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Practical Work in Ireland: A Time of Reform and Debate

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This paper describes and discusses the role of practical work in science education in Ireland. The 2002 report of a government Task Force on the Physical Sciences, set up to consider the problems facing the teaching of the physical sciences in second-level schools in Ireland, has resulted in rapid reform of the science curriculum at both junior and senior secondary school level. Whilst practical work has a long and varied history in science education in Ireland, it was only in 2003 that practical work became compulsory with the introduction of a new Junior Certificate science syllabus for students in the 12 – 15 year old age group. The paper describes the two types of practical work introduced in the syllabus and discusses the results of a survey carried out by the Irish Science Teachers' Association to ascertain the response of teachers to this practical work. Compulsory practical work has also been introduced into physics, chemistry and biology at senior secondary school level (ages 16 – 18). The paper reports on a research study to evaluate the effectiveness of a proposed new assessment model for practical work involving the use of a visiting examiner to interview students and examine their ability to carry out tasks in the school science laboratory. The main finding was that the new model provided a more valid and fairer assessment of students' ability in the area of practical work.

Keywords: *practical work, assessment of practical work, investigations, syllabus revision*

INTRODUCTION

Over the past twenty years there has been considerable disquiet expressed (Task Force, 2002) about the decreasing numbers of students in Ireland opting to study science, particularly physics and chemistry, in the senior cycle of secondary school. In 2000 the Irish government set up a Task Force on the Physical Sciences to try to identify the factors contributing to this decline and to formulate a strategy that would attempt to reverse the trend of falling numbers. The report stressed the fact the Ireland's economic future depends on the supply of an increasing number of people qualified in science and engineering. It expressed serious concern at the sharp fall-off in interest since 1987 in the physical sciences and drew up an action strategy to address the many inter-linking facets of the problem (Task Force, 2002).

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One of the key recommendations of the Task Force was that increased resources be provided to support practical work in schools with particular emphasis on increasing the number of science laboratories in secondary schools as well as improving the standard of equipment in these schools. In addition, it recommended that curriculum reform in science should be prioritised and it challenged the National Council for Curriculum and Assessment (NCCA) in Ireland to fast-track action on school science syllabi. The latter recommendation was quickly implemented and resulted in a flurry of activity in curriculum reform which helped to focus the spotlight on the role of practical work in science education in Ireland.

Science was only introduced into the primary school curriculum in Ireland on a phased basis in 1999 and became compulsory in 2003. Hence the emphasis in this paper will be on science practical work at secondary school level.

The Development of Practical Work in Ireland

There is a long tradition of practical work in Ireland and it is reported that the chemistry laboratory set up by

State of the literature

- Pupil practical work forms a significant part of the science curriculum in many countries. However, the wide variety of aims has resulted in a lack of clarity over the purpose of much practical activity in science lessons.
- Practical work has an important function in making phenomena real for pupils.
- Practical work can help students gain some understanding of the way in which scientific knowledge progresses.
- The devlopment of valid assessment of the skills and abilities associated with investigative work for pupils in the 11 – 16 age group is very challenging.

Contribution of this paper to the literature

- This paper describes and discusses the challenges faced by teachers in Ireland when investigative type practical activities were recently introduced for pupils in the 12 – 15 age range.
- This paper describes an attempt to devise a new model for assessment of practical work at the senior secondary school level (age 16 – 18) in Ireland..
- The new model of assessment has been found to have reliability and validity and hence aspects of this model help to inform us on the most appropriate way to give students credit for their performance in laboratory practical work.
- The description of the assessment model involving a visiting examiner to interview students and examine their ability to carry out laboratory practical work could have application in the educational systems of other countres.

the Royal Dublin Society in 1796 was probably the first of its kind in the United Kingdom (Ryan, 1998). However, the secondary schools of Ireland had a long wait before science appeared as a subject. The reason for this was because prior to the Relief Acts of 1782 and 1792, the Catholic population of Ireland had no access to a formal system of secondary education and the Protestant grammar schools in existence at the time, did not teach science as a subject. The first Irish secondary school to enrol students for a science examination was St Kieran's College, Kilkenny and in 1874 students from that school sat for the science examination of the South Kensington Department of Science and Art (Wallace, 1972).

The number of schools offering science as a subject steadily increased in the late 19th century but the 1882 report of the Intermediate Education Board of Ireland was critical of the amount of practical work in natural philosophy (physics) and commented that "candidates have been prepared solely by reading books without, in the great majority of cases, having had any opportunity of becoming practically acquainted with even the most elementary experiments". The report also commented that "many of the candidates in both grades (middle and senior) had clearly never seen experiments performed and had simply committed portions of the textbook to memory" (Intermediate Board of Education, 1882, p22).

The first steps taken towards rectifying these defects in the teaching of practical work in science came in 1899 when a commission set up by the Intermediate Board recommended that grants should be paid to schools "to enable them to provide proper equipment and appliances for the teaching of practical science" (Intermediate Education Commission, 1899, p25). This was a turning point for science practical work in schools and during the period 1900 – 1904 the number of schools that had a science laboratory increased from 6 to 214 and the number of boys taking science increased from less than 1000 in 1900 to 6,300 in 1908 (Board of Education, 1905). At that time science was not considered a subject for girls!

However, with the foundation of the Republic of Ireland in 1922, the new government Department of Education took over the function of the Intermediate Education Board and issued new syllabi at junior cycle level and senior cycle level. Practical work was encouraged by abolishing a 'payment by results' system for teachers that had been in operation and by increasing grants paid for the equipping and maintenance of science laboratories. In addition, per capita grants that were based on the number of students studying science subjects were paid to schools. This resulted in a steady increase in the number of junior cycle students taking science subjects to over 50% in 1930. Minor revisions to the junior cycle science syllabi and the senior cycle syllabi in physics, chemistry, botany and a combined physics / chemistry subject took place in the period 1930 – 1960 but the basic structures were not fundamentally altered. It is clear that practical work played an important part of the science syllabi of that time and this is reflected in the textbooks used in the 1940s and 1950s (e.g. O'Brien 1953; O'Brien 1954). However, it is difficult to gauge to what extent students were involved in carrying out practical activities themselves. This appears to have depended on the teaching approach of individual teachers and on the school laboratory facilities.

In Ireland, as in many other countries, the 1960s were a time of great change in science education sparked by the fact that the USSR became the first nation to launch a satellite (Sputnik 1) into space in 1957. One of the driving forces behind this change was the Irish Science Teachers' Association (ISTA) which was founded in 1961 at a meeting held in the Chemistry Department of University College Dublin. From the moment of its foundation, the ISTA put emphasis on school practical work. In fact, it is reported (Somerfield, 1982) that an exhibition of laboratory apparatus and demonstration lectures were organised for the inaugural meeting of the ISTA.

The ISTA worked closely with the inspectorate of the Department of Education to revise all science syllabi at junior and senior cycle and to organise inservice courses with a particular emphasis on practical work at numerous venues around Ireland. The local ISTA branches organised the venue and the speakers in co-operation with the Department of Education which funded the costs involved in running the inservice courses (Somerfield, 1982). A new junior cycle science syllabus was introduced into schools in 1967 followed by senior cycle syllabi in physics, chemistry and biology in 1969. In addition, a new scheme of capital grants was initiated by the Department of Education to assist schools in providing laboratory facilities and equipment and the Irish television broadcasting service (Radio Telefís Éireann) began broadcasting television programmes involving laboratory practical work. These programmes were designed to help teachers implement the practical component of the new syllabi. In addition, a grant was given to schools to enable them to pay a higher salary to science teachers to encourage more science graduates to enter the teaching profession.

Over the next 25 years considerable progress was made in the partnership between the inspectorate of the Department of Education and science teachers in providing continuing professional development courses for science teachers and maintaining an emphasis on practical work in school science. New syllabi in physics and chemistry in which practical work was emphasised were introduced in the 1980s. These syllabi laid down specific objectives and were aimed at reducing theoretical content, making the material relevant to everyday life, and contributing to an appreciation of industrial, economic, social and environmental aspects of the syllabus. The importance of practical work was clearly stressed in the introduction to the chemistry syllabus that was introduced in 1983:

The development of appropriate experimental and manipulative skills and abilities is an integral part of this course…The fostering of these experimental skills, along with abilities to evaluate and express procedures, hypotheses, data and results in a concise and comprehensive manner is strongly urged. Because laboratory work is seen as an intrinsic part of the syllabus, it is recommended that 40% of time allocated to the subject be devoted to laboratory activity (Department of Education, 1983, p225).

In addition, the Department of Education specified that students had to maintain records of their practical work in laboratory notebooks and these notebooks were to be available for inspection by the science inspectorate. If an inspector felt that an adequate course of laboratory work had not been followed, then the student could be refused admission to the Leaving Certificate examination.

In order to ascertain the level of success on the emphasis placed on the 1983 Leaving Certificate Chemistry syllabus, a survey of chemistry teachers was carried out in the 1985 – '86 academic year by Smyth and Childs (1990). This survey found that 54.76% of teachers reported that around 40% of their teaching time was devoted to practical work and 11.91% reported that they spent more than 40% of their time. When questioned about difficulties encountered with the practical component of the syllabus, teachers gave examples such as lack of equipment, large class sizes, lack of technical assistance, and difficulty with accessing laboratories as being the main impediments. Whilst the survey was carried out only two years after the introduction of the syllabus, it is clear that despite encountering many problems, the majority of teachers (66.66%) appear to have embraced the practical work involved in the 1983 Leaving Certificate chemistry syllabus.

Progress was also made in increasing the number of girls taking the physical sciences as a result of an intervention project organised by the Department of Education (O'Brien and Porter, 1994). However, the status given to practical work still depended very much on individual teachers and available lab facilities as the examination system was geared towards a terminal written examination paper. Hence, in the mid 1990s work began on the drafting of new syllabi in which student practical work was mandatory at both junior and senior cycle. The senior cycle syllabi in physics and chemistry were introduced in 2000, the senior cycle biology syllabus was introduced in 2002 and the junior cycle science syllabus in 2003.

Practical work at Junior Secondary School level (ages 12 – 15)

In Ireland students enter secondary school at the age of 12 and undertake a three-year course called the Junior Certificate programme. Students study six mandatory subjects (Irish, English, Mathematics, Civic Social and Political Education, Social Personal and Health Education, Physical Education) and approximately six optional subjects. Science is one of these optional subjects but, in fact, it is studied by approximately 95% of students. All students follow the same programme in science which is available at Higher Level for high ability students and at Ordinary Level for lower ability students. A government body called the State Examinations Commission (SEC) has responsibility for setting and marking the examination papers.

A revised Junior Certificate Science syllabus was introduced to schools in September 2003 (NCCA, 2003). Some of the syllabus aims that are relevant to practical work are that science education at junior cycle should:

- ✓ *Encourage the development of manipulative, procedural, cognitive, affective and communication skills through practical activities that foster investigation, imagination and creativity.*
- ✓ *Provide opportunities for observing and evaluating phenomena and processes and for drawing valid deductions and conclusions. (NCCA, 2003, p4)*

In addition, the syllabus objectives emphasise skills and list the following examples of skills:

- ✓ *Manipulation of equipment and manual dexterity with due regard to issues of health and safety.*
- ✓ *Develop skills associated with procedural plans and the use of the scientific method in problem solving.*
- ✓ *Develop skills associated with observation, measurement and the accurate recording of data(NCCA, 2003, p4)*

Whilst the syllabus document is non-prescriptive in terms of pedagogy, the Teacher Guidelines which accompany the syllabus (NCCA, 2006) make clear the emphasis on the investigative approach to science teaching:

The syllabus emphasises an investigative approach to science, which is aimed at facilitating students in the development of skills, knowledge, understanding and attitudes that are appropriate in a society increasingly influenced by science and technology (NCCA, 2006, p21).

This syllabus was ground breaking as, for the first time in Ireland, compulsory practical work was introduced into the Junior Certificate science programme. In addition, students were given credit for the practical work completed as part of the overall assessment. The practical work undertaken in the syllabus consists of two parts referred to as Coursework A and Coursework B.

Coursework A consists of 30 mandatory experiments equally divided into physics, chemistry and biology. In the introduction to the syllabus, the National Council for Curriculum and Assessment makes clear the purpose of the experiments in Coursework A.

In conducting an experiment, the student follows a prescribed procedure in order to test a theory, to confirm a hypothesis or to discover something that is unknown. Experiments can help to make scientific phenomena more real to students and provide them with opportunities to develop manipulative skills and safe work practices in a school laboratory (NCCA, 2003, p7).

Over the three years of the programme, each student is required to carry out each of these mandatory experiments and maintain a laboratory notebook, in which a record of these experiments is kept according to certain criteria laid down by the State Examinations Commission. The practical notebooks must be available for inspection by the science inspectorate of the Department of Education and this coursework is allocated 10% of the overall marks. Some examples of these Coursework A experiments are shown in Table 1.

In addition to the mandatory experiments in Coursework A, students are also required in the third year of the course to undertake two investigations set by the State Examinations Commission. These investigations are referred to as Coursework B and the rationale for including these investigations is clearly outlined in the introduction to the syllabus:

The term investigation is used to represent an experience in which the student seeks information about a particular object, process or event in a manner that is not pre-determined in either procedure or outcome. Such experiences can enable the student to observe phenomena, select and follow a line of enquiry, or conduct simple practical tests that may stimulate thought or discussion,

Table 1. Some examples of the mandatory experiments for the Junior Certificate science course in Ireland (Coursework A).

Biology
Carry out qualitative food tests for starch, reducing sugar, protein and fat.
Investigate the action of amylase on starch; identify the substrate$_e$, product and enzyme.
Prepare a slide from plant tissue and sketch the cells under magnification.
Investigate the conditions necessary for germination.
Chemistry
Separate mixtures using a variety of techniques: filtration, evaporation, distillation and paper chromatography.
Prepare a sample of oxygen by decomposing H_2O_2 using MnO_2 as a catalyst.
Carry out an experiment to demonstrate that oxygen and water are necessary for rusting.
Investigate the reaction between zinc and HCl, and test for hydrogen.
Physics
Measure the mass and volume of a variety of solids and liquids and hence determine their densities.
Investigate and describe the expansion of solids, liquids and gases when heated, and contraction when cooled.
Investigate the reflection of light by plane mirrors, and illustrate this using ray diagrams; demonstrate and explain the operation of a simple periscope.
Set up simple electric circuits; use appropriate instruments to measure current, potential difference (voltage) and resistance, and establish the relationship between them.

thus leading to a clearer understanding of the facts or underlying principles. It should involve the student in following a logical pattern of questioning and decision-making that enables evidence to be gathered in a similar way to that used by scientists.

Investigations can be used to develop skills of logical thinking and problem solving, and can give the student an insight into the scientific process. Thus, the student can appreciate the importance of using a fair test in order to arrive at valid deductions and conclusions, and the significance of making and recording measurements and observations accurately (NCCA, 2003, p6).

In October of each year the State Examinations Commission distributes a circular to schools in which the three investigations for that year are listed. The investigations are changed each year and every student must carry out two of these three investigations. (It is also possible for students to substitute an investigation of their own choice but this is not a common choice). Coursework B investigations are written up by the students in booklets supplied by the State Examinations Commission and are externally marked by the same examiner who marks the terminal written examination of that student. Coursework B is worth 25% of the overall marks and the terminal written examination of two hours duration is worth 65% of the overall marks. As already mentioned, Coursework A is worth 10% of the overall marks. Some examples of investigations assigned to date by the State Examinations Commissions are listed in Table 2.

In general, it is clear that the State Examinations Commission appear to be in agreement with the commonly used definition of an investigation, i.e. "a task for which the pupil cannot immediately see an answer or recall a routine method for finding it". (Gott and Duggan, 1995, p14). It is also clear that the investigations set by the State Examinations Commission to date are a good mixture of the traditional variable-based type of investigation and the more exploratory type investigation. Thus, the investigations set in Ireland have avoided the problems encountered in the UK where investigations initially were restricted solely to exploring relations between variables, i.e. the emphasis was on identifying one (or more) independent variables which were manipulated independently of other factors which were then controlled to ensure a 'fair test'. The problem of restricting the type of investigations in the UK was summarised by Gott and Duggan as follows:

If we take a restricted view of investigations as being solely to do with variables and numerical data, then large swathes of science ……can become neglected. This has proved a problem with the National Curriculum in the UK. A broader viewpoint would consider not simply variable based tasks but also other types of investigative work….. We should regard focussing on variable-based tasks as being no more than a start (Gott and Duggan, 1995, pp48-49).

Response of Teachers to Practical work at Junior Secondary School level

A survey was carried out by the Irish Science Teachers' Association (Higgins, 2009) to ascertain the views of its members regarding their experience of implementing the 2003 Junior Certificate science syllabus. A total of 310 teachers completed the survey (response rate = 31.4%) which yielded some interesting results about science practical work being carried out in Ireland. These results are summarised under the following headings:

(i) Access to laboratories and laboratory technicians

In the majority of schools (71.4%) there were between three and five science class groups in third year of secondary school. However, most schools (75.7%) had three or less laboratories and this resulted in a lot of pressure being placed on teachers to get access to laboratories in order to carry out the practical work required by the syllabus. In fact, only 39% of third year science lessons were held in a laboratory. In Ireland the pressure on teachers is increased by the fact that schools do not receive funding from the state to employ laboratory technicians. A small proportion of schools (11%) reported that they employed laboratory technicians and these were mainly fee-paying schools.

(ii) Response to Coursework A practical work

The lack of laboratory technicians and the issue of access to laboratories are two factors which may partly explain the fact that 79% of respondents indicated that the introduction of Coursework A (the 30 mandatory experiments) has increased their workload Further light is thrown on this matter by the following explanations given by teachers:

- ✓ *Preparation and cleaning up after practical work take a lot of time.*
- ✓ *The writing up of the practical activities takes up a huge amount of time.*
- ✓ *There are too many mandatory experiments to be undertaken.*
- ✓ *Students' absences from class require experiments to be repeated.*

The preparation for laboratory work and cleaning and tidying up of the laboratory after laboratory work was the main reason why teachers felt their workload had increased with the introduction of the revised Junior Certificate Science syllabus. Teachers also found that because of the necessary preparation and clean up of the laboratory they had to sacrifice the majority of their free time to carry out these activities. Some teachers reported that they either had to come to school

Table 2. Some examples of Coursework B investigations assigned by State Examinations Commission

Biology
A gardener suggests that the length of time taken for marrowfat peas to germinate is decreased if they are soaked in water in advance. Carry out a quantitative investigation of this suggestion.
Carry out a quantitative survey of the plant species in a local habitat.
Florists often supply a sachet of flower food/preservative with bunches of cut flowers. Carry out an investigation to compare the effectiveness of using a commercially supplied flower food/preservative with two other household substances as additives to prolong the life of cut flowers in a container of water.
Chemistry
Investigate a range of plant pigments to evaluate their effectiveness as acid-base indicators.
Investigate how the concentration of a hydrogen peroxide solution affects the speed at which it decomposes to produce oxygen gas.
Compare by way of investigation the abilities of different indigestion remedies to neutralise excess stomach acid.
Physics
Investigate the relationship between the temperature of a rubber squash ball and the height to which it bounces.
Carry out an investigation of the relationship between the length of a metallic conductor (e.g. nichrome wire) and its resistance.
Clothes made from certain fabrics, e.g. denim, are not suitable for hill walking or mountain climbing. Carry out an investigation to compare the thermal insulating properties of three different fabrics when they are dry and when they are wet. Denim must be included as one of the three fabrics.

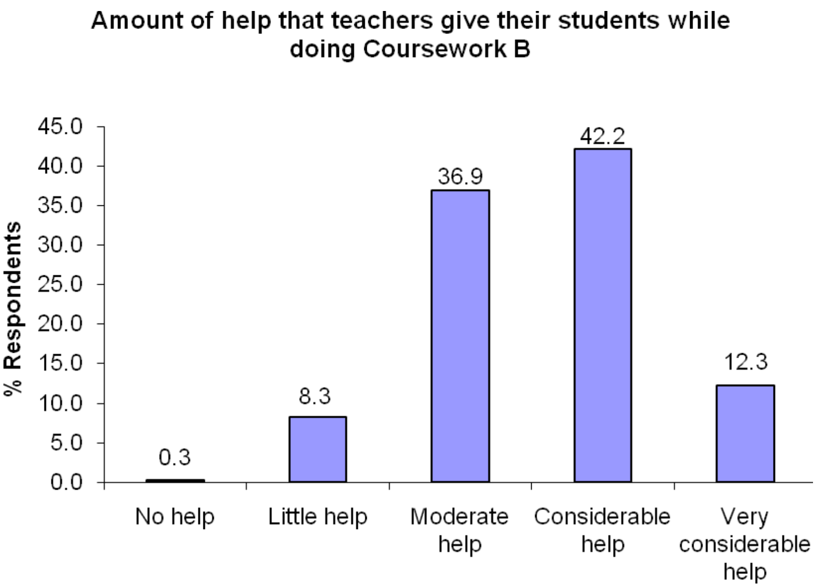

Figure 1. Indication given by teachers of the amount of help given to students carrying out the two investigations of Coursework B.

in the morning one hour before school began or else they had to work an hour or more after school in the evenings.

(iii) Response to Coursework B practical work

When questioned about the Coursework B investigations, 96% of respondents stated that students carry out these investigations themselves. This high percentage is probably related to the fact that this coursework is worth a total of 25% of the marks in the Junior Certificate Science examination and hence is taken seriously by teachers and students.

While, it is very encouraging that such a high percentage of students carry out the investigations themselves, it is clear from Fig.1 that the majority of teachers give a considerable amount of help to their students.

In addition, the majority of teachers (71.8%) reported that a significant amount of time (4 – 6 weeks) is spent completing the coursework B investigations. Some of the key comments made by the respondents to explain the length of time spent completing the investigations may be summarised as follows;

- ✓ *The students need a lot of help and guidance.*
- ✓ *The students find the language in the pro-forma booklet of the State Examinations Commission difficult to understand and this must be explained to them.*
- ✓ *The amount of time spent depends on the ability range in the class*
- ✓ *Health and safety issues – the experiment must be explained in detail.*
- ✓ *Brainstorming takes time.*
- ✓ *Apparatus must be set up for the class and students helped through the investigation.*

However, it is clear that the amount of time spent by students on coursework B has impacted on the course in other ways. A very high percentage of teachers (95.7%) expressed the opinion that the introduction of coursework B has affected the completion and revision time of the course. Unfortunately, this extra pressure appears to have led to a negative impact on teachers' views regarding this type of practical work.

When teachers were asked to indicate their level of agreement with the statement 'Coursework B is an accurate indicator of students' ability to carry out science investigations', it is significant that 68.7% of respondents either 'disagreed' or 'strongly disagreed' with this statement (Fig. 2).

Teachers gave the following comments in relation to their disagreement of the above question:

- ✓ *One student does the investigation and the weak students just copy it down.*
- ✓ *No marks are allocated for skills learned when carrying out the investigations.*
- ✓ *Marking the State Examinations Commission booklet which is completed by the students is not assessing how well the students have performed the investigation – it only tests the student's ability to write and present information neatly.*
- ✓ *Coursework B is a test of the teacher, not the student.*
- ✓ *Students receive help from others, e.g. parents, relatives and fellow students.*

The problem of assessing how well students perform investigations has been discussed by Roberts and Gott (2004), who echo some of the issues raised in the above comments. They make the point that assessing the complex activity of an investigation is a research task in itself and would involve detailed checklists and interviews with students while carrying out the investigation or after the investigation. However, whilst this is a valid assessment, it would not be a practical proposition in Ireland where approximately 50,000 students are assessed for the Junior Certificate examination. Hence, assessment of the investigations in Ireland is restricted to asking the students to record their work under various headings in a booklet supplied by the State Examinations Commission. This booklet is then marked by the same external examiner who marks the written examination paper of that student. Interestingly, Welford, Harlen and Schofield (1985) found in their report for the Assessment of Performance Unit that older students (aged 15) were fairly accurate in their reporting of investigations. Whilst Baxter, Shavelson, Goldman and Pine (1992) found that inexperienced students showed a low level of agreement between observations and reports, training supplied to these students resulted in a reasonable correspondence between actual performance and the students' reports.

The question of the reliability of the assessment of investigations in Ireland was raised by many teachers when asked whether they would like to see coursework B type investigations introduced to the senior cycle science subjects. A total of 74.3% of respondents disagreed with such a proposal and their responses are summarised as follows:

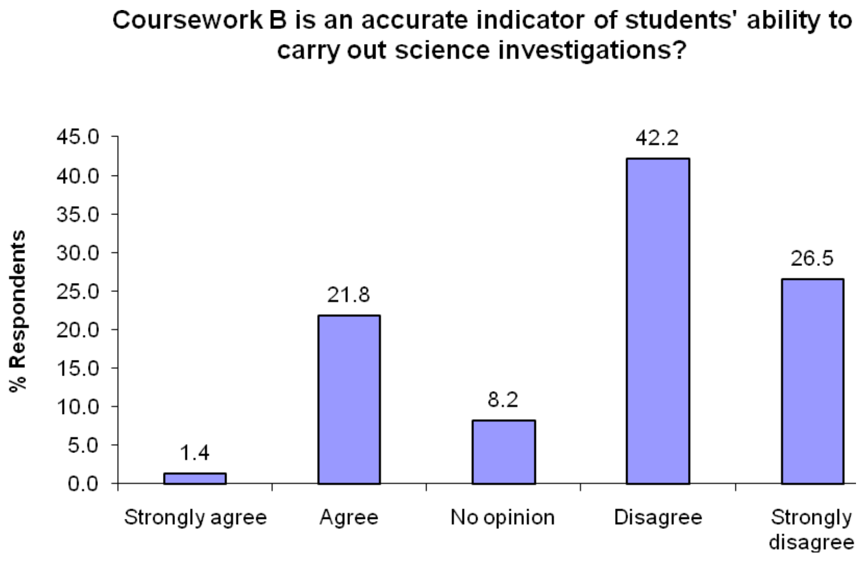

Figure 2. Response of teachers to indicate their level of agreement with the statement 'Coursework B is an accurate indicator of students' ability to carry out science investigations'

- ✓ *It discourages the Junior Certificate science students from further study of science.*
- ✓ *Investigations are not a good measure of a student's ability at practical work.*
- ✓ *An external examiner should monitor a practical exam*
- ✓ *Investigations involve more work for the teachers and more time taken up doing it.*
- ✓ *Teachers have to give lots of help to the students and it would not be a fair exam at senior cycle level.*

The question of reliability of assessment of investigations was discussed by Roberts and Gott (2004) who concluded that one needs to do lots of investigations of different types and in different contexts (lab, field, category of investigation, etc) and then average out the marks assigned to the students. They suggest that one would need up to ten assessed investigations to be reasonably sure that the result was a reliable predictor of future ability to carry out investigations. Questions regarding the reliability and validity of science coursework in the UK were raised by the Qualifications and Curriculum Authority (2005) who summarised the situation as follows:

Teachers for both GCE and GCSE science referred to coursework as 'jumping through hoops' in order to maximise marks, and regarded coursework as a poor educational tool. Teachers and moderators stated that since the introduction of coursework there had been a narrowing of the curriculum, with teachers using only a small range of investigations or practical experiments in order to satisfy the qualification requirements (Qualifications and Curriculum Authority, 2005, p10).

In Ireland, there appears to be a direct contradiction between the concept of what can be achieved by investigations as outlined in the introduction of the syllabus and the experience of the science teachers themselves. Whist the feedback from teachers in Ireland (Higgins, 2009) is not quite as negative as the comments in the QCA report (2005), it is clear that, given the experience of Coursework B investigations, serious questions are now being debated in Ireland regarding the value of these investigations

Practical work at Senior Secondary School level (16 – 18)

The senior cycle of secondary school in Ireland begins after the Junior Certificate examination (12 -15 age group). The fourth year of the secondary school cycle is called Transition Year and is an optional one-year type of 'gap year' in which students study a wide range of subjects and engage in various types of project work. There is no state examination at the end of Transition Year which serves as a stepping stone to the Leaving Certificate programme undertaken by students in the 16 – 18 age groups. Students study seven subjects over two years in the Leaving Certificate programme. At present, physics, chemistry and biology are all examined by means of written examination papers taken at the end of the two-year period. The Leaving Certificate examination is a 'high stakes' examination as places at third level institutions (Universities and Institutes of Technology) are allocated on the basis of the marks obtained by students in their best six subjects.

There has been considerable disquiet for a number of years over the status and assessment of practical work at Leaving Certificate level. Practical work has historically been assessed through the use of questions on the written papers in the Leaving Certificate examination. There have been two particular, and linked, concerns about practical work at Leaving Certificate level. The first of these centred on the extent to which the use of written questions provided a valid assessment of practical abilities. The second is about the nature of the experience of practical work gained by Leaving Certificate students. It was felt that there was a danger that the limited nature of the assessment was indirectly encouraging many science teachers to include in their lessons only the minimum amount of practical work necessary to answer the written examination questions.

Allied to the concerns about practical work, there is considerable concern in Ireland over the trend of falling numbers of students taking physics and chemistry as subjects in the Leaving Certificate examination, Fig. 3. During the period 1987 – 2010, there has been a decrease of 26.63% in the numbers of students choosing chemistry and a decrease of 35.74% choosing physics as subjects for the Leaving Certificate programme.

In 2000 new Leaving Certificate physics and chemistry syllabi were introduced and a new biology syllabus was introduced in 2002. Major revisions were made to these syllabi in order to try and enhance their appeal. Among these revisions, mandatory student practical work was introduced in which each student had to carry out a fixed number of experiments in physics (24 experiments), chemistry (28 experiments) and biology (22 experiments). Some examples of the mandatory practical work undertaken by students are shown in Table 3.

The Leaving Certificate syllabus revisions provided the impetus and opportunity to undertake a significant review of the way in which practical work in physics, chemistry and biology is assessed. The course committees responsible for drawing up the new syllabi (the National Council for Curriculum and Assessment, NCCA) held extensive discussions about the role of practical work in science education. The members of these committees, the majority of whom were practising science teachers, felt very strongly that there were considerable educational benefits and motivational factors associated with a properly constructed course in practical work. The aims of practical work as stated in the syllabus were (a) to develop skills in laboratory

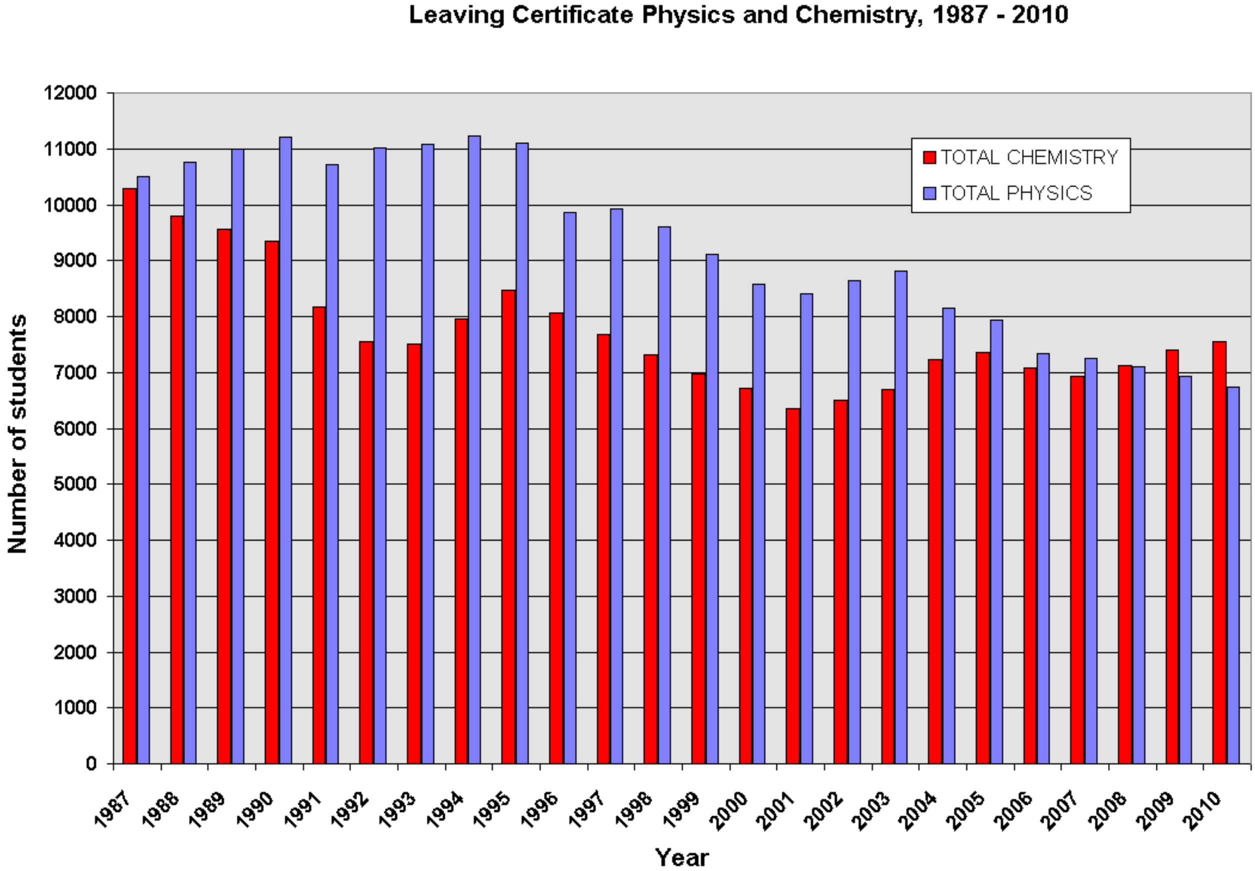

Figure 3. Numbers of students studying the subjects chemistry and physics in the Leaving Certificate examination in Ireland (1987 – 2009)

Table 3. Some examples of Mandatory Student Experiment for Leaving Certificate science students.

Biology
Conduct a quantitative study of plants and animals of a sample area of the selected ecosystem. Transfer results to tables, diagrams, graphs, histograms or any relevant mode.
Prepare and examine one animal cell and one plant cell – unstained and stained – using the light microscope
Investigate the influence of light intensity or carbon dioxide on the rate of photosynthesis.
Isolate DNA from a plant tissue.
Investigate the effect of exercise on the breathing rate or pulse rate of a human.
Chemistry
Tests for anions in aqueous solutions: chloride, carbonate, nitrate, sulfate, phosphate, sulfite, hydrogencarbonate.
Determination of the percentage (w/v) of hypochlorite in bleach.
Studying the effects on the reaction rate of (i) concentration, (ii) temperature, using sodium thiosulfate solution and hydrochloric acid.
Extraction of clove oil from cloves (or similar alternative) by steam distillation
Separation of a mixture of indicators or coloured substances using paper chromatography or thin-layer chromatography or column chromatography.
Physics
Investigation of the relationship between period and length for a simple pendulum and hence calculation of g.
Measurement of the specific latent heat of vaporisation of water.
Measurement of the refractive index of a liquid.
To investigate the variation of the resistance of a metallic conductor with temperature.
Verification of Joule's law

procedures and techniques, carried out with due regard for safety, together with the ability to assess the uses and limitations of these procedures, and (b) to develop skills of observation, analysis, evaluation, communication and problem solving.

The members of the course committee did not see the need to change these aims, but decided that the assessment method needed to be revised to ensure these aims were being adequately met and assessed. Hence the course committees set out the following recommendations concerning practical work:

- ✓ *Practical work should be an integral part of the syllabus*
- ✓ *All students should perform a set of mandatory experiments listed in the syllabus*
- ✓ *Students should be given credit for practical work.*
- ✓ *There should be an assessment of the practical work done by each student*
- ✓ *The assessment should be valid, fair and impartial.*
- ✓ *The assessment should be externally monitored.*
- ✓ *The student's record of practical work carried out should be central to the assessment*
- ✓ *The practical assessment should be worth 15% of the overall mark in the Leaving Certificate examination*

Four years prior to the implementation of the syllabi, the Department of Education and Science in Ireland set up a Steering Committee to investigate if a system could be devised to give students credit for practical work which they would perform over the two-year Leaving Certificate chemistry and physics courses. This project became known as the 'Feasibility Study on Practical Assessment for Leaving Certificate Physics and Chemistry'. The main thrust of the Feasibility Study was to provide a reliable and valid means of assessing practical abilities and, in doing so, to raise the profile of practical work in schools by giving both students and teachers more confidence in undertaking practical work. In devising a new system, the Steering Committee recognised that it would have to operate within certain practical constraints relating to time and cost. Additionally, the Committee felt that any change which was perceived as very radical by teachers would be less than effective as it would require too great a shift in practice.

Three assessment models were considered: (i) teacher assessment, (ii) an end-of-year examination and (iii) the use of an external examiner as assessor. The advantages and disadvantages of the first two models have been well-documented (Fairbrother, 1991; Jenkins, 1995). Course-based teacher assessment permits a wider range of practical abilities to be tested and gives students more opportunities to demonstrate their abilities, but places very high demands on the time and skills of teachers. The end-of-course practical examination is economical of time and could be described as more objective in the sense that the teacher is not involved in making the assessment. However, it runs the risk of not providing adequate opportunities for students to demonstrate the abilities they have developed over the course, and encouraging teachers to focus practical work on those skills and techniques most likely to be tested in the practical examination.

A move to a system of continuous assessment of practical abilities by teachers was not considered to be feasible. In part, this was because it represented a large shift from current practice. Additionally, teachers expressed very strong concerns over the reliability of teachers assessing their own students. For the teachers, an external assessment system was seen to be the 'fairest' way of assessing practical abilities.

The most obvious choice of external assessment, the end-of-year practical examination, was also considered by the Steering Committee and rejected. As already mentioned, the vast majority of schools in Ireland do not have laboratory technicians and it was felt that the preparation for an end-of-year practical examination would put an undue demand on teachers' time and resources. The Steering Committee therefore decided to explore the possibilities of assessing practical work through the use of a visiting examiner. Though such a method is used in the oral examination of modern foreign languages in Ireland, it has not been widely employed in the assessment of practical work in science. The Committee therefore felt it was highly desirable to undertake a trial in a number of schools of the proposed new assessment model to test its viability for implementation on a national basis. The proposed method of practical assessment developed by the Steering Committee had the following aims:

- ✓ *To test abilities not capable of being assessed by means of a written examination.*
- ✓ *To test the ability to interpret data, to assess the accuracy of experimental results, to test the understanding of practical work and equipment to a far greater degree than is possible in a written examination.*
- ✓ *To give credit to students for the practical work done by them during the course.*
- ✓ *To devise a means of assessing practical abilities which provided both a valid assessment and was efficient in terms of resources, including staff time and costs.*

In addition to the above aims, it was also hoped that the course of practical work and the proposed model of assessment would help to achieve the following:

- ✓ *To motivate students through their direct involvement in practical work.*
- ✓ *To provide an extra incentive for teachers and students to carry out the mandatory practical work.*
- ✓ *To provide all students with opportunities for acquiring and developing a range of practical skills and abilities.*

Given the constraints outlined above, an assessment model was developed involving a 20 minute assessment of each student. This assessment was carried out by an external examiner in which five minutes were spent reviewing and grading the student's notebook on the basis of the number of experiments written up and 15 minutes spent interviewing the student. A total of 60 marks (i.e. 15% of the 400 marks on the Leaving Certificate physics and chemistry written papers) were allocated for this practical assessment. Of the 60 marks allocated, 20 marks were assigned for the work in the student's practical notebook and 40 marks were assigned for the assessment of the student's proficiency at practical work. In the assessment of the student's proficiency at practical work, marks were awarded for manipulative skills, observational and measurement skills, recognition and understanding of apparatus, and understanding of the experimental work as written up in the student's notebook.

The structure of the marking system in chemistry is given in Table 4. A similar system was used for the assessment of physics practical work but as the physics model is not as fully developed as the chemistry model, it will not be discussed further in this paper.

The teacher made the class set of laboratory notebooks available to the external examiner at the beginning of the examination period. The interview took place in a school laboratory. As the practical assessment model did not aim to assess the student's recall of practical procedures, the assessment model allowed students to consult their notebooks during the interview as appropriate.

To ensure that the assessment was carried out as reliably as possible, all external examiners underwent training over a two-week period. This training involved lectures and workshop sessions conducted by the external moderators and the Science Inspectorate of the Department of Education. Some of the training sessions were spent in schools, where each examiner was observed examining students by their fellow examiners and moderators. After each student was examined, the examiners and moderators compared and discussed the marks each of them allocated in the testing of the particular student. In this way, a consensus was reached over the details of the marking scheme and its method of implementation. All those involved expressed their satisfaction over the reliability of the assessment method.

The Feasibility Study also involved looking at two particular aspects of the validity of the new model, the content validity and the face validity. The content validity of the new model (i.e. the extent to which the assessment model represented a fair assessment of the aims) was explored through the use of Bloom's Taxonomy of Educational Objectives (1979) to analyse both the old and new models.

The face validity of the new model (i.e. the extent to which the examiners and teachers felt confident that the model was providing a good assessment of the specified practical abilities) was explored through the use of questionnaires with examiners and teachers.

Findings of Feasibility Study on Assessment of Practical Work

In keeping with recommendations of sample size and statistical considerations in the literature (Cohen, Manion & Morrison, 2000), a 5% sample of the schools offering physics and chemistry were chosen for participation in the Feasibility Study. These schools were chosen from the 193 schools that applied to participate in the study. A total of 29 schools in chemistry and 30 schools in physics were selected to participate in the study. Selection of the examiners for physics and chemistry (12 in each subject) was made by the Inspectorate of the Department of Education. These examiners were highly experienced teachers with a good track record in using practical work in their teaching. A training course was provided for these examiners. Additionally, during the two-week period in which the assessment of students was undertaken, three examiners took on the role of moderators. Each examiner was visited by a moderator to ensure (i) that the assessment was carried out in accordance with the guidelines and (ii) that standards were correctly applied. Examination centres were also visited by the Inspectorate and by the project officer appointed by the Steering Committee.

At the conclusion of the practical assessment, all examiners and teachers involved in the study filled in detailed questionnaires. These questionnaires sought their opinions on the assessment model, the various elements of the assessment procedure and the extent to which syllabus objectives were being met.

Table 4. Marking scheme for the assessment of practical work in chemistry

Type of assessment	Number of marks
Laboratory Notebook (20 marks)	
Experiments completed and recorded	8 marks
Standard of practical reports	12 marks
Oral Assessment (40 marks)	
Manipulative skills	12 marks
Observation / measurement skills	12 marks
Recognition / understanding of apparatus	8 marks
Understanding of experimental work	8 marks

Full details of the outcomes and evaluation of the Feasibility Study are reported elsewhere (Bennett and Kennedy, 2001) but the main outcomes are summarised as follows:

1. When students who participated in the Feasibility Study were 'tracked' to ascertain how they performed on the questions examining practical work on the written examination papers in chemistry and physics, it was found that there was a low correlation between the marks obtained on the written examination and the marks obtained by the same students in the Feasibility Study.

Correlation analysis was carried out using the standard methods outlined in the literature (Weiss & Hassett, 1993). Given that one aim of the new model of assessment was to assess abilities not capable of being tested in written examination questions, the above finding was not entirely unexpected. In order to offer a more detailed explanation for this finding, both the old and new assessment models were subjected to analysis using Bloom's Taxonomy of Educational Objectives (1979). Essentially, the Taxonomy provides a hierarchy of objectives in terms of level of sophistication, grouped into three 'domains', cognitive, psychomotor and affective. The analysis of each individual part of each of the written questions examining practical work in physics and chemistry revealed that the questions examined a rather limited number of areas at the lower levels in the cognitive domain, mainly knowledge, comprehension and application. As would be expected from a written examination, none of the areas in the psychomotor or affective domains was assessed. The analysis also revealed that key areas in the cognitive domain which it could be argued are central to practical work (analysis, synthesis and evaluation) were not assessed to any great extent by the written examination questions on practical work. The analysis of the new assessment model indicated that a much wider range of abilities was being assessed in both the cognitive and psychomotor domain. For example, tasks set in the new model required students to analyse and evaluate data they had collected, demonstrate proficiency in selected manipulative skills and demonstrate manual dexterity in carrying out procedures safely and accurately.

The new model was not designed to measure any components of the affective domain as it was felt that these, if they were to be assessed, could only be monitored using a continuous assessment model.

The above analysis appears to suggest that it is unlikely that the 'practical' questions on the examination papers assess adequately the practical work carried out by students but merely examine the same areas as assessed by the theoretical questions on the examination paper. The analysis confirms that the questions used on the written papers examined practical abilities to only a very limited extent. Set in the context of the aims of practical work as specified in the syllabus, it is clear that the content validity of the new model of assessment is much more satisfactory than that of the old model.

2. The marks obtained by students in the assessment of practical work as carried out in the Feasibility Study were higher than those obtained in the assessment of practical work as tested on the Leaving Certificate higher level chemistry examination papers.

This may be due to the fact that all schools that participated in the Feasibility Study were volunteer schools. In general, the schools that volunteered would be expected to be strong in the area of practical work and their teachers would feel confident in putting their students forward for assessment. Thus, some degree of selection bias is, perhaps, inevitable, because of the voluntary nature of school participation. The students in the participant schools would have developed the necessary skills and abilities that were assessed in the Feasibility Study on Practical Assessment and hence would be expected to score high marks. Evidence for this was given by the examiners in their questionnaire responses.

Also, from the analysis using Bloom's taxonomy of the examination questions focusing on practical work, it is clear that a wider range of practical skills was measured in the Feasibility Study as compared with the relevant questions on the Leaving Certificate examination papers. Many of the skills and abilities assessed in the Feasibility Study are not assessed in the questions examining practical work on the written paper.

3. The examiners were largely very positive about the new assessment model, with questionnaire responses indicating the relevant aims were generally assessed 'extremely well' or 'very well'.

Questionnaires were used with examiners and teachers in order to gather information on both practical and educational aspects of the new model of assessment. Certain sections explored matters to do with the face validity of the model. In particular, both questionnaires contained a common section which presented the respondents with the aims of practical work as specified in the syllabus, and asked them to indicate how well they felt the new model assessed each of these aims on a five point Likert scale running from 'extremely well' to 'badly'. The respondents were also asked to expand on these ratings in written comments. Typical comments included:

- ✓ *The combination of tasks and questions gave candidates an opportunity to display their practical knowledge/experience (or otherwise).*
- ✓ *I feel they [i.e. the tasks] have been very well selected, producing a model which provides an accurate perception of the student's facility with, and understanding of practical work.*

- ✓ *On balance I feel it is quite a realistic and viable model to contemplate introducing into the Leaving Certificate exam. It certainly strives to reward practical work carried out and practical skills acquired during the course.*

Such comments indicate that the new model had face validity in the eyes of the examiners. Further evidence for the face validity of the model is provided by the responses on the teachers' questionnaire. All the teachers were positive about the new model. As was the case with the examiners, relevant aims were generally seen as being assessed 'extremely well' or 'very well'. Comments made by the teachers included:

- ✓ *An excellent way to determine a student's confidence and familiarity in practical situations.*
- ✓ *This must be part of the assessment. To be good at any practical task, one must be familiar with the tools and know how they work.*
- ✓ *A good indication of the practical work done.*

Where changes were suggested by the examiners and moderators, they were of a minor nature and involved some 'fine tuning' of the assessment model.

In reaching overall conclusions about the Feasibility Study on Assessment of Practical Work, it is necessary to look at the findings in the context of both the original specific and more general aims of the study. The principal aim of the study was to devise a means of assessing practical abilities which provided both a valid assessment and was efficient in terms of resources. All the evidence collected would support the claim that these aims had been achieved. Additionally, analysis of the data collected indicated very strongly the inadequacies in the current model of assessment of practical skills and abilities, with written examinations questions on practical work examining only a very limited range of abilities.

CONCLUSION

Over the past ten years, considerable curriculum reform has taken place in Ireland with the introduction of a new science syllabus at Junior Certificate level and the introduction of new syllabi in physics, chemistry and biology at Leaving Certificate level. The introduction of these new syllabi has focused the spotlight on the role of practical work in science education. Whilst the catalyst for reform has been the report of the Task Force on the Physical Sciences and the concerns of falling numbers of students choosing the physical sciences at Leaving Certificate level, the new Junior Certificate science syllabus has not yet fulfilled the expectations of those who hoped that it would succeed in increasing the uptake of the physical sciences at senior level. In addition, as in other countries, it is clear that considerable debate is taking place among science teachers regarding the value of Coursework B investigations being carried out at Junior Certificate level.

The Feasibility Study on Assessment of Practical Work has clear implications for the future assessment of practical work in the Leaving Certificate science examinations. There is a need for changes to be made in the assessment procedure as it stands at present (i.e. assessment only by means of a written examination) in order to give a more valid and fairer assessment of students' ability at practical work. There is strong evidence to support the claim that the use of written examination questions to assess practical abilities is likely to permit only a very limited range of skills to be assessed. On the basis of the research evidence which emerged from the study, the Steering Committee felt confident in recommending the introduction on a national basis of the model that was trialled in the Feasibility Study. At the time of writing, the National Council for Curriculum and Assessment is carrying out further studies involving modifications and further trials of the Feasibility Study model to make it more cost effective. It is hoped that this modified model will be implemented in the near future.

Thus, considerable debate and discussion is taking place in Ireland on the role of practical work at both Junior Certificate level and Leaving Certificate level. Hopefully, the outcome of these debates will help to clarify the role of practical work and chart the way forward for the future of science education in Ireland.

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