognitive Conflict

In the cognitive conflict process, deliberate intellectual challenges are presented to students in order to encourage cognitive growth by equilibration or accommodation of new information.

An example of cognitive conflict is taken from the fourth lesson in the Acids and Bases series, where the concept of neutralisation is introduced. Universal indicator is placed in two solutions, one acidic and one basic, both of equal volumes and equal strengths. The students are asked to consider what will happen when both are mixed in together. They must consider both physical and chemical changes, using what they know about the solutions and colours. This provides conflict in terms of what happens when the two solutions, which they know about separately are mixed together. Students must use their formal modeling schema to predict/ explain the outcome.

Research by Kuhn [156] on the area showed that cognitive conflict examples used in class that were exceeding the student's cognitive level by one level produced the most significant changes in cognitive development. Further findings implied that it was the amount of exposure to formal thinking exercises that affected the rate of cognitive development [157].

The management of cognitive conflict in the lesson is the responsibility of the teacher, and it cannot be fully encompassed in teacher materials or worksheets. Examples of activities that induce cognitive conflict can be outlined in great detail in the materials provided but unless the teacher has the skills to manage the scenario the beneficial effects on cognitive development are likely to be very minimal.

Before designing lessons with cognitive conflict it was first necessary to study the concepts which students have perceived difficulties with and the most common misconceptions. These misconceptions are reviewed for the topics for which *Thinking through Science* lessons were developed for.

- Acids and Bases

  Much of the reported research on children's conceptions of acids and bases point to the notion that much of their ideas of acids stem from their everyday experiences such as tasting foods, using antacid remedies and hearing about the effects of acid rain [138]. Findings from interviews conducted by Hand

and Treagust [158] with 15 year old students showed that they had two major conceptions of acids and they were that they 'eat materials away' and 'acids can burn you'. Further questioning revealed that students believed that 'strong acids eat away material faster than weaker acids' and 'the only test for an acid is to see whether it eats something away'. Possibly due to the use of the word 'base' to a lesser extent in everyday life, students were less likely to form preconceptions of bases until they have been taught about them. Hand and Treagust found that 15 year olds have the idea that 'a base is something that makes up an acid' and that neutralisation was about breaking down an acid or changing from an acid to something else. Confusion was also noted in the area of acid strength and concentration, with a large proportion of second level students not understanding the difference [159]. Cros *et al.* [160] in a study with first-year university students, found that almost half of a sample of 400 were unable to name more that two bases. This evidence in itself illustrates lack of understanding and conceptualisation of basic substances. Almost one fifth of this same sample thought that pH was a measure of the degree of acidity.

- Chemical Reactions

  There have been numerous studies into the various aspects associated with chemical reactions [138, 161, 162, 163]. To begin extensive studies have shown that children have great difficulty distinguishing between chemical and physical changes [138]. In the case of combustion, Meheut *et al.* [161] studied the views of 400 11-12 year olds and found that their ideas were 'far removed' from the concept that the process was a chemical reaction between a substance and oxygen. Research by Andersson and Renstrom [164] and Donnelly and Welford [165] on the ideas of 15 year olds about change of mass on combustion found that 60 percent of those with above average ability predicted a loss of total mass on the combustion of iron wool. Their reasons for this prediction included that the iron is lost through burning, the air or moisture is lost from the wool and the powder weighs less. A number of features of student's thinking about burning is echoed in their thinking about rusting. A sample of 15 year old British students were asked, prior to the teaching of the topic, to predict what will happen to the mass of iron nails if they are left out in air until the nails rust [162]. The group responses were divided evenly, with one thirds respectively predicting that the mass of the nails would increase, stay the same and decrease. It is suggested by Driver [162] that despite school instruction, where the products of combustion may be solid and can weigh more than the initial substance, students seem to remain faithful to their prototypic thinking. Andersson [163] proposed that children's understanding of chemical changes follow a general pattern and he identified the following features in the development of children's thinking in the area of chemical change;

1. Children are unquestioning about chemical changes whether it is the rusting of nails or the burning of paper and seem to accept that that is how things happen.
2. In terms of the displacement of matter, children appear adamant that when a 'new' substance appears from a chemical reaction it has just been moved from another place. For example, the smoke that forms when wood burns is seen by the child to have been forced out of the wood by the flame.
3. In the case of modification, when a new substance has been formed it is seen as the original substance but in a new form. When asked about the burning of a splint, some children say the ash is the same splint but in a different form.
4. In the case of transmutation, the original substance is considered by the child to be transformed into a completely new substance.
5. When children view chemical interaction they see the substances as being composed of atoms of different elements and new substances are formed by the recombination of atoms of the original substances.

Driver [162] proposes that students construct ideas about atoms and molecules and their symbolic representation in the way compatible with that taught in school science lessons. However, when students are asked to explain physical phenomena they tend to abandon the taught ideas and revert to their intuitive ideas, based on their experience. Driver questions whether students understand the theoretical models or ideas that they are exposed to in science lessons and also whether the use of these ideas is either useful or appropriate for students in interpreting real life events.

- Pressure

  Predominantly research into students' ideas in this area is based on air pressure and pressure in liquids. To begin with pressure in liquids, research by Clough and Driver [166] with 12, 14 and 16 year olds found that high proportions in each age category think that pressure increases with depth (67, 80 and 87 percent respectively). However, in the same sample students were less likely to think in terms of pressure acting in all directions in air or water (13, 19 and 34 percent respectively). In general, they were inclined to think of pressure acting downwards. In a study of French 11 to 13 year olds on their concepts of air pressure differences, Sèrè [167] found that 85 percent of a sample of 600 accurately described the air in a ball, before and after blowing it up. However, when asked to compare the air pressure inside the ball with the air pressure outside, only 63 percent could compare it accurately. Sèrè's study showed that students associate pressure in gases with moving air and are less inclined to associate it with static gases. Driver [162] suggests that students are taught comparisons with 'outside' are necessary to interpret what happens 'inside' a container. This may help students to reason more in terms of interactions between systems, as opposed to just one quantity of air.

- Density

  Biddulph and Osborne [168] researched 7 to 14 year old's understanding of floating. When asked why some things float the most frequent suggestion was because the objects were light. Only three pupils answered 'light for their size'. The majority could not give one single consistent reason as to why things float. In the same study, children aged 8 to 12 years were asked how a longer piece of candle would float compared to a shorter piece. The results showed a correlation between increasing age and increasing percentage, suggesting that the longer candle would float at the same level as the smaller candle. However, even at 12 years of age there were still 40 percent who considered that length would affect floating. Approximately 35 percent of the 11 to 12 year old sample thought that the depth of the water affects the level at which an object floats.

  It was Piaget's work [169] that revealed that notions of density and weight develop when children become less egocentric and begin to take other points of view into account. Piaget postulated that at the ages of 9 to 10 years children relate density of one substance to that of another.

  However, Rowell [170] in his work with Australian 11 year old pupils found that misconceptions about volume were prevalent amongst the sample, with over 80 percent having misconceptions. This shows signs of potential serious difficulties in the understanding of the concept of density.

- Forces and Moments

  There is much evidence to suggest that the area of force and introductory mechanics is one area where students bring much of their firmly held preconceived ideas from their day-to-day experience. As Driver [162] documents it is one of the areas that is most challenging to change students' beliefs, even after instruction. Some of the main misconceptions brought to light by extensive international research are briefly outlined below.

  Students generally bring the everyday meaning of the word 'force' to their learning and Driver [138] cites that many studies reported the word 'force' as being associated with opposing resistance and with physical activity and strength. Much research has found that students link forces with movement and are reluctant to accept the presence of a force if there is no motion.

  Studies by Sjoberg and Lie [171] and Erickson and Hobbs [172] report that it is common for students to perceive force as a property of a single object rather than as an interaction between two objects. In addition, students seem to have great difficulty in identifying the magnitude and direction of forces. Brown and Clements' [73] research with high school students found that when students considered a collision between two objects they think of one object as having more force i.e., the moving object or the faster moving one.

  In terms of equilibrium, Eriksson and Hobbs [172] found that pupils between the ages of 6 and 14 years appeared to think of numerous forces engaged in a struggle in which the strongest force overcame the other weaker forces. Ten out a group of seventy-six pupils viewed equilibrium as the resolution of the struggle, after which all the forces involved stopped acting. Less than half of a group of thirty-two pupils predicted that if a system in equilibrium were displaced, it would stay in the new position.

  Without necessarily being aware of it, children have an intuitive grasp of turning forces, as articulated by Inhelder and Piaget [38]. When children encounter a see-saw for example they know that a 'weight' further away from the center point has a bigger force and in general they intuitively know how to balance a beam using different weights on either side of the beam.

Metacognition

This is the whole-class reflection of the outcome of the activity, but much more importantly the thinking processes required to reach a solution are identified and made explicit. This part of the lesson cannot be explicitly defined in a lesson plan but it is a key feature that is emphasised in the training of teachers and one that teachers implement through their direct questioning. Teachers provide scaffolded support to the students and help them to use the data collected and the processes of reflection to connect their experience to their learning. As Adey describes '*it is only after one has solved a problem that one can learn most effectively how one should have solved it*' [76].

In an activity where students have been asked to formulate a model for a chemical reaction, for example, after they have been given some time to do so, the teacher regroups the class for the metacognition exercise. It may begin with different groups presenting their model to the class and verbalising their reasoning. The key role of the teacher in this part of the lesson is to constructively question the students on their reasoning and their mental processing methods of arriving at conclusions. The teacher's questioning must be strategic and must provide cognitive challenge to the students. On occasion worksheets or exercises can be the starting point of for metacognitive activity but in general it is the teacher that plays the key role in building and elaborating on metacognitive activity. For example, as part of the lesson outlined in Figure 3.8 on neutralisation the students were asked to reflect and verbalise their model of a neutralisation reaction. They were asked to explain the outcome of the reaction between an acid and a base of half strength. In this way the students are engaging in dialogue where the student gets a chance to express their model for neutralisation, albeit in a new scenario. Often in the lesson the student is unconscious of the reasoning pattern they have developed until they have verbalised or expressed it and then they become conscious of the rule or law they have just constructed. The teacher's role is in the questioning and extending the boundaries of explanation for the students. The difficult part for the teachers is resisting the temptation to inform the students of the answer they should have had, if their reasoning was incorrect or inaccurate.

Bridging

Bridging, as discussed in Chapter 1, is the pillar taken from Feuerstein's IE programme [48]. It is the '*final link in the chain of developing, abstracting, and generalising reasoning*' [25]. The difference between its use in CASE and IE is the context; it is context-dependent in CASE and context-independent in IE. In the original *Thinking Science* materials [59], bridging was the pillar that was '*an optional short episode*' [77] where the ideas developed in class could be linked to other contexts in science or everyday life. Since the early days of CASE the concept of bridging has attracted much more interest [77].

Metacognition is a necessary precursor for bridging. If bridging requires the transfer of a reasoning pattern from a context in which it is first encountered to a new context, the transfer is more likely to be successful if the reasoning pattern has being explicitly verbalised by the student.

In the *Thinking through Science* lessons, bridging occurred in various forms. With classes that had done the *Thinking Science 1* and/or *Thinking Science 2* programmes, there were explicit links made with reasoning patterns developed in previous lessons, typically taking place in the concrete preparation part of the class. For example, in the lessons where the controlling variables schema was employed, students were referred to the first few *Thinking Science 1 and 2* lessons, namely 'What varies?', 'Two variables', 'The 'fair' test' and 'What sort of relationship?', where the schema was first introduced in relation to input and output variables and the relationships that exist between variables. The relevance of this schema could then be discussed in relation to the lesson. Another form was when the reasoning pattern developed in a lesson was applied to a topic where it had a different form, e.g., compound variables in the density topic applied to the topic of pressure.

3.2 Implementation and Evaluation of the *Thinking through Science* lessons

3.2.1 Selection of schools

Due to the complex nature of the number and type of schools involved in the study up to this point, it was necessary that some careful selection of the intervention and non-intervention classes was carried out. Up to this point there were four combinations of groups of students, namely those who had done the *Thinking Science 1* programme and the *Thinking Science 2* programme, those who had done the *Thinking Science 1* programme only, those who had done *Thinking Science 2* only, and those who had done neither. The study was designed in such a way that the intervention and non-intervention group for this part of the study would incorporate students from each of these groups. In addition, two new schools were invited to be part of this phase of the study in order to increase the sample size of the intervention and non-intervention groups. Figure 3.7 shows the intervention and non-intervention classes for this phase of the study and from what primary level schools and/or 1st year classes they came from.

In four of the school groups, namely schools 2, 5, 7 and 8, there was one intervention class and one non-intervention class. In school 6, both classes involved in the study were intervention classes. The details of the schools involved are given in Table 3.8. The non-intervention classes in each of the schools covered the same topics in the same allocated time as the intervention groups, with their regular science teacher. The classes in schools 2, 5, 6 and 7 were mixed ability, while the classes in school 8 were streamed.

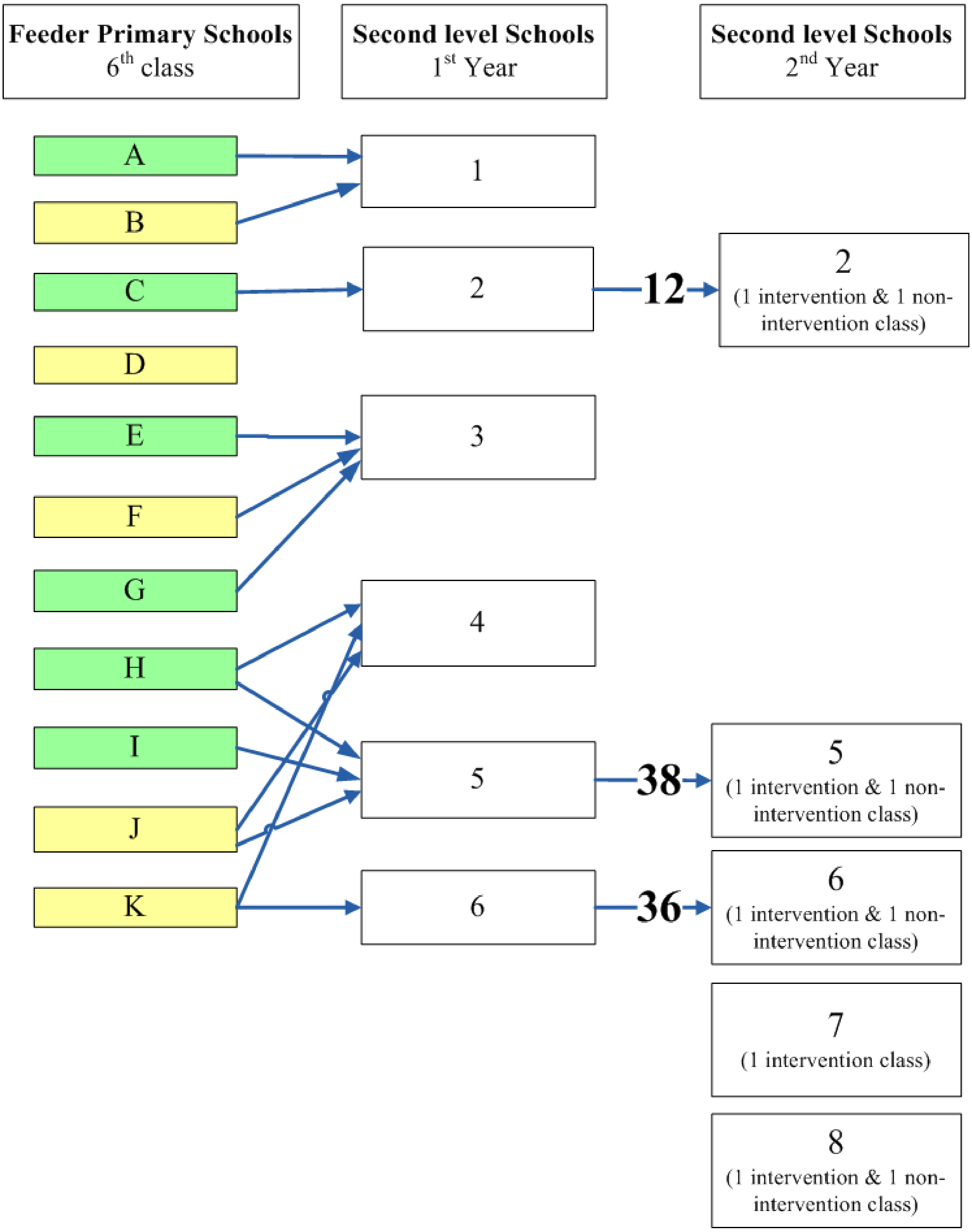


Figure 3.7: **Intervention and non-intervention 2nd year classes, and where applicable their feeder primary schools**

Table 3.8: **Profile of second level schools and class groups, both intervention (E) and non-intervention (C), that participated in the *Thinking through Science* programme**

School Code	Type	Class group	Group	N
2	Semi-urban/ All-girls	2.2.1.1	C	22
		2.2.2.1	E	22
5	Urban/ All-girls	5.2.1.1	E	20
		5.2.2.1	C	19
6	Urban/ All-boys	6.2.1.1	E	22
		6.2.2.1	E	20
7	Urban/ All-girls	7.2.1.1	C	18
		7.2.2.1	E	23
8	Urban/ All-boys	8.2.1.1	C	22
		8.2.2.1	E	27

3.2.2 Teacher training

After schools were selected and teachers had agreed to become involved, one of the first objectives was to begin the teacher training aspect of the study. Two of the five teachers implementing the *Thinking through Science* programme had used the CASE methodology previously in the implementation of the *Thinking Science 2* programme, in Phase 1 of the study. For the other three teachers this was their first experience teaching science through the CASE methodology.

The main aim of the teacher training part of the programme was to make teachers very familiar with the CASE methodology and equipped enough to teach a topic that they are very familiar with, using this alternative methodology. The first workshop, carried out in each of the five schools, on a individual basis with each teacher, addressed the main aims of the programme, the results of previous CASE programmes, an introduction to the five pillars and Piaget's schemata of formal operation thought. The next workshop addressed, in much more detail, each of the pillars, how they would be conducted and managed in the classroom and some examples from the original CASE materials [59] and some of the lessons, which at that time were in development. After some time spent by the teachers practising the lessons and familiarising themselves with the methodology, especially the metacognition and bridging pillars, a third workshop took place where concerns that teachers had about the methodology, or any practical difficulties that arose from their trials were addressed. After this the programme began in each school and the researcher played a supportive role with the teachers and feedback from the teachers was obtained regularly. At the end of the programme there was a de-briefing session with each of the teachers of the intervention classes to discuss what was done in the class, how the lessons went and to get the teacher's perspective on the methodology, their use of it and their future plans for using the programme. In the case of one of the classes, there was a team-teaching arrangement involving the researcher and the class teacher. After each class there was a de-briefing session.

Informing teachers about cognitive levels

The practice of informing teachers of their students' cognitive level was introduced in this part of the study, in support of Adey and Shayer's work [1]. They believed that the value of informing teachers of student's cognitive levels was immense and necessary for good teaching. From mixed ability to streamed classes, there is always a range of cognitive levels within the student cohort. Adey and Shayer propose that if you teach a class as if they were all exactly the same then those that do not understand are viewed by themselves and others as 'incompetent'. When teachers are aware that all students within the class are not at the same cognitive developmental level they can alter their lessons to accommodate the various abilities and ensure a more engaging learning environment for the entire cohort of students. Knowledge of this cognitive developmental level of students is first necessary.

Most teachers, after some time teaching their class are aware of mixed abilities within their class. They may gain this insight from class exam results, standards of class-work and homework and general class interaction. However, gaining insight into student's level of cognitive development provides another dimension to the knowledge that teachers have about their students. It can, when interpreted correctly, unveil situations of student success by rote-learning, lack of interest/ motivation and the necessity for a different teaching style. It can provide insight into the depth of understanding that the student can have of a concept or theory and so provides scope for the teacher to teach more effectively to the various range of students in his/her class.

Simon [173] illustrates that when teaching science through the CASE approach in a streamed or mixed-ability environment, there are three important features of a lesson. The first involves recognising the Zone of Proximal Development of the students so as to engage them in cognitive challenges that are appropriate for the individual. Another feature that is essential is ensuring that all students are engaged, on some level with the cognitive aspects of the lesson. In order for this to happen the class must be of interest to the students from the beginning of the lesson. Finally, it is essential in a CASE lesson that students interact with each other and the teacher, through mediation and social construction and in order for this to happen the environment must be very open, social and engaging.

According to these features highlighted by Simon, it is evident that teacher's knowledge of their students is a very necessary requirement, if the methodology and lesson is to be cognitively engaging for students. In addition, teacher's prior knowledge of student's cognitive levels is essential in gauging the difficulty of the content of the lesson or how the lesson is to be delivered.

In order for the *Thinking through Science* programme to be successful in its aims, it was necessary to provide teachers with a deep understanding of the concept of cognitive acceleration. When teachers were informed about the particular level of each of their students, they were faced with the proof as such, as opposed to an arbitrary notion that it was a mixed ability class or otherwise. This information also provided valuable information in the role of organising groups for group work, allocating project tasks, setting cognitive challenges and identifying students that were at particularly high or low cognitive levels and preparing for their interaction in the class.

Materials provided

Each class that was part of the *Thinking through Science* intervention programme was provided with all the materials necessary for the topics that they were covering. Each student got a *Thinking through Science* workbook. Each teacher got a teacher book with the lesson plans and outline of the CA methodology. All equipment and chemicals needed for each of the lessons was provided to the classes. Figure 3.8 shows a typical layout of the lesson plan. Each of the pillars are identified, as well as the minimum cognitive level necessary for the potential grasp of the concept.

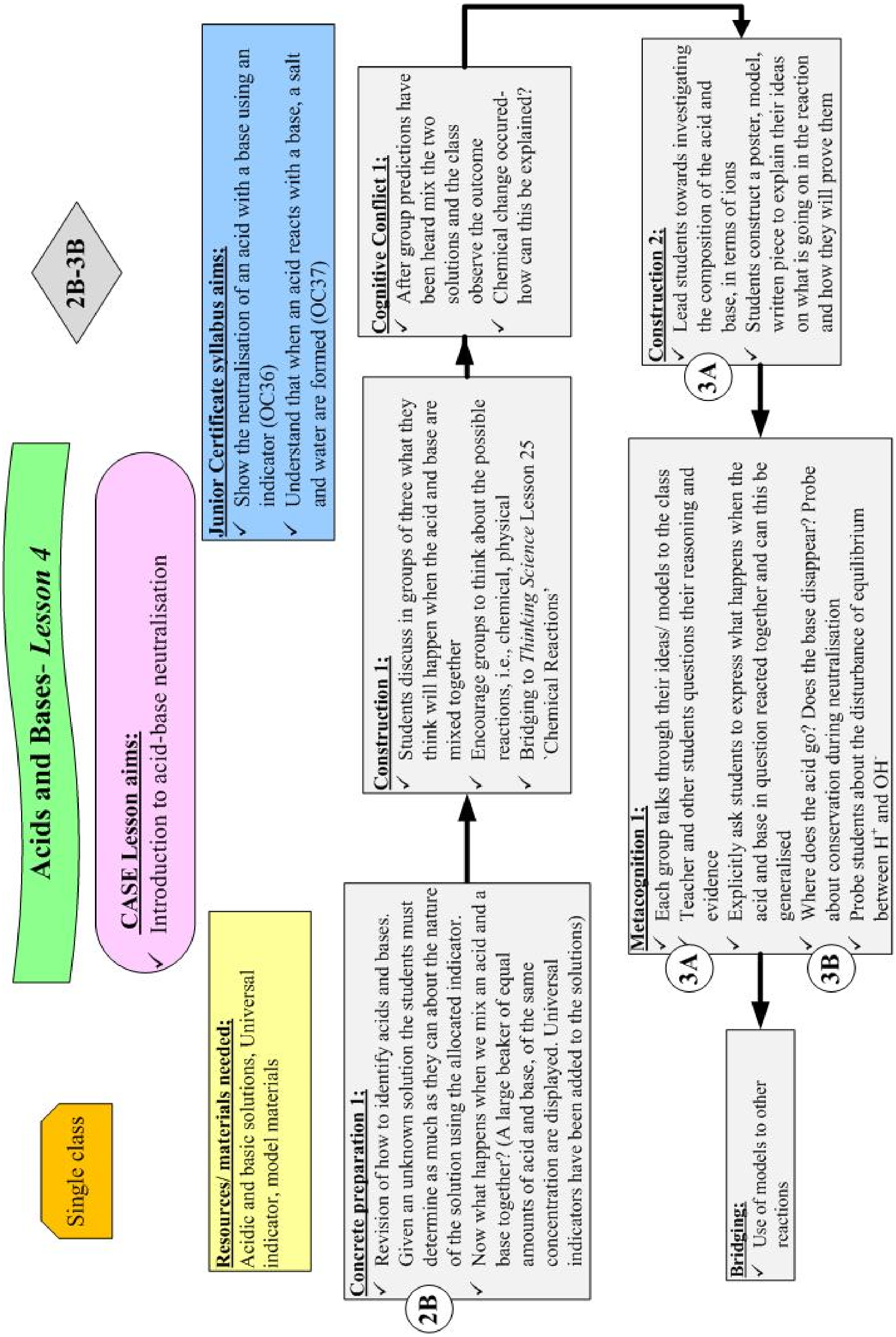


Figure 3.8: *Thinking through Science* Lesson plan 4; Acids and Bases

Experimental Time-frame

The sequence and testing timetable for the three *Thinking Science* programmes is shown in Figure 3.9. The *Thinking through Science* programme is the final in the series and was implemented in the 2nd year of the three year Junior Certificate cycle.

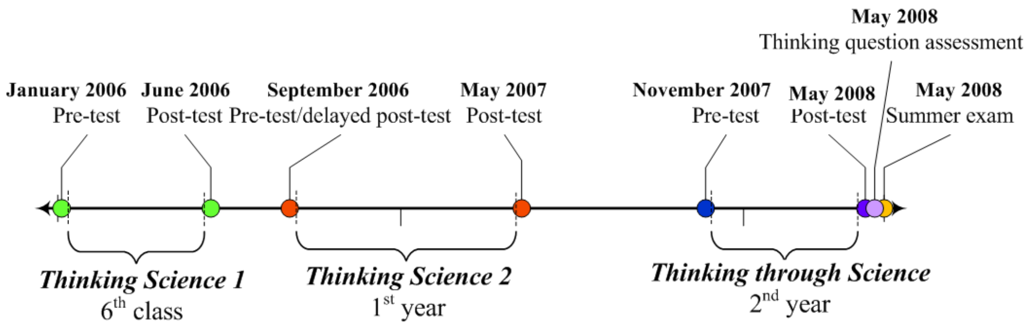


Figure 3.9: **Timeline of *Thinking Science* programmes implemented over the three years**

In order to assess the effectiveness of the *Thinking through Science* programme Science Reasoning Tasks [32] were used before and after the intervention to gauge any cognitive development. The schedule for pre- and post-testing is shown in Figure 3.9. In addition the students did their summer examination and answered thinking questions, based on concepts taught through the programme at the end of the year.

3.3 Evaluation of the *Thinking through Science* programme

3.3.1 Cognitive development

As a means of evaluating the effectiveness of the *Thinking through Science* programme both the non-intervention and intervention groups' cognitive levels were tested before and after the implementation of the programme. The SRTs selected for use were Task IV and VII. The details of these tasks are discussed below.

- Pre-test

Task IV, *Equilibrium in the balance* (Appendix A), was used to gauge the initial cognitive levels of the sample, prior to the commencement of the programme. This task was previously used in the evaluation of the *Thinking Science 2* programme. It was hoped to use Task V, *The inclined plane* or Task VI, *Chemical combinations* but as they were out of print it was decided to use Task IV. It was suitable to re-use this task as no answers of the task were given and student's performance would not have been affected or they would be at no advantage having done the task before. In addition, the task was been used over eight months after it was first conducted with the students, so it was reasonable to assume that the details of the task were forgotten by the students.

The task was suitable as a pre-test as it covered a range from late concrete (2B) to late formal operational thought (3B). The task assessed student's ability to recognise and use inverse proportions in the context of a simple balance beam. Most of the questions were pitched at the concrete and early formal levels, with late formal operational thought being assessed towards the end of the task.

The Cronbach Alpha co-efficient for Task IV in this study was found to be 0.7.

- Post-test

Task VII, *Flexible Rods* (Appendix A) was used as a post-test to determine the student's cognitive levels after the intervention was complete. This task was based on the work of Inhelder and Piaget in *The Growth of Logical Thinking* [38]. The task investigates the ability of student's to sort out the effects of variables which affect the flexibility of rods made of different metals. In particular the task tests the student's strategy for controlling variables when conducting experiments and their deductive reasoning. Towards the end of the task the ability of the students to manage variables that act in opposite directions to compensate for each other is investigated. The apparatus used in the task is shown in Figure 3.10.

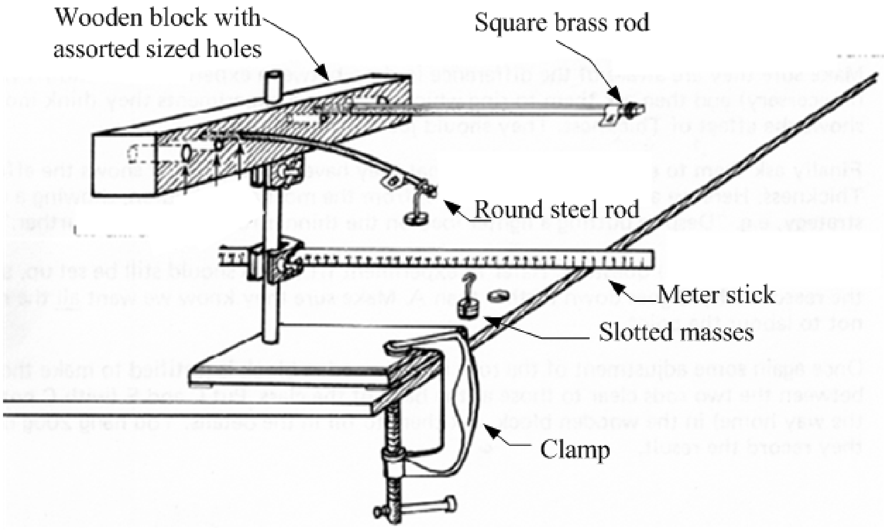


Figure 3.10: **Labeled diagram of apparatus used in Task VII *Flexible rods* (taken and adapted from [32])**

Question 3 of the task, as shown in Figure 3.11, is a late concrete question (2B) assessing the student's ability to identify the effect that various variables have on the flexibility of rods. Question 10, as shown in Figure 3.12 is a late formal operational (3B) level question and demands the student's ability to handle variables which act in the opposite directions to compensate for each other, or reciprocity as termed by Piaget.

3.	Give all the reasons why C goes down further than A ....
	....

Figure 3.11: **Task VII *Flexible rods* Question 7 [32]**

The Cronbach Alpha co-efficient for Task VII in this study was found to be 0.8.

10. If a ROUND steel rod and a SQUARE steel rod, of equal length with equal weights, drop the same, what can you say about them ?

....

Figure 3.12: **Task VII *Flexible rods* Question 10 [32]**

3.3.2 Summer examination

Each of the five schools provided their own end-of-year examination and so the summer tests were not standardised. The general structure of the summer science examinations were similar to Junior Certificate science questions, and were mostly recall questions. Each student's result of the summer test was obtained and while no direct conclusions could be drawn from the results, interesting comparisons could be made between intervention and non-intervention classes in each school. However, this examination was not considered as a sufficient measure of the level of understanding that the students achieved in the topics covered.

3.3.3 Thinking questions

The same topics were taught to non-intervention and intervention groups in each school during this period and in essence the questions were designed to assess the student's understanding of the concepts covered via the *Thinking through Science* programme or the normal/non-intervention method of instruction. The idea was that the questions were not simply re-call questions but rather they were designed to assess understanding of the scientific concepts. The questions assessed students' conceptual understanding in five areas, namely moments, pressure, density, acids and bases and conservation. The questions were matched to a cognitive developmental level according to Adey and Shayer's Curriculum Analysis Taxonomy [1]. The content of the questions was not explicitly covered in the *Thinking through Science* classes.

The questions were designed to incorporate features of the two-tier diagnostic tests developed by Treagust [174] in order to identify and evaluate students' scientific misconceptions in specific content areas. The design of Treagust's tests involved three main stages. The first stage involved the identification of the specific scientific content area to be questioned. The next stage involved identifying students misconceptions in that specific area, either through literature or interviews with students and lastly the development of multiple choice two-tier items. The first tier of the item involves a response, while the second tier requires a reason for the response, both multiple-choice items. The second tier of questions was developed for each item based on students' reason for their choice as well as information gathered at interview.

The Thinking questions devised for this study were designed using elements of this two-tier strategy. The first tier was presented as a scenario on a particular concept on the topics taught. There were a set of multiple choice answers, including one correct answer, one wrong answer, one answer with an identified misconception and then a fourth option, for example 'I cannot tell' or 'Other'. The second tier of the conceptual questions was an open-ended question where students, in their own words, define or describe their reasoning for their choice of answer. This is the difference between the method described by Treagust and also used by Tobin and Capie [175]. The method employed in this study allowed the open-ended question to be categorised as displaying correct understanding of the concept or identifying student's misconceptions. These were classified for the purpose of analysis.

The questions for each of the concepts are described below and they are included at the end of this section;

- Conservation

This question does not explicitly cover any of the topics addressed in the programme but the question does assess early formal operational thought in one of the 'schema' required for the understanding of science, i.e., conservation. This question, as shown in Figure 3.13 asks students to compare what would happen to metal and plasticine dice (same volume but different weight) when placed in containers of water. According to Adey and Shayer [1] children realise that 'the volume of a liquid displaced by a body does not depend on its weight' at the early concrete (3A) stage. As in all of the questions the level of understanding that the student has of the concept is measured from the explanation of their choice.

- Pressure

The question, shown in Figure 3.14 tests understanding of the 'pressure is treated as force per unit area' concept, which according to the curriculum analysis taxonomy is also a concept that requires early formal (3A) operational thought.

- Pressure in Liquids

The question assessing students' conceptual understanding of pressure in liquids is shown in Figure 3.15. The concept tested in this question is that of 'pressure in liquids increases with depth'. Adey and Shayer define this concept as one acquired at the late concrete (2B) stage.

- Density

This question, shown in Figure 3.16, is classified as a late concrete (2B) question. At this stage, according to the taxonomy children have an understanding that a large and small piece of a substance, for example plasticine will sink, because it is made out of the same material, and essentially they have 'the same heaviness'.

- Acids and Bases

Figure 3.17 shows the conceptual question on acids and bases. At the 2B level students have an understanding that neutralisation will occur when equal quantities of equivalent solutions of acid and alkali are mixed. They also understand that if you double the quantity or concentration of acid you will need twice the quantity of alkali. In order to correctly answer this question both of these concepts need to be consolidated and understood.

- Moments

Figure 3.18 shows the questions on moments. In this question there are two independent variables (i.e., mass and position on the see-saw) and in order for the student to be able to find the effect of each of the variables they must use a control of variables strategy [1]. This requires early formal (3A) operational thought.

3.3.4 Conclusion

In order to increase the use of the CASE methodology at second level, the *Thinking through Science* programme was developed. This involved embedding the existing CASE methodology into 2nd year science topics, in order to increase the cognitive development of students. The main features used to develop the programme were the pillars of CASE, the Curriculum Analysis Taxonomies, the Junior Certificate Science curriculum and Piaget's schemata of formal operations. The results of this programme on students' cognitive development are discussed in Chapter 4.

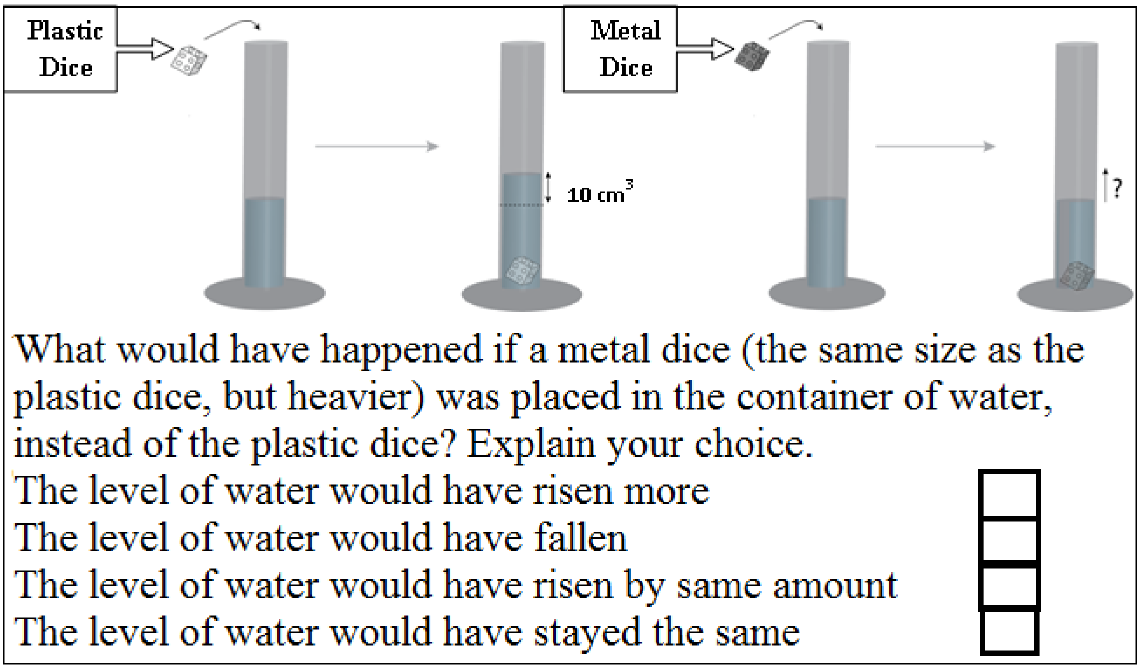
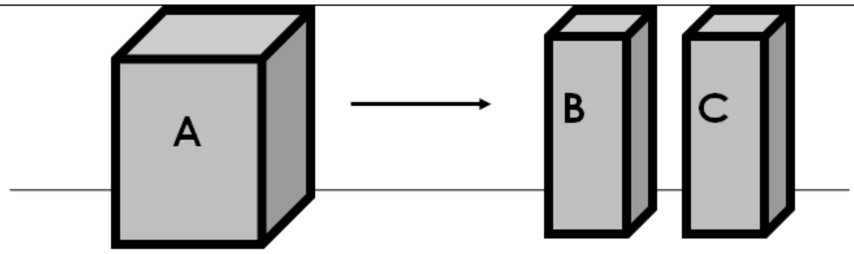


Figure 3.13: **Thinking question: Conservation**

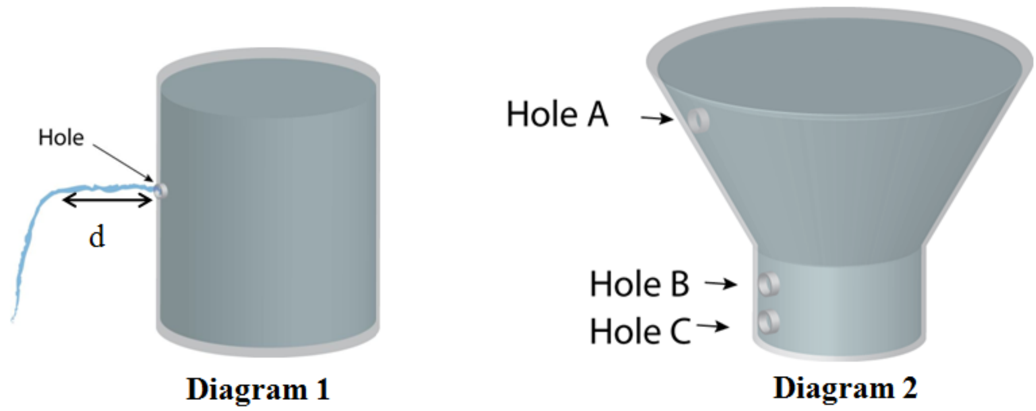


A solid wooden block exerts pressure on a soft lino floor. The solid block A is cut in half to make blocks B and C.

Does block B exert more pressure than the original block A? ☐
Does block B exert the same pressure as the original block A? ☐

Figure 3.14: **Thinking question: Pressure**

When a hole is drilled into a container full of water, the water flows a distance, "d" from the container, as shown in Diagram 1.

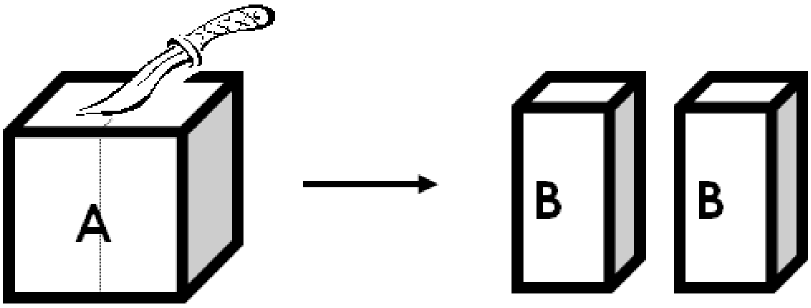


In diagram 2 when the container is full, the distance the water flows out of hole A is;

Greater than the distance of the water flowing out of hole B ☐
Equal to the distance of the water flowing out of hole B ☐
Less than the distance of the water flowing out of hole B ☐
Other ☐

Figure 3.15: **Thinking question: Pressure in liquids**

Block A is made of steel. It is cut in half to make 2 blocks the same size as B.



Select and explain your choice of answer.

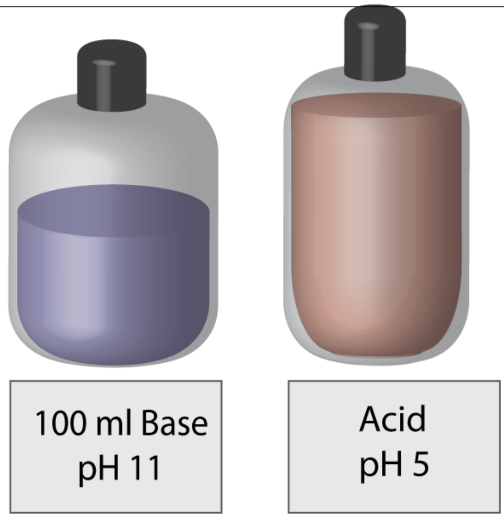
(i) A is more dense than B ☐

(ii) A is less dense than B ☐

(iii) A and B have the same density ☐

(iv) I cannot tell ☐

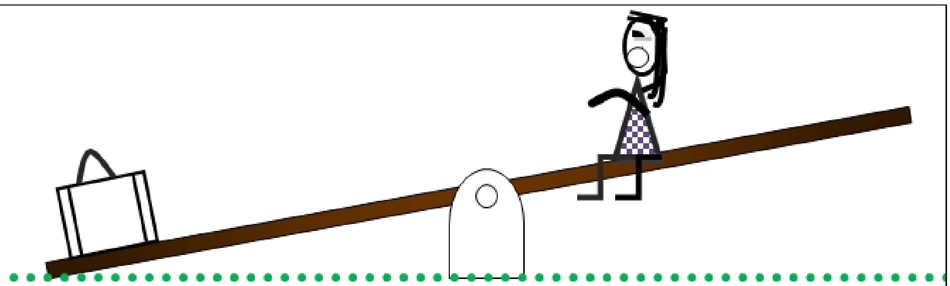
Figure 3.16: **Thinking question: Density**



Would you add more or less than 100 ml of the acid to the basic solution in order to neutralise it? Tick your choice and explain your reasoning.

☐ More than 100 ml ☐ Less than 100 ml

Figure 3.17: **Thinking question: Acids and Bases**



1. Why is the see-saw tilted? (Give all the reasons)

2. Select and explain your choice.
   (i) The bag is heavier than the girl
   (ii) The bag is lighter than the girl
   (iii) The bag and the girl are the same mass
   (iv) I cannot tell.

3. Explain what the girl could do in order to make the see-saw balance.

4. Explain why the action described in (3) will balance the see-saw.

Figure 3.18: **Thinking question: Moments**

Chapter 4

The Results of the *Thinking through Science* programme on Students' Cognitive Development and Examination Performance

Introduction

This chapter has three sections. The first section contains the profile of Piagetian levels of the 2nd year students. The second reports the results of the programme on students' cognitive development. The second chapter reports results from intervention and non-intervention students' performance in summer examinations and tests assessing conceptual understanding. Also correlations with the LASSI survey are reported.

4.1 Results of the *Thinking through Science* programme on students' cognitive development

As there were several combinations of students in the cohort who received the interventions, the data was analysed in three sections. The cohort that only received the *Thinking through Science* intervention was analysed first and compared with the non-intervention group, i.e., the group that received no intervention in any of the stages. The group that received all the *Thinking Science* programmes was then analysed and this was followed by the group that did only one of the respective programmes. The analysis aims to give a clear picture of the effectiveness of the *Thinking through Science* programme and the background required for its success or otherwise on cognitive development. However, initially the profile of the Piagetian levels of the 2nd year students were analysed.

4.1.1 Profile of Piagetian levels of 2nd year students in second level

As an initial step, the pre-test, Task IV (*Equilibrium in the balance*) was carried with all the 2nd year students. This served as a tool to determine the cognitive levels of the students before any intervention began and to determine a profile for the 2nd year students. The Piagetian levels of the total cohort of students, including all those who have completed the previous interventions, are displayed in Figure 4.1. These levels represent a stage of cognitive development characteristic of certain age-groups, as shown in Table 4.1.

Table 4.1: **Age/stage picture (taken from [25])**

Piagetian level	**Symbol**	**Age**
Early concrete	2A	5/6
Mid concrete	2A/2B	7/9
Late concrete	2B	10/11
Early formal	3A	11/13
Late formal	3A/3B	14/15

In total there were 199 students who completed Task IV. The average age of the students at time of testing was 14 years and 2 months. It can be seen from Figure 4.1 that the majority of this 2nd year group are at the mature concrete stage (2B), the typical stage of a 10/11 year old, in the view of Piaget. There is an approximate equal percentage (44 percent) of students at the concrete generalisation stage (2B*). Perhaps the most striking feature of these results is that little over ten percent of the cohort display formal operational thinking (3A). The age/ stage picture presented by Piaget suggested that by the age of 14/15 years adolescents would display mature formal thinking (3A/3B). Within the sample represented here just over 2 percent of the cohort display this type of thought. With many concepts in second level science requiring competency in formal operational thought, this picture implies that 2nd year students are not at a cognitive developmental level required to understand Junior Certificate science.

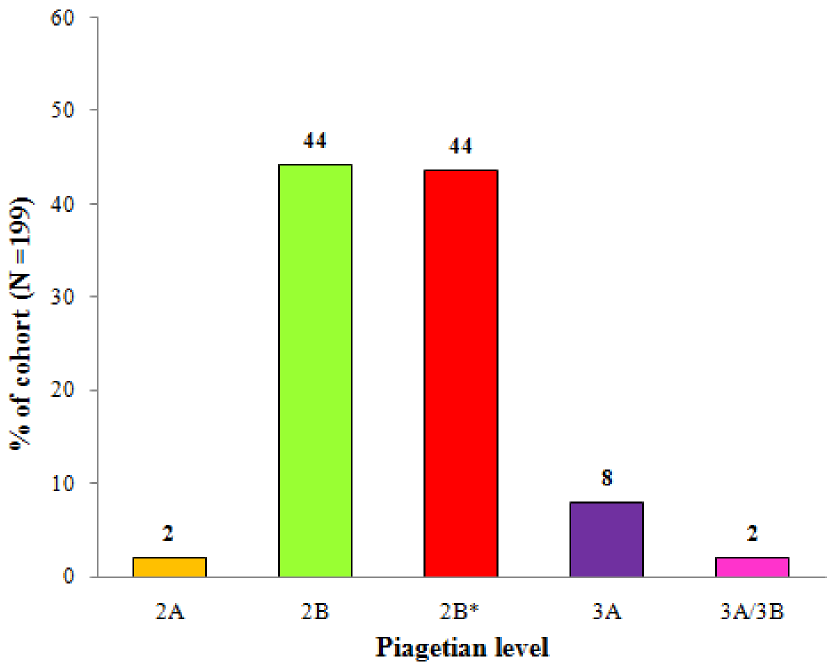


Figure 4.1: **Piagetian level profile of 2nd year group at time of pre-test (Entire group)**

The Piagetian level picture among the genders is shown in Figure 4.2. There was statistically no difference in the Piagetian levels of the female and male cohorts at this stage, (t(198)= 0.81, $p > 0.05$). The chart shows that the majority of the female sample are at the 2B level (48 percent) while the majority of males (51 percent) are at the 2B* level. In terms of the numbers at the formal operational levels it appears that the female cohort narrowly overtakes the males by just over 1 percent in each case.

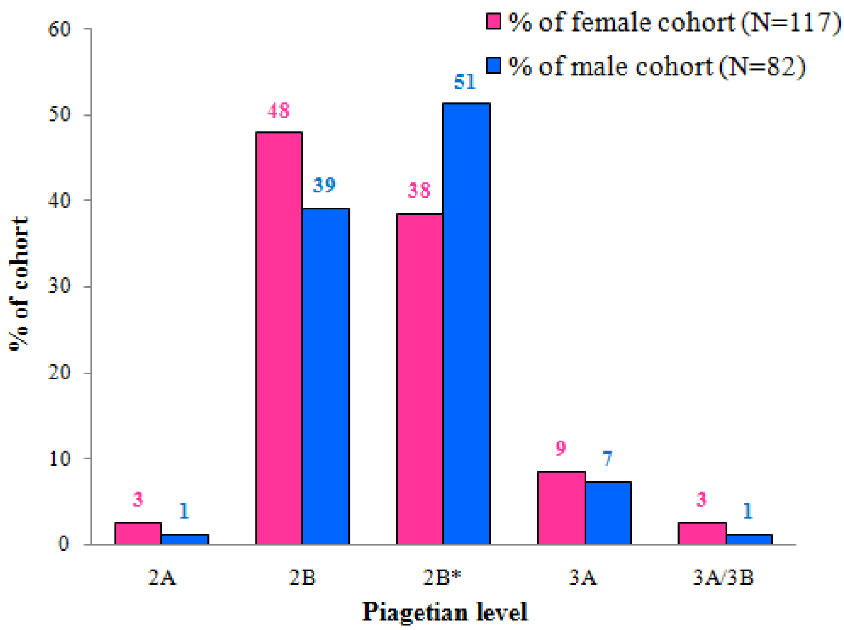


Figure 4.2: **Piagetian level profile of 2nd year male and female group at time of pre-test**

However, this group contained the individuals that received part or whole of the *Thinking Science* interventions in primary school or 1st year at second level. In order to gain a more accurate picture of the 2nd year students in second level education, it was necessary to remove all of the cohort that were part of the *Thinking Science* intervention groups. The following results are reported for this group, that comprised of neither the *Thinking Science 1* or *Thinking Science 2* intervention cohorts, unless otherwise stated.

This group's Piagetian levels are shown in Figure 4.3. Essentially the same picture is portrayed but some difference can be noticed. For example as Figure 4.1 shows there are 10 percent of the sample at the early formal operational levels (3A and 3A/3B). However, when the group that have received the intervention programme are removed from the sample the percentage at these formal levels decrease to 8 percent, as shown in Figure 4.3. There is a slight increase in the percentage of students at the early concrete (2B) operational level in this cohort.

Figure 4.4 shows the cognitive levels of the 2nd year group, based on gender, excluding the students who were taught through the *Thinking Science 1* and *2* programmes previously. As the figure implies the male cohort appear to have the higher cognitive developmental levels, with greater percentages towards the formal operational levels (3A and 3A/3B). The majority of males (55.5 percent) are at the concrete gener-

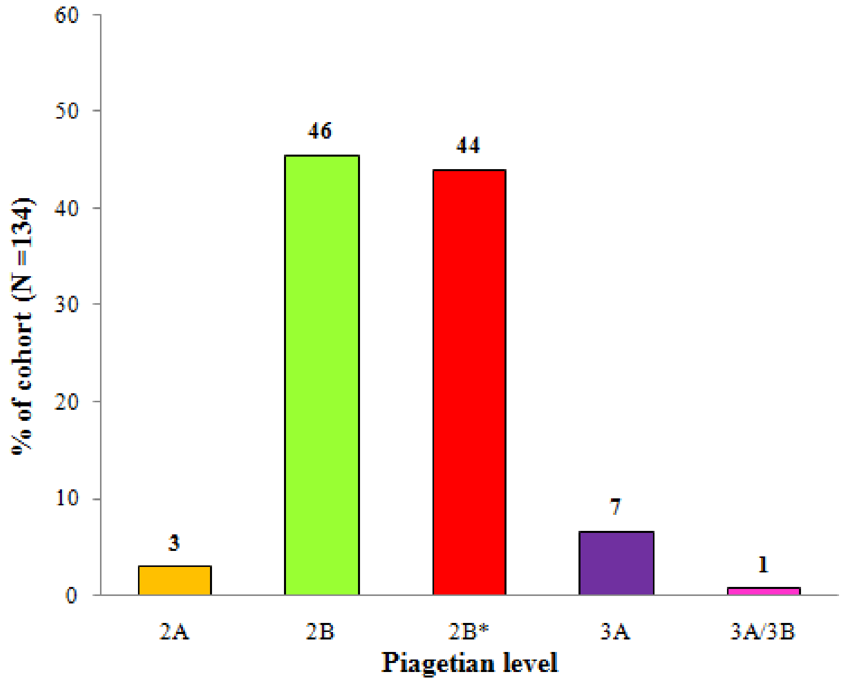


Figure 4.3: **Piagetian levels of 2nd year group (students who were part of the *Thinking Science 1* and *2* intervention groups have been omitted)**

alisation (2B*) stage, compared with the majority of females at the concrete level (54 percent). The difference between the groups is also evident at the early formal (3A) level. 11 percent of males are at this level, compared with just over 4 percent of the female cohort. Just 2 percent are at the late formal level, and these are part of the male cohort. There was a statistically significant difference in the pre-test cognitive levels of the male and female groups. The cognitive level of the male group was slightly higher and the difference was significant (t(132)=2.84, $p < 0.05$). The magnitude of this difference was moderate (η^2=0.06).

Figure 4.5 was used to match the Irish and UK sample cohorts. The X marks on the figure show how the points on the chart from which Table 4.2 was generated.

Table 4.2 shows the proportions of the children, at the approximate age of 14.2 years, at the different Piagetian stages in the British population and the Irish students in this study. It can be seen that the proportion sample from this study had levels, at the pre-test stage, that were comparable but lower than the original British population survey. Furthermore, the average age of the sample was 14 years and 2 months. At this age, according to Piagetian theory, students should be at the mature formal (3B) stage. However, the case for both the British and Irish cohorts appear different. The stark contrast implies that within the British sample population just

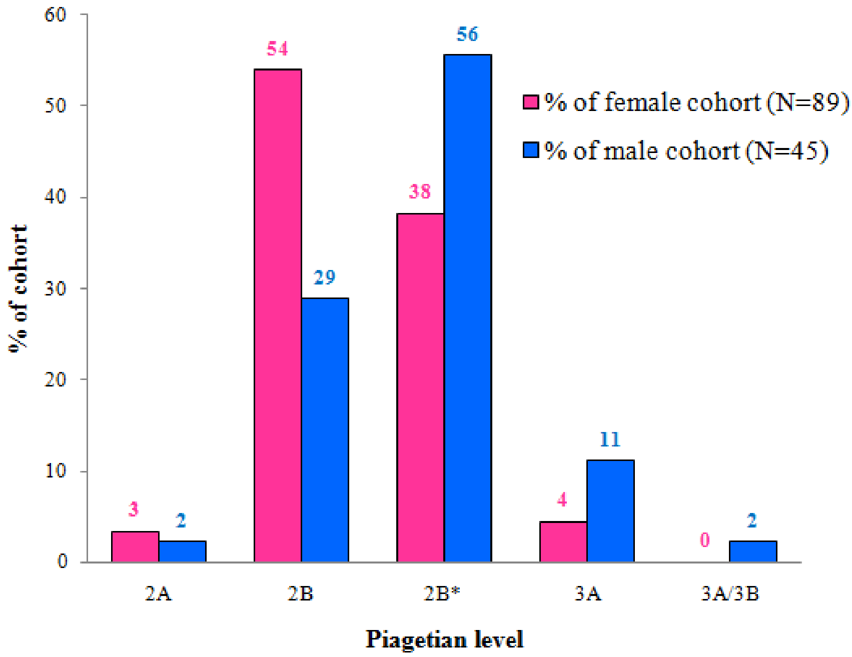


Figure 4.4: **Pre-test Piagetian levels of 2nd year male and female groups in 2nd year group (without students who were part of the *Thinking Science 1* and/or *2* programmes)**

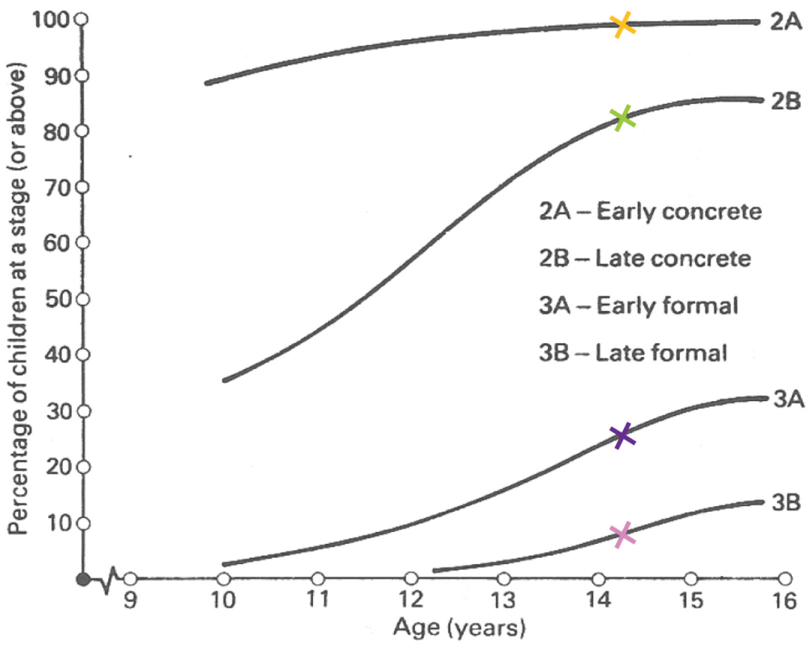


Figure 4.5: **Proportion of children at different Piagetian stages in the representative British child proportion (taken and adapted from [1])**

37 percent have acquired formal operational thought. However, in the Irish cohort less than 10 percent of the 14 year olds are at the formal operational level.

Table 4.2: **Approximate proportion of British and Irish children (* based on data from this study) (14.2 years) at respective Piagetian levels**

Piagetian level	**Approximate proportion at stage in British child population (14.2 years) [1]**	**Extrapolated proportion of Irish children at stage* (14.2 years)**
At 2A or above	100 percent	100 percent
At 2B or above	83 percent	97 percent
At 3A or above	28 percent	7.5 percent
At 3B or above	9 percent	>1 percent

Figure 4.6 shows the distribution of Piagetian levels over the three main age groups of students. There is very little apparent difference between the 13-14 years and 14-15 years age group. Both approximately occupy the same developmental level. The difference begins to appear in the 15-16 year age group with lower numbers appearing at the concrete stages and a shift towards the formal operational level. However, it must be noted that the sample number is much smaller for this age group which makes it difficult to comment with certainty.

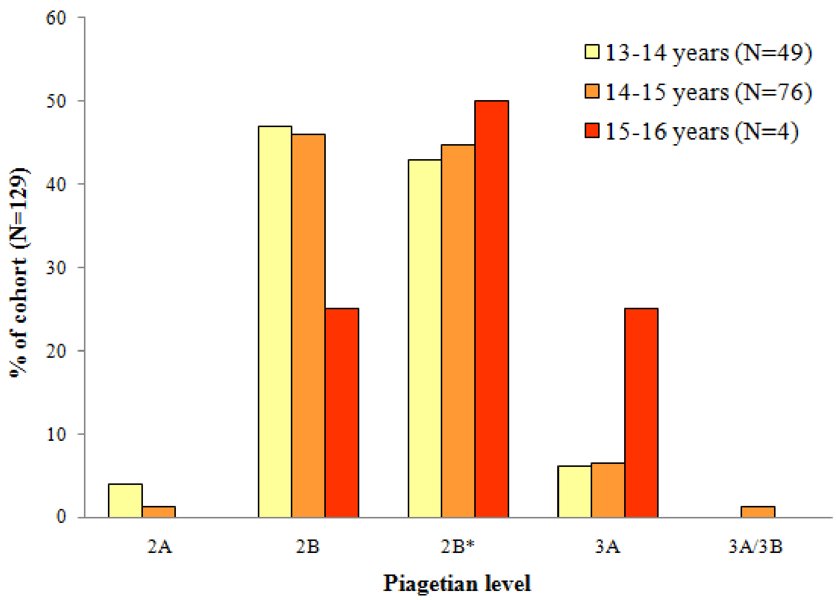


Figure 4.6: **Pre-test Piagetian levels of the 2nd year group (without *Thinking Science 1* and/ or *Thinking Science 2* intervention groups), based on age**

4.1.2 Method of analysis and results of the *Thinking through Science* programme in 2nd year

Method of Analysing Results

The effectiveness of this programme was measured by pre- and post-test, which assessed students' Piagetian level. In addition, the effect of the intervention on students' terminal examination performance and performance in questions requiring conceptual understanding were assessed and will be discussed in Section 4.2.

The results in this section are reported in the following way. Firstly the pre-test scores of the intervention and non-intervention groups are compared to assess if there was any initial differences between both groups at the start of the study. The effects of the intervention are discussed in terms of change of cognitive levels and mean scores of cognitive tasks between the time of pre- and post-test. However, a basic comparison of means was not seen as sufficient and so Residual Gain Score analysis was also carried out. The method of this analysis is discussed below. In addition the results are reported in terms of effect sizes, a technique which reports the difference between the mean post-test scores of the intervention and non-intervention groups, in terms of the standard deviation of the non-intervention group. Due to the complex nature of the study it is first necessary to discuss the sample numbers in this part of the study.

Sample numbers

In order to gain greater insight into the effectiveness of the intervention programme *Thinking through Science*, it was first necessary to consider the backgrounds that each of the students came from. Cohorts of the intervention and non-intervention groups came from primary schools that did the *Thinking Science 1* programme and 1st year second level classes where the *Thinking Science 2* programme was implemented. Others did only one of the intervention programmes, either *Thinking Science 1*/*Thinking Science 2*, while other cohorts were in the non-intervention groups in both cases. A selection of students were not part of either the intervention or non-intervention group until this phase of the study. Figure 4.7 displays the number of students that participated as part of the intervention group for the *Thinking Science 1* (6th class) programme, the *Thinking Science 2* programme and the *Thinking through Science* programme, and all other possible combinations of programmes. Overall there were 133 students who were taught through *Thinking through Science*. 44 of these students were also taught through the *Thinking Science 2* programme. 5 students were taught through both the *Thinking through Science* and the *Thinking Science 1* programme at primary level. There were only 11 students who received all three *Thinking Science* programmes, over the three years of the study.

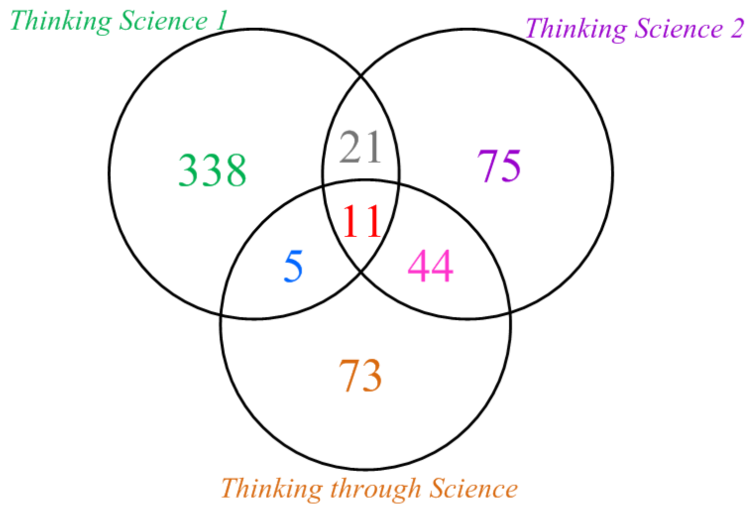


Figure 4.7: **Number of students in the intervention group of the three *Thinking Science* programmes and their respective combinations**

Comparing the intervention and non-intervention groups, at pre-test stage

In order to assess if there was an initial statistical significant difference between the non-intervention and intervention groups, an independent t-test was performed on the samples. As can be seen in Table 4.3 the mean for the intervention group (M=3.99, SE=0.25) was higher than that of the non-intervention group (M=3.46, SE=0.18). However, this difference was not significant (t(121.6)=-1.67, $p > 0.05$) and essentially the two groups were classified as being at the same cognitive developmental levels, at the pre-test stage.

Although there was no significant difference between the non-intervention and the intervention groups at the beginning of the programme, there were differences evident within the intervention group itself. As highlighted in the previous section,

Table 4.3: **Pre-test means for non-intervention and intervention groups**

Group	**N**	**Pre-test mean**	σ
Non-intervention	66	3.46	1.50
Intervention	68	3.99	2.09

there was a statistically significant difference between the pre-test cognitive levels of the male and female gender groups. As Table 4.4 shows, the mean score of the male group (M=5.07, SE=0.38) was higher than that of the female group (M=3.23, SE=0.28). This difference was statistically significant (t(66)=3.96, p=0.00).

Table 4.4: **Pre-test mean score for gender groups**

Group	**Gender**	**N**	**Pre-test mean**	σ
Non-intervention	Male	17	3.59	1.70
	Female	49	3.42	1.44
Intervention	Male	28	5.07	2.02
	Female	40	3.23	1.80

Pre- and post-test cognitive levels

The tests used to assess the changes in cognitive development were two from the series developed by the CSMS team [32]. Task IV, *Equilibrium in the balance* was used as the pre-test in this study. Task VII, *Flexible rods*, was used as a post-test. Both assess competency in formal operational thought. This and subsequent analysis required the students to complete both the pre- and post-tests. Figures 4.8 and 4.9 show the numbers of the students in the non-intervention and intervention groups and the numbers of those eliminated from the analysis. In total, 28 students in the non-intervention group and 14 in the intervention group did not complete both tasks and so the data for these students was eliminated. The non-intervention group in School 7 had to drop out of the study due to time constraints, which explains the large drop-off in numbers in the non-intervention group.

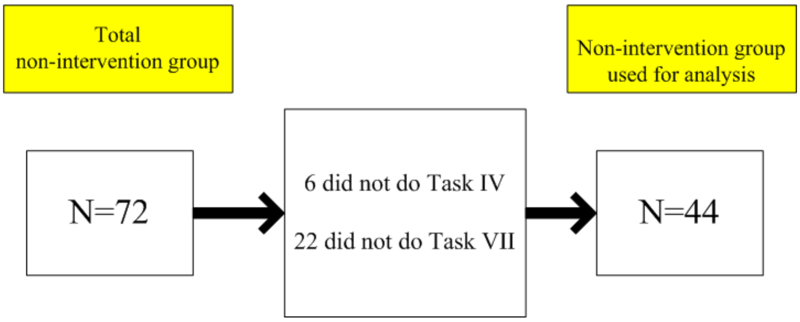


Figure 4.8: **Numbers of students in 2nd year non-intervention group**

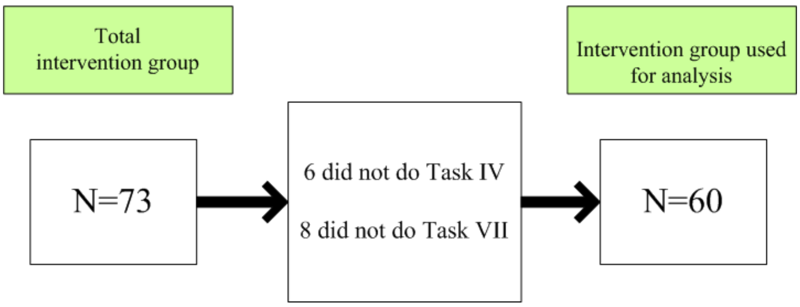


Figure 4.9: **Number of students in 2nd year intervention group**

Table 4.5 shows the mean pre-test and post-test scores for the non-intervention and intervention groups. There was no statistically significant difference at the pre-test stage (t(101.54)= -1.04, $p > 0.05$). However, the intervention group had a greater mean post-test score (M= 9.45, SE=0.41) compared to the non-intervention group (M=4.30, SE=0.36). There was a statistically significant difference between the two groups (t(101.89)= -9.43, $p < 0.01$).

Table 4.5: **Pre- and post-test mean scores of non-intervention and intervention groups**

Group	**N**	**Pre-test mean score**	σ	**Post-test mean score**	σ
Non-intervention	44	3.72	1.46	4.30	2.40
Intervention	60	4.08	2.15	9.45	3.17

Piagetian level analysis

The first crude step of analysis involved analysis of the Piagetian levels, determined from the pre- and post-tests. Figure 4.10 and 4.11 show the Piagetian levels of the intervention and non-intervention groups, respectively.

It is clear from initial inspection that the intervention group made a greater shift towards formal operational thought, towards the right hand side of the chart. The greatest increase in level in the intervention group was at the early formal (3A) level where at pre-test, 12 percent occupied this level. At the time of post-test 32 percent were at this level. At pre-test just under 50 percent of the cohort occupied the 2A and 2B concrete levels, but by the time of post-test all these students had moved to concrete generalisation (2B*) or the formal operational levels.

In the non-intervention group, the progress of the sample was not so convincing, when compared with the intervention group. The majority of the cohort at the time of pre-test (59 percent) were at the concrete generalisation stage but this majority (52 percent) at the time of post-test was back at the late concrete (2B) level. There was no significant change at the early formal (3A) level or beyond. It is clear from both charts that the intervention group made the greatest increase in cognitive developmental level over the period of the *Thinking through Science* intervention.

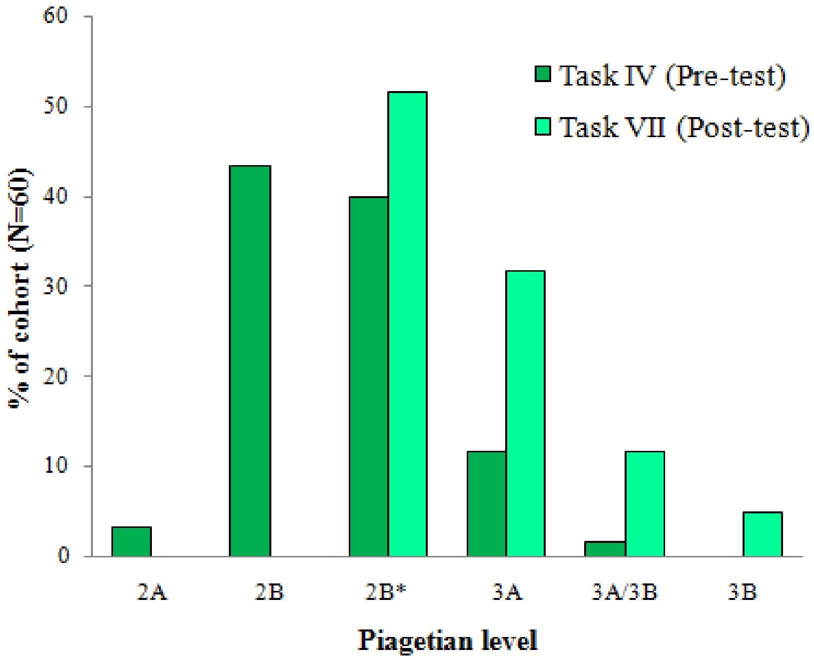


Figure 4.10: **Piagetian levels of intervention group at pre- and post-test**

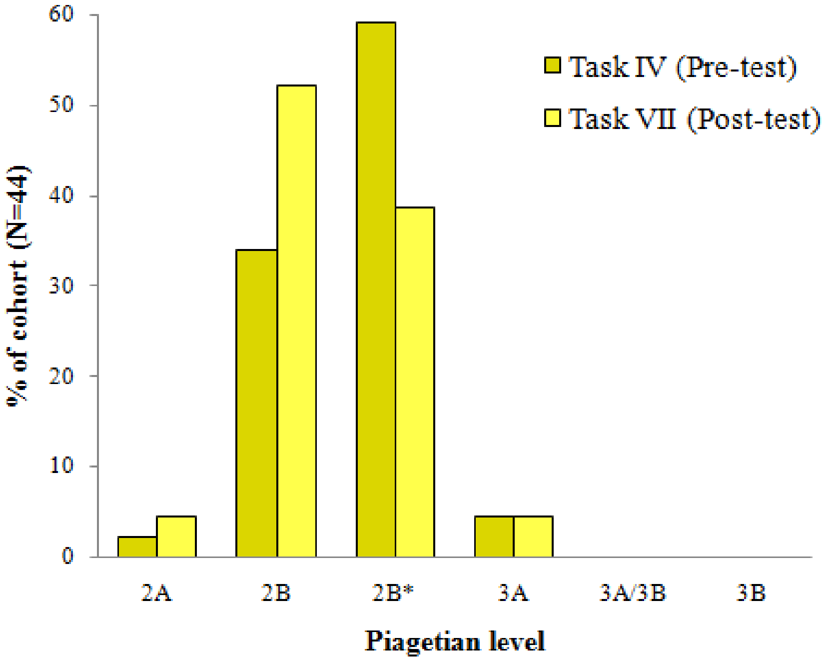


Figure 4.11: **Piagetian levels of non-intervention group at pre- and post-test**

The degree of change in levels can be seen in Figure 4.12. This was done by counting every student's progress/regress from the pre-test to the post-test, in terms of their Piagetian sub-level. If, for example, a student attained a 2B level in Task IV and a

2B* in Task VII, they were ascribed as +1, representing a gain of one sub-level. If a pupil was at the 2B* level at pre-test and 3A/3B at post-test there were ascribed as +2, i.e., gaining two levels, and so on.

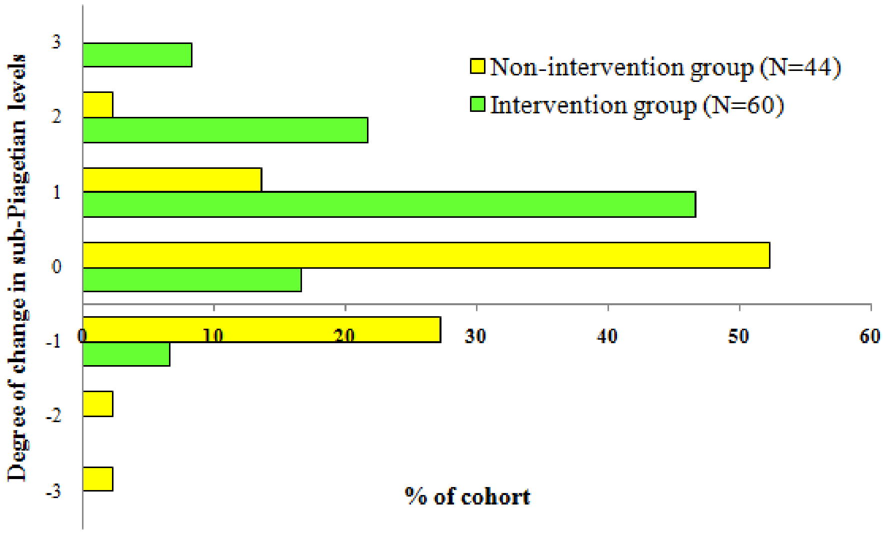


Figure 4.12: **Degree of change in Piagetian sub-levels of 2nd year non-intervention and intervention groups**

As Figure 4.12 shows, there is a striking difference between the number of students in the non-intervention and intervention groups that made no change in cognitive level over the course of the intervention programme. Almost 17 percent of the intervention group made no change compared with 52 percent of the non-intervention group. Furthermore, the difference in the numbers that increased one sub-level was quite high. Almost half (47 percent) of the intervention group increased one level, compared with 14 percent of the non-intervention group. There was a difference of almost twenty percent of students in the intervention and non-intervention groups that increased two sub-levels. It is also worth noting that the percentage of the non-intervention group that decreased by one sub-level was much higher than for the intervention group. It is difficult to identify specifically what the cause of this decrease was but one possible explanation is the failure of the second level system to cognitively stimulate and enhance the development of these students, in the non-intervention group. The main differences between the intervention and non-intervention groups was the intervention programme itself, so it is reasonable to suggest that the intervention programme had positive effects on the students' cognitive development.

The percentage of students in each class at the respective Piagetian levels at the pre-and post-test stages is shown in Table 4.6. In the case of School 2 for example there is a greater shift towards the formal operational level of thought for the intervention group (E) from the pre- to post-test stages, compared with the non-intervention group (C). These trends are also present in the cases of Schools 6, 7 and 8.

Table 4.6: **Percentage of students in each class, intervention (E) and non-intervention (C), at respective Piagetian levels, at pre- and post-tests**

			2A		**2B**		**2B***		**3A**		**3A/3B**		**3B**	
Class	**E/C**	**N**	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
2.2.1.1	E	16	0	0	38	0	44	56	19	25	0	13	0	6
2.2.2.1	C	21	0	5	33	43	67	48	0	5	0	0	0	0
5.2.1.1	E	14	0	0	14	7	36	43	36	36	14	14	0	0
5.2.2.1	C	14	0	0	50	50	43	43	7	7	0	0	0	0
6.2.1.1	E	13	0	0	31	31	62	54	8	8	0	8	0	0
6.2.2.1	E	17	0	0	53	47	41	53	6	0	0	0	0	0
7.2.1.1	E	19	11	0	74	0	16	68	0	32	0	0	0	0
7.2.2.1	C	18	6	n/a	61	n/a	33	n/a	0	n/a	0	n/a	0	n/a
8.2.1.1	E	27	0	0	33	0	52	33	11	37	4	19	0	11
8.2.2.1	C	15	7	0	27	73	60	27	7	0	0	0	0	0

Effect sizes

The effect size of the *Thinking through Science* programme was calculated using Equation 2.2, described in Chapter 2. The effect size for the *Thinking through Science* programme on the entire group was very large, with a value of 1.74 σ.

Residual Gain Score (RGS) analysis

Adey and Shayer [25] used this method of analysis to predict subsequent academic success from the scores of SRTs. In this study RGS analysis was used to predict post-test scores of the intervention group, based on the actual pre- and post-test scores of the non-intervention group. The regression line used in this analysis is shown in Figure 4.13.

In this part of the study the non-intervention group was composed of all the students who did both the pre- and post-tests and that never received any form of the *Thinking Science* interventions. The intervention groups had many variables. There were five cohorts who received different combinations of the three intervention studies.

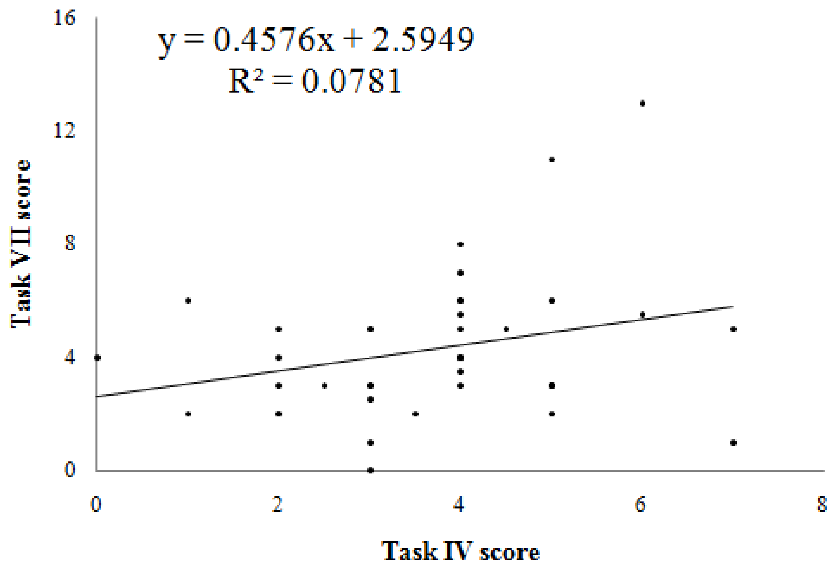


Figure 4.13: **RGS plot of 2nd year non-intervention group**

To begin, the first data discussed is that of the group that were taught through the *Thinking through Science* intervention only.

The mean RGS values of the intervention and non-intervention groups are shown in Table 4.7. The intervention group had the greatest mean RGS (M=4.99, SE=0.39) compared with the non-intervention group (M=0.00, SE=0.35). The difference between the two groups, in terms of mean RGS, was statistically significant (t(101.79)=-9.54, p=0.00).

Table 4.7: **Task IV, VII and RGS means for non-intervention and intervention groups**

Group	**N**	**Mean Task IV score**	**Mean Task VII mean**	**Mean RGS**	σ
Non-intervention	44	3.72	4.30	0.00	2.31
Intervention	60	4.08	9.45	4.99	3.02

For both genders the intervention group attained greater mean RGS values than the non-intervention groups. In order to assess if the *Thinking through Science* programme had a greater effect on the male or female groups, Table 4.8 was compiled. The male group attained a higher mean RGS (M=5.66, SE=0.66) than the female group (M=4.43, SE=0.45). However, this difference was not statistically significant (t(58)= 1.59, p= 0.12). In conclusion, it can be said that there was no difference in the mean RGS values of the male and female groups within the intervention group.

However, prior to the intervention there was a significant difference between the pre-test scores of the male and female groups. The male cohort had a higher mean (M=5.07, SE= 0.40) than the female group (M=3.27, SE=0.33) and the difference between the means was significant (t(58)= 3.54, p= 0.00). At post-test stage there was also a difference between the scores among the gender groups. The male group yet again had a higher mean (M=10.57, SE=0.67) than the female group (M=8.53, SE=0.45) and this difference was also significant (t(58)=2.60, p=0.01).

Table 4.8: **Task IV, VII and RGS means for genders in intervention group**

Gender	**N**	**Mean Task IV score**	**Mean Task VII mean**	**Mean RGS**	σ
Male	27	5.07	10.57	5.66	3.40
Female	33	3.27	8.53	4.43	2.58

Figure 4.14 displays pictorially the mean RGS of the different combinations of groups that were taught science through the *Thinking Science* methodology at different levels. Due to the complexity of the sample there was a range of data which was analysed. To begin the largest mean RGS value appears to be for the group that did both the *Thinking Science 1* and *Thinking through Science* programmes, with a very large RGS of 6.8. Only 4 students did both of these programmes. It must be noted that the RGS calculated here is from the responses to Task IV and Task VII and hence presents the most recent findings of the students and their associated cognitive levels. The second highest mean is for the group who did *Thinking through Science* only and followed closely the group that were taught through all three programmes. Technically the RGS measures the gain from pre- to post-test but more findings may be found when other pre-tests used. The group to make virtually no gain in residual score is the non-intervention group throughout the study.

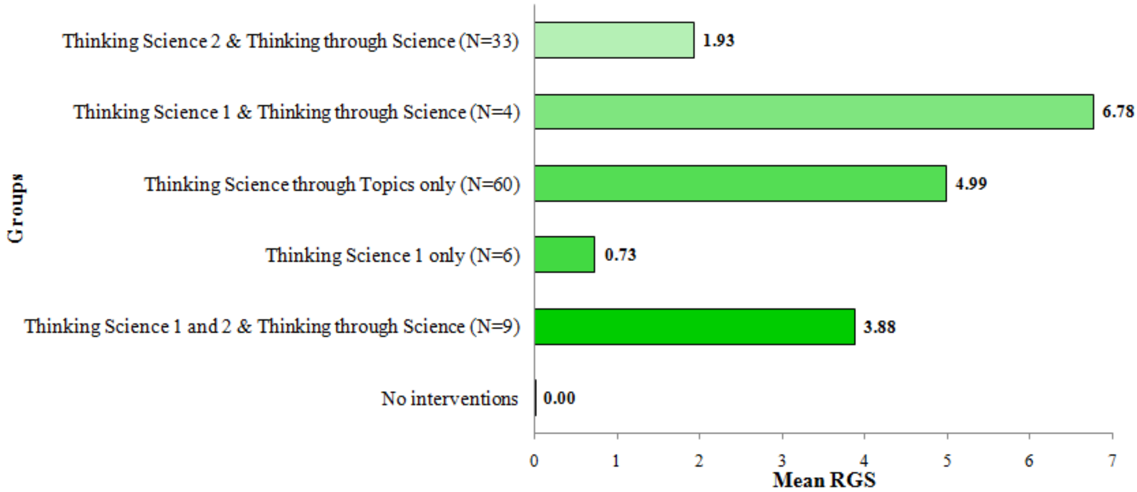


Figure 4.14: **Chart of mean RGS values for the combinations of *Thinking Science* programmes**

The *Thinking through Science* programme was implemented in six classes over the phase of the study. Four non-intervention classes were also part of this study. In order to gauge if there is a 'class-effect' it was necessary to analyse the RGSs within different class groups. Table 4.9 outlines the mean RGS for each of the class groups and their corresponding standard deviation (σ). It can be noted that on the table there are two RGS scores for each class grouping; one showing the RGS excluding the students that did *Thinking Science 1* and *Thinking Science 2* and the other data is inclusive of these groups. All the RGS data was computed from the cohort that have never been taught through any of the *Thinking Science* interventions. In some cases, for example school 6, the sample size is very low when all the other students were eliminated.

Figure 4.15 shows the mean RGS value of the class groups. In general from the class RGS values it can be said that the intervention classes made the greater gains. In total three school groups had mean RGS values greater than 4. One class group had a gain of 1.5.

Table 4.9: **Mean RGS values for intervention (E) and non-intervention (C) class groups**

School	Class code	E/C	N	Mean RGS (excluding *TS1* and *TS2*)	σ	N	Mean RGS (including all students)	σ
2	2.2.1.1	E	14	4.31	3.50	16	4.33	3.39
	2.2.2.1	C	21	0.15	2.05	21	0.15	2.05
5	5.2.1.1	E	-	-	-	14	4.07	2.98
	5.2.2.1	C	8	0.49	3.34	14	0.59	2.72
6	6.2.1.1 and 6.2.2.1	E	2	1.40	1.70	30	1.48	3.16
7	7.2.1.1	E	19	4.52	1.73	-	-	-
8	8.2.1.1	E	25	6.00	3.28	27	6.11	3.33
	8.2.2.1	C	15	-0.46	2.10	-	-	-

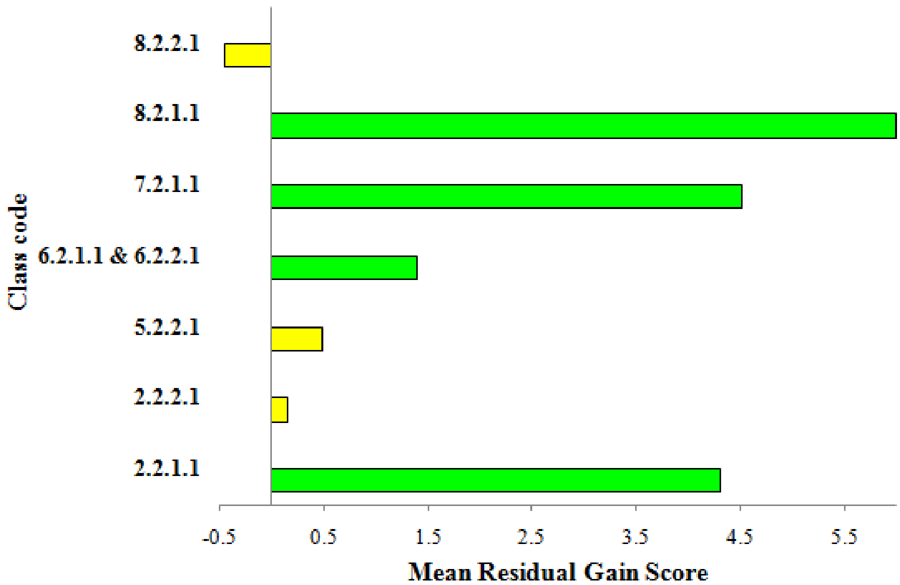


Figure 4.15: **RGS values of intervention (green) and non-intervention (yellow) 2nd year classes**

Bimodality

Adey and Shayer reported bimodality in the results of the original CASE experiment [25]. Bimodality was also a feature of the results in the *Thinking Science 1* programme. In order to investigate if bimodality was a feature of these results, the distribution of RGS values within the class groups was analysed. Figure 4.16 shows the distribution of the RGSs in the intervention class in School 2. The mean for this class was 4.3 and the figure shows that the majority have a RGS greater than 4. However, the other 50 percent of the group have an RGSs lower than that which ranged from 0 to 4. Figure 4.17 shows the distribution of the RGSs in the intervention class in School 5. The mean RGS of this class was 4.1. 43 percent of the students had an RGS greater than 4. 14 percent had RGS less than zero and the remainder had an RGS between 2 and 4. Figure 4.18 shows the distribution of RGSs in the intervention class in School 6. The mean RGS for this school is 1.5. 10 percent lie between 1 and 2. 44 percent are greater than 2, while 37 percent are less than zero. The results for this class appear to bimodal in nature. Figure 4.19 shows the distribution of the RGSs in the intervention class in School 6. The mean RGS value of this class was 6.1.

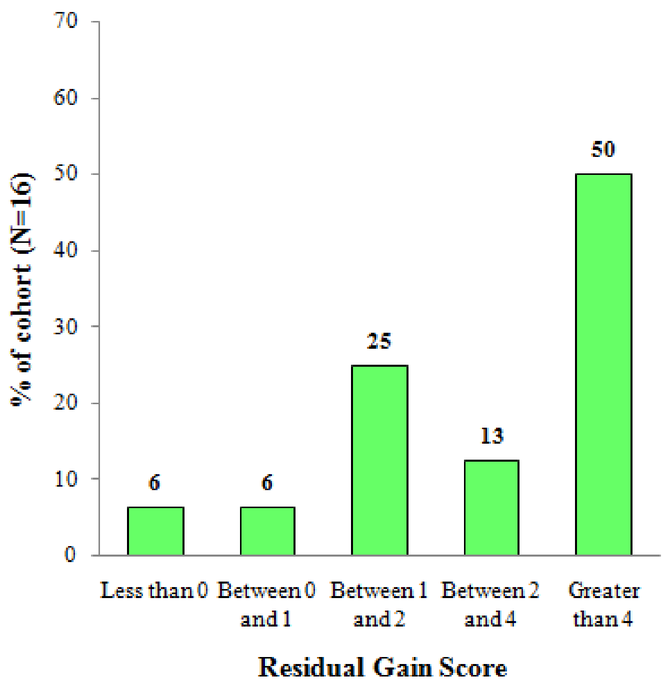


Figure 4.16: **Details of distribution of RGS values in Class 2.2.1.1**

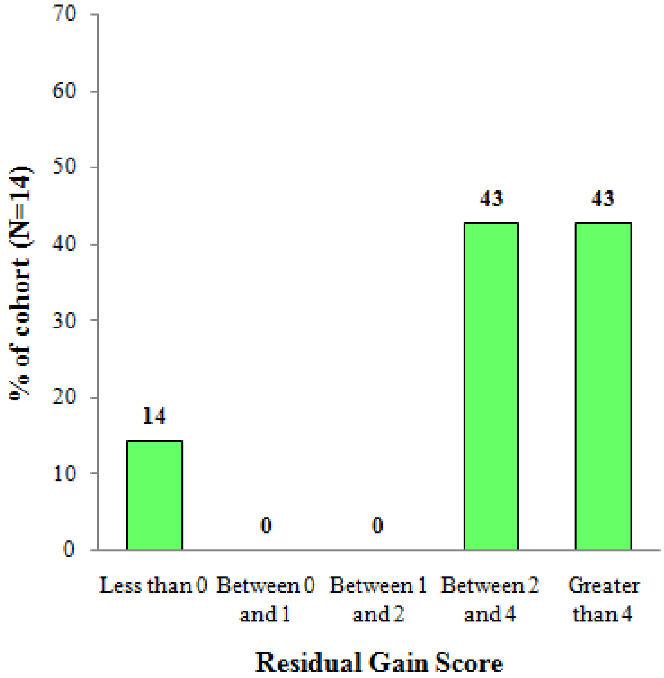


Figure 4.17: **Details of distribution of RGS values in Class 5.2.1.1**

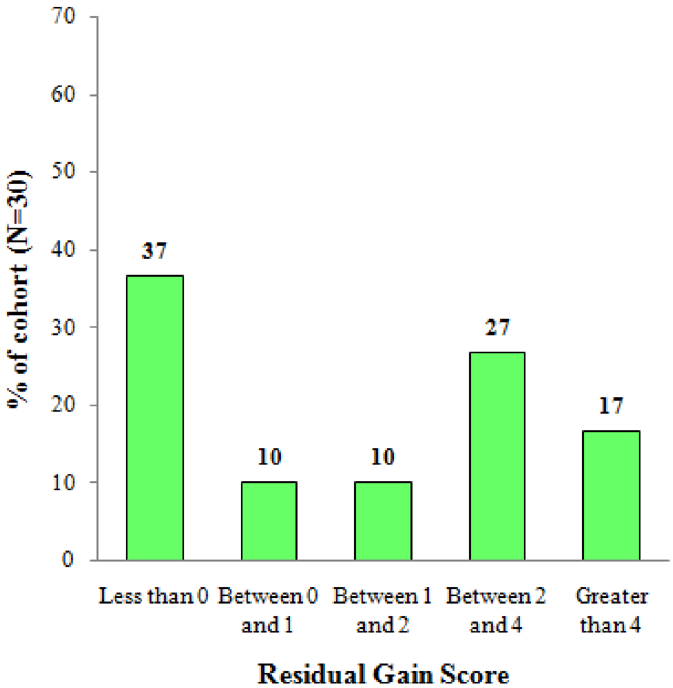


Figure 4.18: **Details of distribution of RGS vaues in Classes 6.2.1.1 and 6.2.2.1**

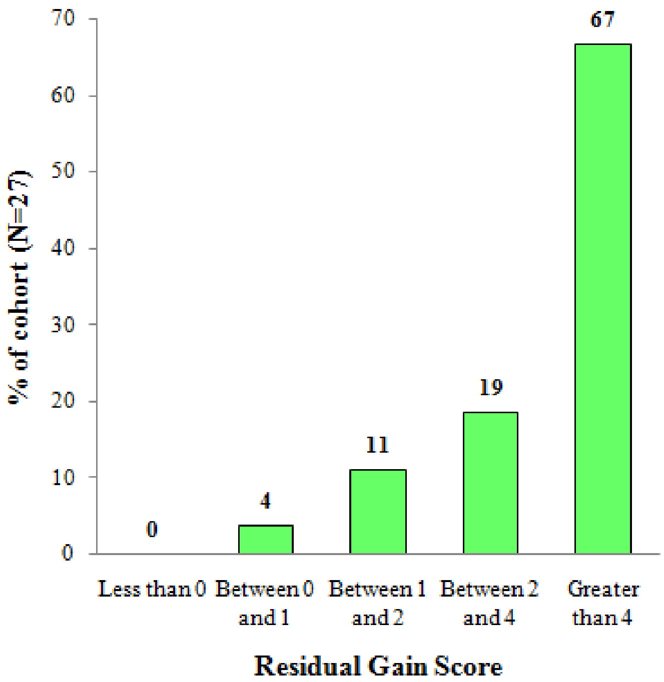


Figure 4.19: **Details of distribution of RGS values in Class 8.2.1.1**

Teacher effect

As described in the previous chapter the *Thinking through Science* programme was implemented via two different methods, namely by the classes science teacher and by a team-teaching arrangement which was a combination of both the class teacher and researcher. This added an interesting dynamic to the study and an analysis of the different teaching arrangements was necessary to assess if the method of implementation effected the success of the intervention. The mean RGS values of the different teaching arrangements are shown in Table 4.10. These data include the entire intervention group, i.e., those that have been taught through the *Thinking Science 1* and *2* programmes. The team-teaching implementation method had the highest RGS (M=4.07, SE=0.80), compared with the class teacher (M= 4.00, SE=0.37). However, this difference was not statistically significant (t(104)=-0.08, p=0.94).

Table 4.10: **Mean RGS values for different teaching arrangements**

Teaching arrangement	**N**	**Mean RGS**	σ
Class teacher	92	4.00	3.52
Team teachers	14	4.07	2.98

Figure 4.20 shows the percentage of the students in the intervention group that covered the various topics in the *Thinking through Science* programme. The most popular programmes were moments, pressure and acids and bases.

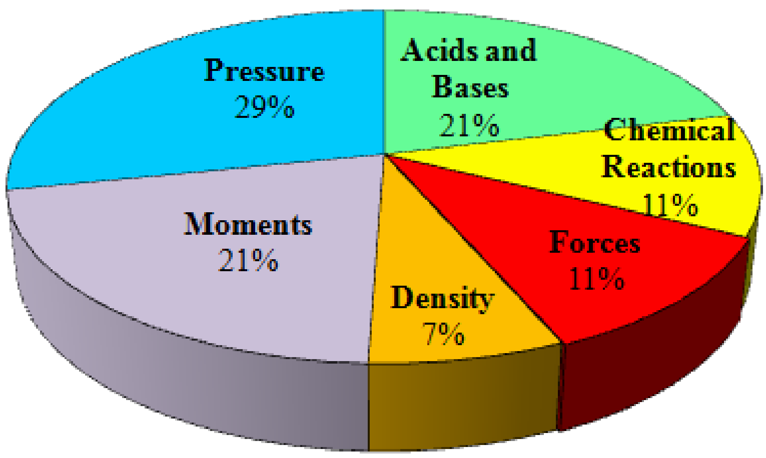


Figure 4.20: **Percentage of students in the intervention group that covered each topic in *Thinking through Science***

Due to the design and implementation of the programme each school could cater for either two or three topics to be taught during the period of the intervention. There was a significant positive correlation between the number of topics taught and the mean RGS of the students (Pearson correlation=0.37, p=0.00). Table 4.11 shows the mean RGS for the students that were taught either two or three topics. The mean for the students who were taught three topics was greater (M=5.17, SE=0.44) that those who were taught two topics (M= 2.66, SE=0.44) and this difference was statistically significant (t(104)=-4.01, p=0.00). The magnitude of this difference was large (η^2=0.13). Table 4.12 shows the topics done in each class and the mean RGS score of the entire cohort.

Table 4.11: **Mean RGS values for different number of topics in *Thinking through Science* programme**

Number of topics	**N**	**Mean RGS**	σ
2	49	2.66	3.07
3	57	5.17	3.34

Table 4.12: **Mean RGS values and *Thinking through Science* topics covered by each intervention class**

Class code	**N**	**Acids and Bases**	**Chemical Reactions**	**Pressure**	**Density**	**Forces**	**Moments**	**Mean RGS**
2.2.1.1	16			√		√	√	4.33
5.2.1.1	14			√		√	√	4.07
6.2.1.1 and 6.2.2.1	30	√	√					1.48
7.2.1.1	19			√	√			4.52
8.2.1.1	27	√		√			√	6.00

The numbers of students that completed all six cognitive tasks over three periods of study and what category they belong to are shown in Figure 4.21. Eight students completed all six SRTs and all three intervention programmes. There were no students part of the non-intervention group over the three programmes, and so no RGS could be computed over the three intervention programmes.

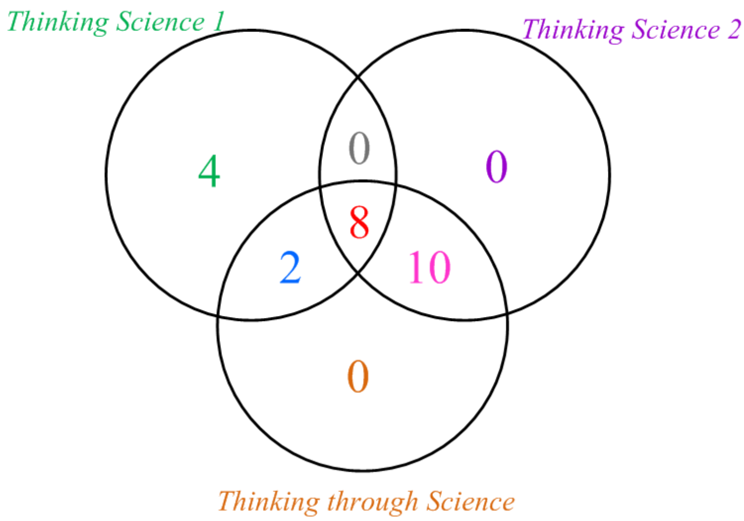


Figure 4.21: **Sample numbers that have done all SRTs and the various combinations of *Thinking Science* intervention programmes**

Figure 4.22 shows the mean cognitive levels of the group that did all three *Thinking Science* programmes.

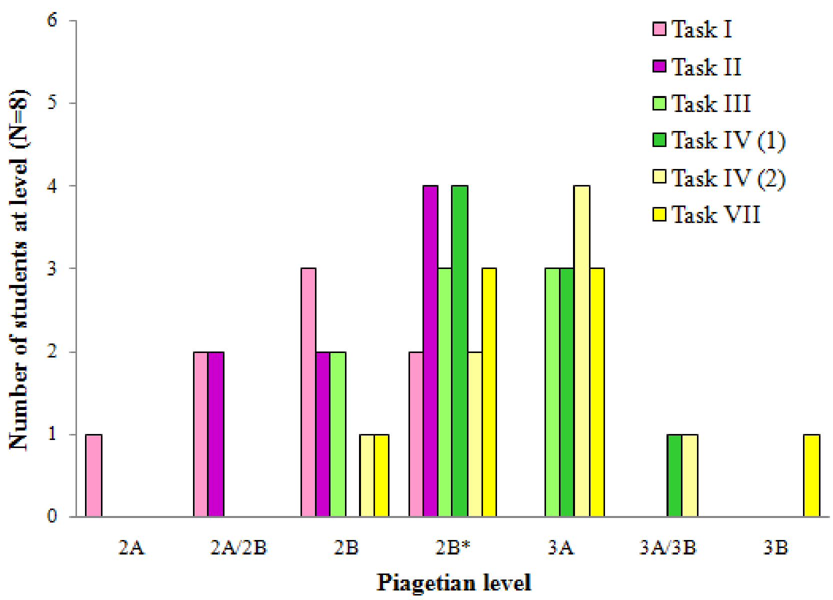


Figure 4.22: **Mean cognitive levels of intervention group, over 6 SRTs**

Figure 4.23 shows the mean cognitive levels over the six cognitive tasks of the group that did the *Thinking Science 1* programme only.

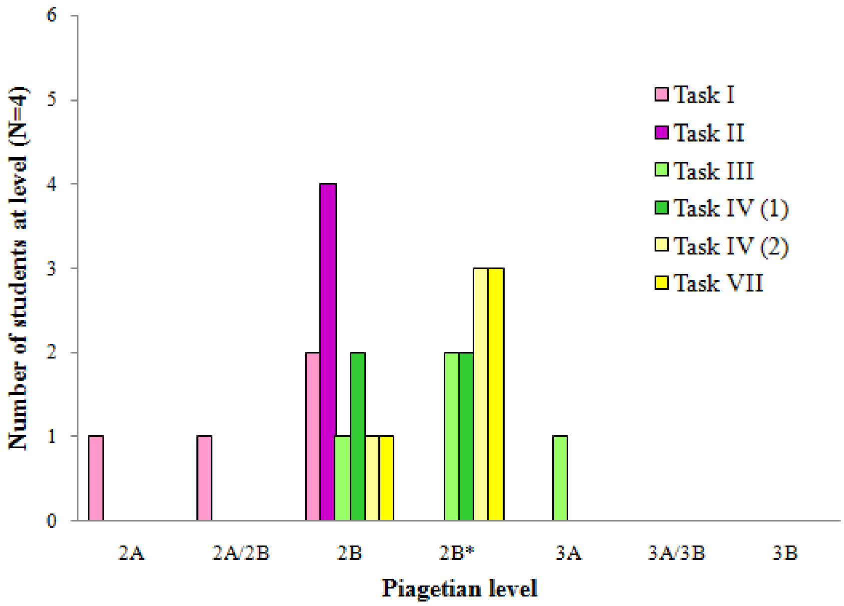


Figure 4.23: **Mean cognitive levels of group that did *Thinking Science 1* programme only, over 6 SRTs**

Figure 4.24 shows the mean cognitive levels over the six cognitive tasks of the group that did the *Thinking Science 2* and *Thinking through Science* intervention programmes.

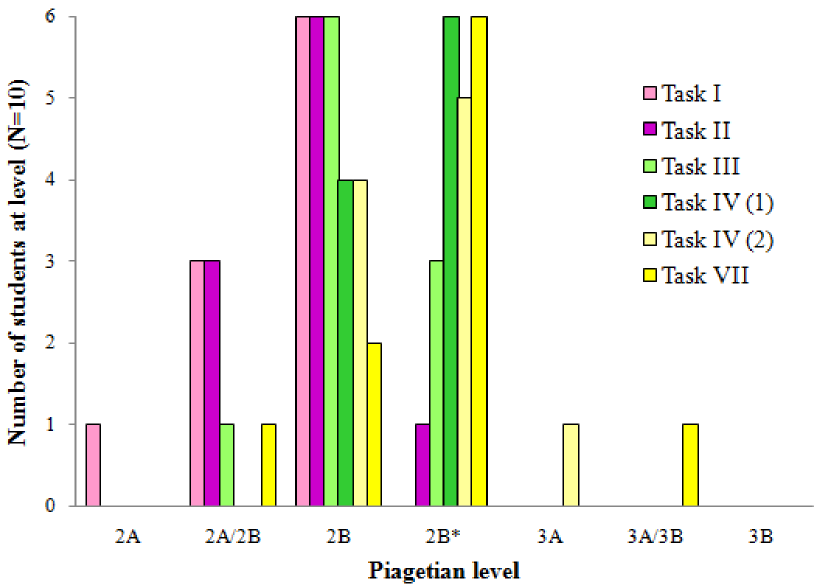


Figure 4.24: **Mean cognitive levels of group that did *Thinking Science 2* and *Thinking through Science* programmes, over 6 SRTs**

It can be seen from Figure 4.22 that the greatest number of students at the formal operational level were towards the later cognitive tasks. The mean cognitive levels for the group that did the *Thinking Science 1* programme only is shown in Figure 4.23. In comparison with the other combinations there is less of this group at the more formal operational level of thought, which implies that any cognitive development that may have been made in the first year of the programme has not continued to be shown in later cognitive tasks.

4.2 Results from summer examination and test of conceptual understanding

Both the intervention and non-intervention groups were examined in terms of their factual recall ability and their conceptual understanding of the concepts covered during the period of the intervention programme. The results from these tests are presented in the following sections. In addition the final part of this section reports if there is any correlation between students' motivation and the effects of the *Thinking through Science* programme on their cognitive development.

4.2.1 Summer examination

Each school had an end of year examination, which tested students' knowledge of topics covered throughout the year. Each test was set by the individual school and by and large the questions featured on the summer examination were recall questions. For the purpose of finding out did the *Thinking through Science* programme effect the students performance in terminal examinations, some comparisons were made. Each of the schools set their own test and corrected them, so it was not a standardised test. The mean results for the intervention group (without the *Thinking Science 1* and *Thinking Science 2* intervention groups) are shown in Table 4.13. The mean of the intervention group was higher (M=65.13, SE=3.04) than that of the non-intervention group (M=58.05, SE=2.49). However, the difference was not statistically significant (t(85)=-1.78, p=0.08).

Table 4.13: **Mean summer examination percentage score for non-intervention and intervention groups**

Group	**N**	**Mean Summer exam percent**	σ
Non-intervention	41	58.05	15.93
Intervention	46	65.13	20.58

It was possible to make comparisons between only three intervention and non-intervention classes. This could be seen as fairer than comparing all the group together as each of the schools set different tests. Within each school there was a common test. In the case of two of the schools, schools 2 and 5, the non-intervention groups actually scored a higher average than the intervention group, however these differences were not statistically significant. In the case of school 8, the intervention class scored higher than the non-intervention group, and this difference was statistically significant (t(45)=8.00, p=0.00). The mean summer exam percentages for the non-intervention and intervention groups in schools 2, 5 and 8 are shown in Table 4.14.

Table 4.14: **Mean summer examination percentage score for class groups, both intervention (E) and non-intervention (C)**

School	**Class code**	**Group (E/C)**	**N**	**Mean summer exam score**	σ
2	2.2.1.1	E	18	52.39	23.89
	2.2.2.1	C	19	62.37	18.56
5	5.2.1.1	E	18	56.00	24.39
	5.2.2.1	C	9	66.78	20.51
8	8.2.1.1	E	27	76.19	11.82
	8.2.2.1	C	20	50.90	8.97

Table 4.15 shows that there was a strong and significant correlation between the RGS values and the summer exam percentages for the students in the intervention group. This was not the case for the non-intervention group.

Table 4.15: **Correlations of mean RGS values and summer examination percentage score (** denotes significance at the 99 percent confidence level)**

Group	**N**		**Summer exam percentage**
E	42	RGS (Task IV and VII)	0.59**
C	28	RGS (Task IV and VII)	0.23

4.2.2 Thinking questions

After assessing the effectiveness of the *Thinking through Science* programme on students' cognitive developmental levels and their performance in a recall-type examination, it was deemed necessary to assess if the students had any conceptual knowledge/understanding of the topics taught throughout the intervention. This was assessed in the form of Thinking questions presented to the students in their terminal examination. The number of questions asked and the content of the questions varied from school to school, depending on the topics covered. Each school was given a different combination of questions based on the *Thinking through Science* topics that were covered during the term. The intervention group (excluding the group that had done *Thinking Science 1* and/or *2*) had the highest mean (M=59.18, SE=3.62) compared with the non-intervention group (M=28.36, SE=2.88) and the difference between the two groups was statistically significant (t(85)=-6.56, p=0.00). Table 4.16 shows the mean Thinking question percentage score for the intervention and non-intervention group.

Table 4.16: **Mean Thinking question percentage score for intervention and non-intervention groups**

Group	**N**	**Mean Thinking question percentage score**	σ
Non-intervention	41	28.36	18.45
Intervention	46	59.18	24.54

The mean thinking questions percentage score for the intervention and non-intervention class groups, using the entire cohort data are shown in Table 4.17.

Table 4.18 shows that there is a strong and significant correlation between the mean RGS value and the Thinking question score for the students in the intervention group. This is not the case for the non-intervention group.

Table 4.17: **Mean Thinking question percentage score for class groups, both intervention (E) and non-intervention (C)**

School	**Class code**	**Group (E/C)**	**N**	**Mean Thinking question percentage score**	σ
2	2.2.1.1	E	18	44.95	21.26
	2.2.2.1	C	19	22.01	18.26
5	5.2.1.1	E	18	47.44	20.98
	5.2.2.1	C	9	28.21	17.20
6	6.2.1.1 and 6.2.2.1	E	39	41.03	34.59
8	8.2.1.1	E	27	71.46	15.62
	8.2.2.1	C	20	34.21	17.98

Table 4.18: **Correlation with mean RGS and Thinking question percentage score (** denotes significance at the 99 percent confidence level)**

Group	**N**		**Thinking question score**
E	42	RGS (Task IV and VII)	0.51**
C	19	RGS (Task IV and VII)	0.78**

Figure 4.25 shows the chart for the intervention and non-intervention students in School 2, and their mean score responses to the different category of questions. The topics covered were pressure and moments and it can be seen that for both categories of questions the intervention group scored higher than the non-intervention group. Figure 4.26 shows the situation for School 5. In this school they also covered pressure and moments throughout the term and it can also be seen that the intervention group had higher mean scores than the non-intervention group. Figure 4.27 shows the results for the intervention and non-intervention groups in school 8, where the topics covered were pressure, moments and acids and bases. In each of the questions on these topics and the conservation question (assessing formal operational thought) the intervention group had greater percentage mean scores than the non-intervention group.

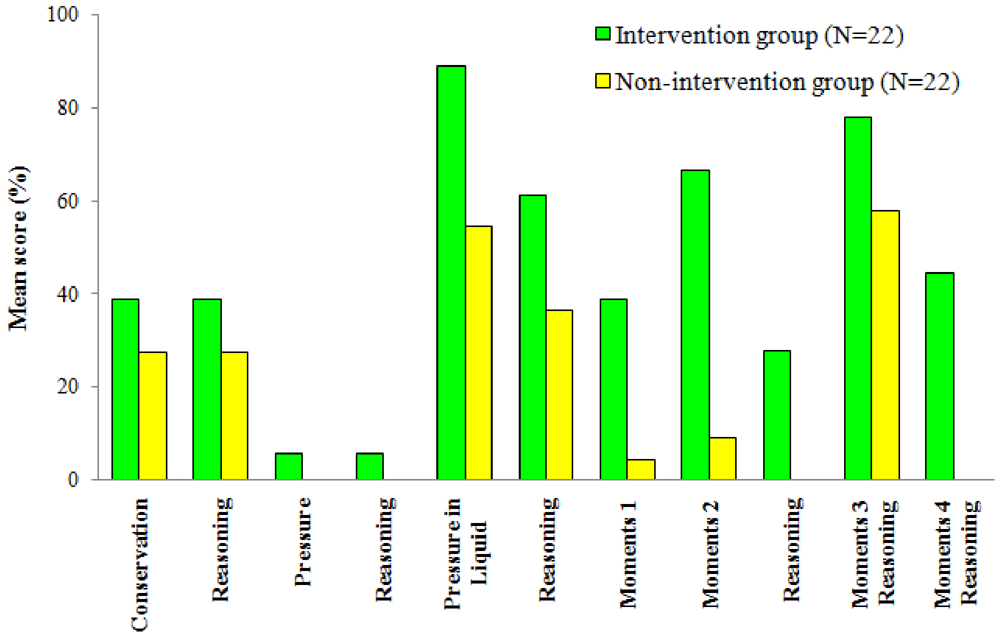


Figure 4.25: **Thinking questions mean score by topic; School 2**

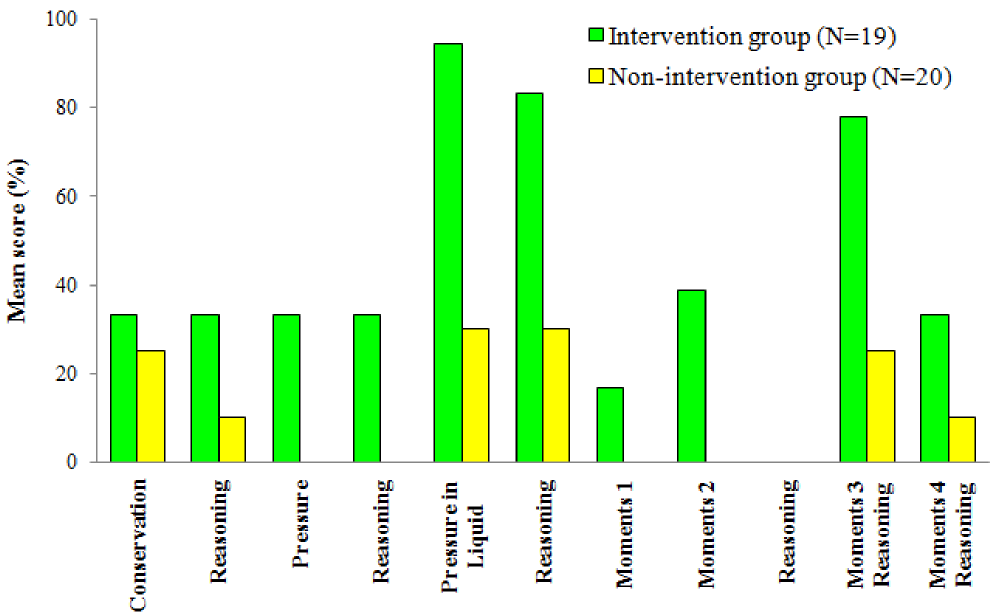


Figure 4.26: **Thinking questions mean score by topic; School 5**

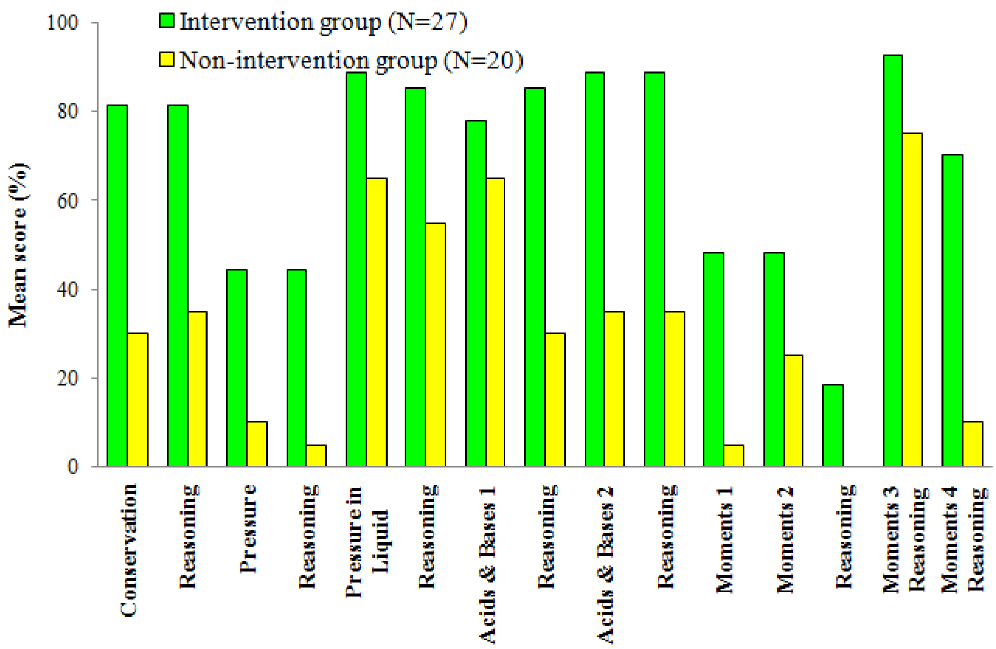


Figure 4.27: **Thinking questions mean score by topic; School 8**

4.2.3 Correlations between cognitive development and motivation

In order to gain insight into the factors that may contribute to the effectiveness of the intervention on certain students, the LASSI-HS inventory was adapted and used, as discussed in Chapter 2. The survey was completed by a sample of non-intervention and intervention students. Table 4.19 shows the correlations between the RGSs, the degree of change in sub-level, the Thinking question percentage score and Summer exam percentage score for the intervention and non-intervention groups and their corresponding attributes from the LASSI inventory. The table shows only significant correlations in terms of the Thinking question percentage score and the summer exam score. There was a high correlation between the Thinking question score and students' attitude (Pearson correlation= 0.5, p=0.00). There were significant correlations between the Thinking question percentage score and students' motivation and between the Thinking question percentage score and concentration, both of the moderate magnitude of 0.3. There were significant correlations between the summer exam score and students' motivation, anxiety and attitude. The correlation between the summer exam percentage score and motivation was slightly higher than its correlation with the Thinking question score. The greatest correlation existed between the summer exam percentage score and students' value for anxiety. Table 4.19 also shows the correlations between the scores for the non-intervention group and their corresponding attributes from the LASSI inventory. There is no significant correlations for the non-intervention group. However although not significant there is a fairly high correlation between the summer exam score and students motivation and attitude.

Table 4.19: **Correlation with scores and LASSI for intervention (E) and non-intervention group (C) (** denotes significance at the 99 percent confidence level, * denotes significance at the 95 percent confidence level)**

Group	**N**		**Motivation**	**Anxiety**	**Attitude**	**Concentration**
E	61	RGS	0.02	0.14	0.80	-0.02
	61	Degree of change	0.19	0.09	0.10	0.09
	49	Thinking Question score	0.29*	0.26	0.50**	0.30*
	49	Summer exam score	0.36**	0.44**	0.43**	0.27
C	28	RGS	0.03	-0.02	-0.02	-0.20
	28	Degree of change	-0.01	0.05	0.16	-0.13
	26	Thinking Question score	-0.01	0.05	-0.02	-0.21
	26	Summer exam score	0.35	0.07	0.34	0.24

4.2.4 Conclusions

The aim of this part of the study was to implement the CASE methodology into specific topics taught on the Junior Certificate Science curriculum. This idea stemmed from the implementation of the *Thinking Science* intervention programme in 1st year at second level. Teachers expressed the need for an intervention programme that was embedded in the contents of the curriculum. The resultant programme, *Thinking through Science* embedded the CASE methodology into the teaching of six Junior Certificate topics. Various combinations of the topics were taught in six 2nd Year classes and a comparable non-intervention group were used to compare the effects of the intervention programme on cognitive development, in comparison with normal science classes.

Prior to the intervention there was no significant difference between the intervention and non-intervention group. The results of the *Thinking through Science* programme were very positive. The programme had a very large effect size of 1.7 σ. In terms of Residual Gain Scores the intervention group had a mean of 5, compared with a mean of zero for the non-intervention group. The difference of these means was significant, with a large magnitude in difference. There was no significant difference between the mean RGS for the male and female groups in the intervention group, implying that the programme had equally positive effects on both gender cohorts. The mean RGS values for the intervention class groups varied from 1.4 to 6. In the case of three class groups their RGS could be directly compared with the non-intervention class group in their school. In all three cases the mean RGS of the intervention class was much greater than that of the non-intervention class. In some intervention classes the results were bimodal, implying that while some students in the cohort made very substantial gains, other students did little better than the students in the non-intervention group. There was a positive correlation between the number of topics covered through the CASE methodology and the mean RGS.

In order to gain insight into other possible effects of the *Thinking through Science* programme the results from students' performance, in both the intervention and non-intervention groups, in a summer examination and conceptual question exercise were obtained. The mean of the intervention group in the summer exam assessment was slightly higher than the comparable non-intervention group, but the difference was not significant. However there was a significant difference in the performance of both groups in the case of the conceptual questions. The intervention group had a mean score of 59 percent, compared with 28 percent for the non-intervention group. In essence these results imply that the intervention group benefited from a better understanding of the concepts which they encountered during the period of the intervention, compared with the non-intervention group who also covered the same concepts. The summer examination results were comparable. This result implies that both groups did equally as well at recall type questions. This finding could also imply that the nature of the terminal exam questions do not require more sophisticated, formal level thought. Perhaps if they did the intervention group would have out-performed the non-intervention group.

Conclusions and Implications

This study was born out of two major questions. The first question was connected with the on-going and international problem of the majority of students not attaining levels of cognitive development necessary for engagement with scientific content in the core curriculum. It was necessary to develop a profile of the cognitive developmental levels of a sample of Irish students to determine if the issues concerning lagging cognitive development were evident here. A profile of cognitive levels of students in the final year of primary level education and the 1st and 2nd years of second level in Ireland was determined. In addition, a profile of the students in a 1st year university science course was determined. This profile of cognitive levels of these groups is shown in Figure 4.28. It shows the numbers of students at the formal operational stage creeps from early adolescence (12 years) to the beginning of adult-hood (19 years).

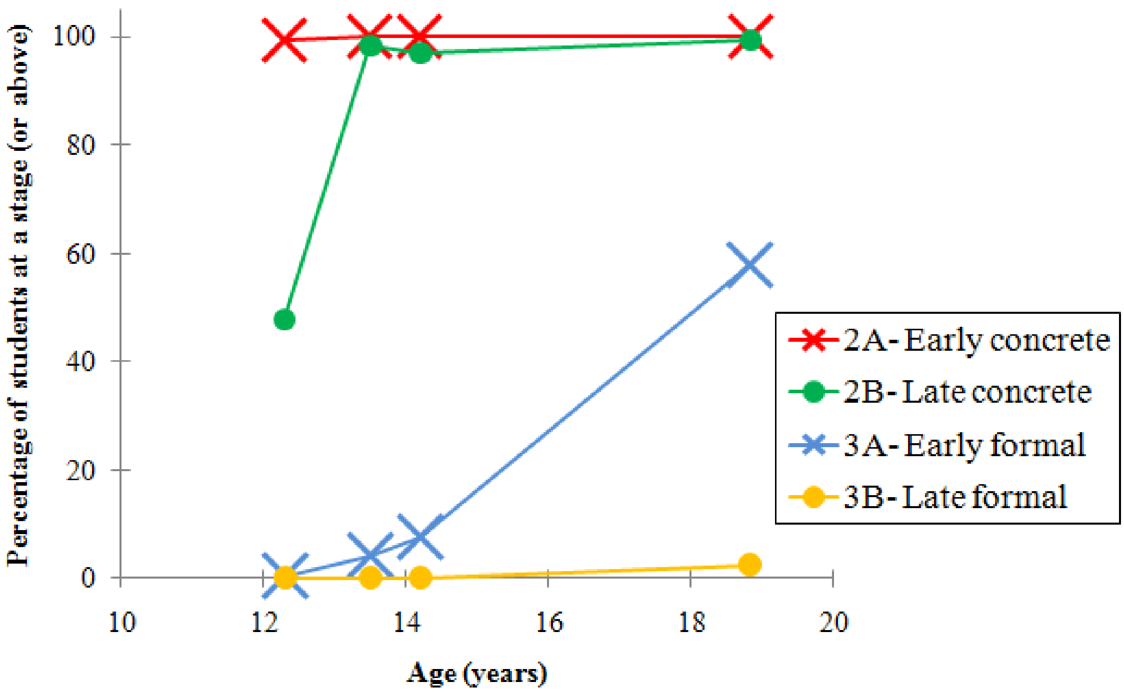


Figure 4.28: **Proportion of students at different Piagetian stages in the Irish population (At ages 12.3, 13.5, 14.2, 18.8 years)**

The cognitive development levels of pre- and post transfer (6th class at primary level and 1st year in second level) students in this study is a cause for major concern. Fewer than 10 percent of 14 year olds are displaying competence in formal operational thought, necessary for the grasp of the majority of concepts on the Junior

Certificate science course. The mismatch has been reported in Britain [1], and in many ways the results of the Irish cohort in this study are even worse.

A small-scale study of 1st year university science students showed that the proportion of students who have reached the early formal (3A) operational stage by age of 18 years, is 58 per cent and little less than 3 percent displaying late formal (3B) operational thought. This result is alarming, suggesting that by the age of 18 years future scientists have not grasped scientific concepts such as proportionality or formal modeling.

The second aim of this study was to explore if the CASE programme can contribute to enhanced cognitive development, in an Irish context, across the primary and second levels. There has been no reported research about the CASE programme been implemented across two levels in the education system. In addition, there are few studies into the use of the CASE materials at primary level. Adey and Shayer [25] expressed their desire to implement the programme in the '*less constrained atmosphere of primary schools*' but their decision to avoid doing so was their doubt about the promotion of formal operations with 9 year olds (in the second last year of primary education in the UK). In this study, the original CASE materials, *Thinking Science*, were adapted for use at both levels and the materials were divided into two, namely *Thinking Science 1* and *Thinking Science 2*. Following teacher training, the programmes were implemented and their effect on students' cognitive development was monitored and analysed in detail.

The overall success of the combined *Thinking Science 1* and *Thinking Science 2* programmes was in accordance with the original *Thinking Science* materials. The effect size of the combined programmes was just over 1 σ, similar to that noted by Shayer. However, it must be noted that the number of students with which both programmes were implemented with was relatively small (N=32). The *Thinking Science 1* programme, implemented at primary level recorded an effect size of 0.5 σ. This programme comprised of approximately half of the intervention lessons delivered over a period of one year. In a Korean study of the entire CASE programme, implemented in the final year of primary level, similar results were noted. However in the Korean study, there was a very evident gender divide between these results, with the female group gaining a greater score in Piagetian tasks, compared with the male group. There was no significant difference in the cognitive development of the male and female cohorts in the *Thinking Science 1* programme. An important and unique feature of primary school, in Ireland and elsewhere, is the non-specialisation in science of the teachers. The teachers of the intervention programme received training in the use of CASE and background knowledge on the content of the lessons. In some cases the researcher taught the CASE lessons and in some classes both the teacher and researcher taught the lessons together. Although the team teaching combination had the highest RGS value, implying greater cognitive development for this group when compared with the non-intervention group, the difference in any of the teaching combinations was not significant. This implies that the implementation of CASE lessons with non-specialised science teachers is possible and also yielded positive effects on pupils' cognitive development.

The *Thinking Science 2* programme was the part of the original programme that was delivered in the 1st year at second level. Some of the students who received the *Thinking Science 1* intervention were part of this second level cohort, while others were not. Due to the extensive number of feeder schools to each second level school it was unrealistic to track all the students at both levels. The effect of the *Thinking Science 2* programme on students who were just tracked at second level was equivalent to 0.5 σ. Similar to the *Thinking Science 1* programme there were three teaching combinations, namely the class teacher who received training in CASE, the researcher and a team teaching arrangement comprised of both. As in the primary school programme, the highest mean was for the team teaching arrangement, followed by the researcher and the class teacher.

In the evaluation of both the *Thinking Science 1* and *Thinking Science 2* programmes, the performance of individual class groups was considered. There was great variation present in the mean Residual Gain Scores (RGS) of certain class groups. Some groups had RGS values little greater than non-intervention groups, while other classes greatly out performed others. Adey and Shayer noted bimodality present in some of their intervention class groups' results and this was also noted in the results of this study.

In order to investigate a possible explanation for the bimodal results in certain class groups, the motivation and attitude of students in the intervention and non-intervention groups was determined. Leo and Galloway suggested that the CASE programme may lend itself to better results with students of a certain motivational type. However, this view was rejected by Adey. The LASSI survey was used in this study to get an insight into how the students rated their motivation, attitude, concentration and anxiety in relation to science. For the group that had done both the *Thinking Science 1* and *Thinking Science 2* programmes there were significant correlations between RGS values and values for attitude and concentration, i.e., students who rated themselves high in attitude and concentration in science also had high RGS means. Although there was a relatively high correlation between motivation and RGS, it was not significant, which contradicts the view of Leo and Galloway.

Arising from some concerns about the implementation of the *Thinking Science 2* programme in 1st year at second level, the *Thinking through Science* programme was developed. When interviewed, second level teachers who taught the intervention programme expressed great praise for the methodology and the aim of the programme. However, their main concern was the time that was spent teaching the CASE lessons, that were not always directly related to syllabus content. This push for time often left teachers behind in other areas of the curriculum. In addition, teachers felt that due to time constraints within a particular class, aspects such as metacognition and bridging were often rushed or omitted. Due to the importance of these features to the methodology in the attempt to enhance cognitive development, efforts had to be made to increase the user-friendliness of CASE in the Irish second level classroom. The resultant programme involved the incorporation of the CASE methodology into physics and chemistry topics on the Junior Certificate course. Adey and Shayer's Curriculum Analysis Taxonomy also provided insight into the sequencing of concepts.

The *Thinking through Science* programme had an effect size of 1.7 σ which corresponds to a very strong effect. The difference in mean RGS of the intervention and non-intervention groups was significant. There was no statistical difference between the male and female groups in the intervention groups. The mean of the class groups in the intervention group varied, but each group did comparably better than the non-intervention groups. There were two possible teaching combinations which included the class teacher and a team teaching arrangement with the class teacher and researcher. There was statistically no difference in the RGS of the students taught through either of these arrangements. The success of this programme on students' cognitive development can be attributed to the CASE methodology and the value of the pillars. However, the results achieved in some ways contradict the beliefs of Adey and Shayer. They believed that in order for an intervention to have any tangible effect on students' cognitive development the intervention would have to last long periods of time, for example two years in the case of the original *Thinking Science* materials. This study supports the view that even over a relatively short period of time, when CASE lessons are used in classrooms on a regular occurrence and the pillars of CASE are adapted throughout science teaching then the benefits are evident. However due to the constraints of this study the effects of this programme beyond three years are yet to be monitored and evaluated.

When the 2nd year intervention and non-intervention groups' performance in a terminal examination were compared, there was no statistical difference. The nature of these questions was mostly recall and in general did not attempt to assess student's understanding of the concept or did not require students to use any formal operational thought. However when both sets of students' conceptual understanding of the topics taught during the time-frame of the programme were assessed, there was a significant difference. The intervention group had a higher mean score (approximately double), when compared with the non-intervention group. Keeping in mind that both groups had covered the same topics, just through a different teaching methodology, the findings are quite conclusive. The intervention students engaged in a deeper understanding of the concepts and so performed better in this examination of conceptual understanding. The reasons for this may have been that the teaching methodology promoted the students' cognitive development and so making them better able to engage and understand the concepts. This finding, although on a small scale, highlights more positive attributes to the CASE methodology.

In order to investigate the effects of student values such as motivation, anxiety, attitude and concentration, the LASSI survey was conducted with the 2nd year students. There was a significant moderate degree of correlation between students' Thinking question score and their attitude, as well as students' summer examination percentage score and their values for anxiety and attitude. Yet again there was no significant correlation between gains in cognitive development and motivation.

To summarise the main findings of this study, the CASE programme was successfully implemented at the final year of primary level and the first year at second level. Both programmes yielded very positive results in terms of students' cognitive development and the combined effect of both programmes was large. In an attempt to make the CASE programme more usable in the Irish context the CASE methodology was embedded into topics on the Junior Certificate Science curriculum. The results of this programme were also positive, in terms of students' cognitive development, where a very large effect size was found. The intervention group also performed significantly better in an examination assessing conceptual understanding. The large effects of this *Thinking through Science* programme can be attributed to the greater linkage with the Junior Certificate science curriculum and as a result the science teacher had greater ownership of the programme. In addition there was greater time spent on the metacognitive and bridging aspects of the programme. This study adds more 'fuel to the fire' in terms of praise for the benefits of the CASE methodology.

Arising from this study, I make the following recommendations for the teaching of science in Ireland;

- The CASE programme should be implemented in the final years of primary level and the first year of second level education in Ireland. Teachers at both levels should receive training in the CASE methodology and the associated underlying theory. They should receive continuous professional development in the area of enhancing the cognitive development of their students.
- Second level science teachers should be suitably trained and supported in incorporating the CASE pillars into their teaching. They should be encouraged to develop CASE-type lessons for the delivery of science topics and to initiate and provide metacognitive exercises for their students.
- Both primary and second level teachers should be encouraged and equipped with methods and resources to assess the cognitive levels of their pupils and students at certain intervals. I believe this is necessary in order to help them to match their students' ability with the cognitive demand of content to be taught and so provide greater insight into the sequencing of the curriculum.

This work has lead to further questions. A large cohort of students that were part of this study completed their Junior Certificate examinations in June 2009. It would be interesting to determine the effect of the intervention programme(s) on their performance in the science examination, as well as in mathematics and English as literature suggests the programme has positive effects on academic achievement [95]. In addition, the profile picture of children's cognitive levels needs to be expanded beyond 6th class in primary school and 1st and 2nd year at second level. This is necessary for several reasons but first and foremost to provide teachers at all stages with an increased knowledge base about their students' cognitive levels and hence to teach more effectively. Also, such a profile is necessary for competent curriculum development. Another area to be explored is the application of the

Curriculum Analysis Taxonomy to the Junior Certificate science examination, in order to balance assessment with curriculum design and teaching methodology for the promotion of cognitive development. In terms of science curriculum continuity, the transition from Junior to Senior cycle in the Irish education system needs to be addressed.

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Appendix A

Science Reasoning Tasks

Appendix B

Adapted LASSI-HS survey

Appendix C

Interview questions and Evaluation forms