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The role of investigations in promoting inquiry-based science education in Ireland

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ABSTRACT: This paper describes recent developments in Ireland to promote a greater interest in science among students in the 12-15 age group by means of practical work involving Inquiry Based Science Education (IBSE). The tasks, know as Investigations, are a component of the assessment of the subject Science which is studied as part of the Junior Certificate examination for 15 year-old students. The introduction of Investigations has been one of a number of responses to 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. This report 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 and the role of Investigations in promoting IBSE in Ireland.

KEY WORDS: Inquiry Based Science Education, IBSE, practical work, assessment

INTRODUCTION

Over the past twenty years there has been considerable disquiet expressed about the decreasing numbers of students opting to study science, particularly physics and chemistry, in the senior cycle of secondary school in Ireland (Task Force, 2002). 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 number. 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

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an action strategy to address the many inter-linking facets of the problem (Task Force, 2002).

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 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, 1882 p.22).

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 p.25). 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's 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 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 p.225)

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 (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 p.4)

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 p.4)

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 p.21)

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 p.7)

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.

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, 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.

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, 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 p.6)

In this paper, the Coursework B type Investigations will be indicated using a capital "I" to distinguish them from the more general term "investigation". 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 each student in a booklet 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.

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.
- Compare by means of investigation the vitamin C content of a number of commercial and fresh fruit juices.

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.
- Compare by means of investigation methanol, propan-1-ol and candle wax in terms of their effectiveness as fuels.

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.

- Investigate any two factors that affect the output from a solar cell when light is shone on it.

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 p.14). 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 p.48-49)

INVESTIGATIONS AND IBSE IN IRELAND

In Ireland the science Investigations are part of an effort by the National Council for Curriculum and Assessment (NCCA) to promote Inquiry Based Science Education (IBSE) among students in the 12-15 age group. Inquiry based teaching has been described as "the art of developing challenging situations in which students are asked to observe and question phenomena; pose explanations of what they observe; devise and conduct experiments in which data are collected to support or contradict their theories; analyse data; draw conclusions from experimental data; design and build models; or any combination of these. Such learning situations are meant to be open-ended in that they do not aim to achieve a single "right" answer for a particular question being addressed but rather involve students more in the process of observing, posing questions, engaging in experimentation or exploration, and learning to analyse and reason" (Hattie, 2009)

In Europe the Rocard Report (2007) has shone the spotlight on Inquiry Based Science Education and has led to the European Commission making IBSE the main focus of it FP6 and FP7 Science and Society calls for research funding.

> "Improvements in science education should be brought about **through new forms of pedagogy**: the introduction of inquiry-based approaches in schools, actions for teachers training to IBSE, and the development of teachers' networks should be actively promoted and supported."
>
> (Rocard, 2007 p.3)

In addition, the Inter Academy Panel (IAP), a global network of Science Academies, in its recommendations from an international conference held to discuss IBSE stated that "that the scientific knowledge, understanding, skills and attitudes needed by all students, regardless of whether or not they will proceed to further study or employment in science-based occupations, are best developed through inquiry-based science education (IBSE) which begins in the primary school and continues throughout the compulsory years of schooling. (Inter Academy Panel, 2010 p.18). Also, the Working Group of the All European Academies (ALLEA) gave a ringing endorsement to IBSE in their publication *A renewal of science education in Europe: Views and Actions of National Academies*:

> "In order to maintain the passion for science and technology among the young and prepare a scientific and technical workforce sufficient for today's knowledge-based societies, 25 European National Academies, all engaged in promoting the renewal of science education, plead for the extension of inquiry-based science education at primary and lower secondary school, and for a strong effort in the sphere of science teacher training (pre- and in-service)".
>
> (ALLEA, 2012. p.1)

Thus, there is strong emphasis not only in Ireland but throughout Europe on the need to promote Inquiry Based Science Education in our science curricula. The Irish Science Teachers' Association (ISTA), through its membership of ICASE, is very aware of these developments. Hence, in co-operation with the School of Education of University College Cork, the ISTA carried out a survey of ISTA members (Higgins, 2009) to ascertain the views of its members regarding their experience of implementing the 2003 Junior Certificate science syllabus. Particular emphasis was placed in the survey on the role of practical work in the syllabus and on the experience of teachers in implementing the mandatory set experiments (commonly referred to as "Coursework A") and the Investigations (commonly referred to as "Coursework B"). 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 (15 year old students). 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 commonly occurring 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 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 Investigations ("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.

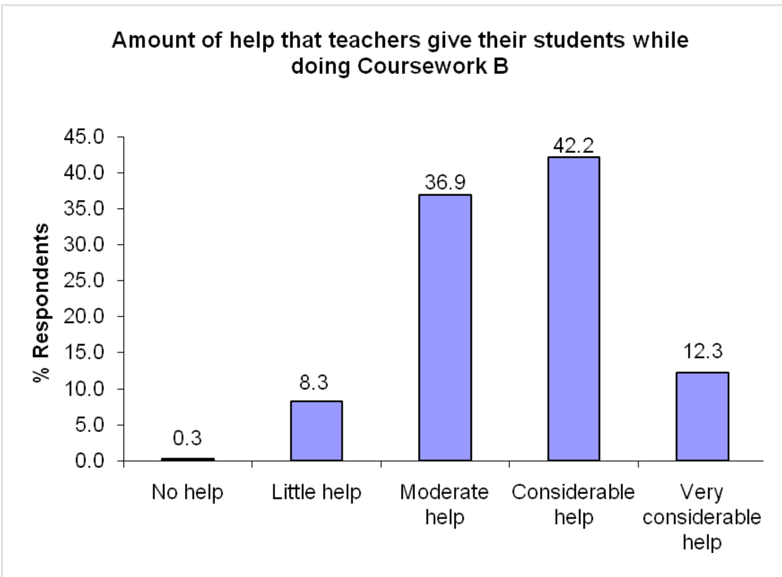

Figure 1. Indication given by teachers of the amount of help given to students carrying out the two Investigations of Coursework B

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 the two Investigations has impacted on the course in other ways. A very high percentage of teachers (95.7%) expressed the opinion that the introduction of the Investigations 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, Figure 2.

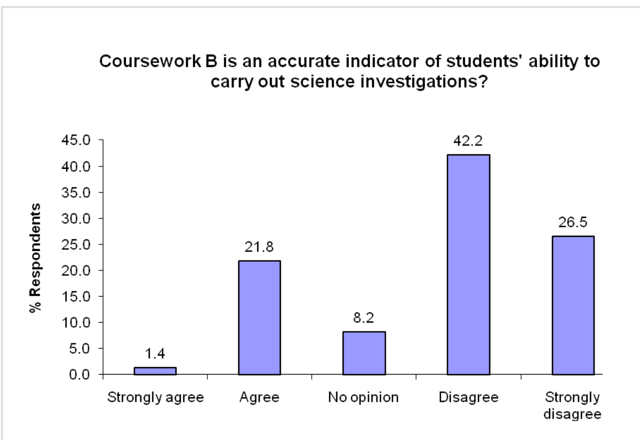

Figure 2. Response of teachers to indicate their level of agreement with the statement "Coursework B is an accurate indicator of students' ability to carry out science investigations"

Typical comments given by teachers in relation to their disagreement of the above question are:

- One student of good ability may carry out the Investigation and the weak students just copy it down.
- No marks are allocated for skills learned when carrying out the Investigations.
- The booklet in which students write up the Investigations is externally marked by the government's State Examinations Commission. However the mark assigned 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 may 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 heading 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 et al. (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 et al. (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 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:

- 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 p.10)

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 working in the school laboratory with their students. 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 impact of these Investigations and the degree to which these Investigations are promoting Inquiry-Based Science Education.

At the time of writing there is considerable research activity taking place in Ireland on Inquiry Based Science Education in EU-funded projects, e.g. PROFILES (Professional Reflection Oriented Focus on Inquiry-based Learning and Education through Science), ESTABLISH (European Science and Technology in Action: Building Links with Industry, Schools and Home) and SAILS (Strategies for the Assessment of Inquiry Learning in Science). Hopefully, the research findings of these projects will help to inform the development of IBSE in Ireland and also at an international level.

IMPACT OF IBSE APPROACHES IN SCIENCE EDUCATION

A considerable amount of research has been carried out in the area of the effectiveness of IBSE. For example, Bredderman (1983) found that when teaching science using inquiry methods using direct experience, experimentation and observation, the effect on developing science process skills (e.g. planning, observing, analysing, drawing conclusions, etc) was much greater than the effect on developing science content. This type of finding was also made by other researchers. Shymansky et al. (1990) also found greater effects of inquiry based teaching on process rather than on content and the effects were greatest at elementary level and decreased as students progressed through the educational system. Smith (1996) found larger effects from inquiry methods in critical thinking skills than in achievement and less in laboratory skills and process skills. Similarly, Bangert-Drowns and Bankert (1990) found clear evidence that inquiry-based instruction can foster critical thinking. In addition, Gott and Duggan (1995) found that the investigations developed by the Assessment of Performance unit "developed innovative techniques which worked well in the classroom as curriculum material rather than merely as assessment items. In particular, the investigations were found to be of considerable interest to pupils in terms of enjoyment".

Minner et al (2010) synthesised research findings from research conducted between 1984 and 2002 to address the research question *What is the impact of inquiry science instruction on K-12 student outcomes?* They found that across 138 studies the findings indicated a clear, positive trend favoring inquiry-based instructional practices, particularly instruction that emphasise student active thinking and drawing conclusions from data. They also found that teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than are strategies that rely on more passive techniques, which are often necessary in the current standardized-assessment laden educational environment.

In a synthesis of over 800 meta-analyses relating to achievement, Hattie (2009) places inquiry-based teaching well down the list (86^{th} place in list of 138 strategies) in terms of the effectiveness of teaching approaches on achievement. Hattie uses a scale of $d = 1.0$ to indicate an increase of one standard deviation on the outcomes. A one standard deviation increase is typically associated with advancing students' achievement by two to three years, improving the rate of learning by 50% or a correlation between some variable and achievement of r = 0.5. When implementing a new program, an effect size of 1.0 would mean that, on average, students receiving that treatment would exceed 84% of students not receiving that treatment. (Hattie 2009). In the case of Inquiry-Based Teaching, Hattie assigns a d value of 0.31 to indicate the effect of Inquiry-Based Teaching on achievement, Figure 3. This is less than the average d value of 0.40 which summarises the typical effect of all possible influences in education and is the benchmark used to judge effects in education.

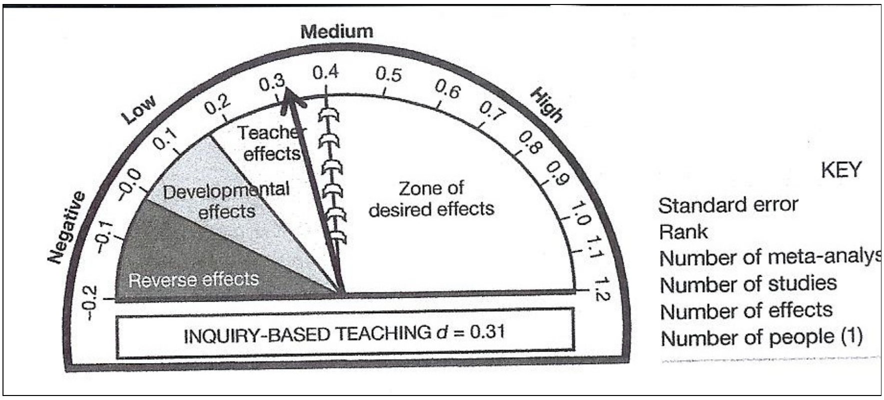

Figure 3 . The effect of Inquiry-Based Teaching on student achievement (Hattie 2009)

On the other hand, research has shown that Direct Instruction, has a greater effect on student achievement than on Inquiry-Based Teaching. Hattie (2009) assigns a d value of 0.59 to Direct Instruction, Figure 4.

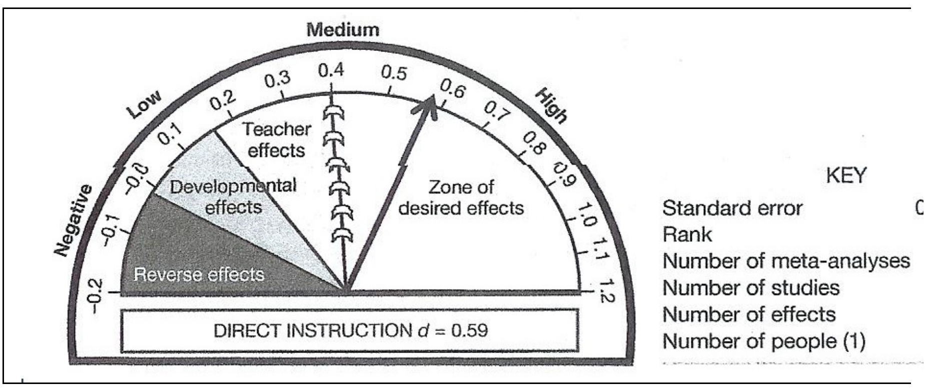

Figure 4 . The effect of Direct Instruction on student achievement (Hattie 2009)

Direct instruction should not be confused with didactic teaching. Hattie (2009) discusses in detail the main characteristics of Direct Instruction (Table 3) and summarises it as follows:

> "In a nutshell: The teacher decides the learning intentions and success criteria, makes them transparent to the students, demonstrates them by modelling, evaluates if they understand what they have been told by checking for understanding, and re-telling them what they have been told by tying it all together with closure"
>
> (Hattie, 2009, p. 206)

Table 3. The seven major steps involved in Direct Instruction (Hattie, 2009)

Direct Instruction involves seven major steps:

1. Before the lesson is prepared, the teacher should have a clear idea of what the *learning intentions* are. What, specifically, should the student be able to do, understand, care about as a result of the teaching?

2. The teacher needs to know what *success criteria* of performance are to be expected and when and what students will be held accountable for from the lesson/activity. The students need to be informed about the standard of performance.

3. There is need to *build commitment and engagement* in the learning task. In the terminology of Direct Instruction, this is sometimes called a "hook" to grab a student's attention. The aim is to put students into a receptive frame of mind; to focus student attention on the lesson; to share the learning intentions.

4. There are guides to *how the teacher should present the lesson* – including notions such as input, modelling, and checking for understanding. Input refers to providing information needed for students to gain the knowledge or skill through lecture, film, tape, video, pictures, and so on. Modelling is where the teacher shows students examples of what is expected as an end product of their work. The critical aspects are explained through labelling, categorizing, and comparing to exemplars of what is desired. Checking for understanding involves monitoring whether students

have "got it" before proceeding, it is essential that students practice *doing it right,* so the teacher must know that students understand before they start to practice. If there is any doubt that the class has not understood, the concept or skill should be re-taught before the practice begins.

5. There is the notion of *guided practice.* This involves an opportunity for each student to demonstrate his or her grasp of new learning by working through an activity to exercise under the teacher's direct supervision. The teacher moves around the room to determine the level of mastery and to provide feedback and individual remediation as needed.

6. There is the *closure* part of the lesson. Closure involves those actions or statements by a teacher that are designed to bring a lesson presentation to an appropriate conclusion; the part wherein students are helped to bring things together in their own minds, to make sense out of what has just been taught. "Any questions? No. OK, let's move on" is not closure. Closure is used to cue students to the fact that they have arrived at an important point in the lesson or the end of a lesson, to help organize student learning, to help form a coherent picture, to consolidate, eliminate confusion and frustration, and so on, and to reinforce the major points to be learned. Thus closure involves reviewing and clarifying the key points of a lesson, tying them together into a coherent whole, ensuring they will be applied by the student by ensuring they have become part of the student's conceptual network.

7. There is *independent practice.* Once students have mastered the content or skill, it is time to provide for reinforcement practice. It is provided on a repeating schedule so that the learning is not forgotten. It may be homework or group or individual work in class. It is important to note that this practice can provide for decontextualisation: enough different contexts so that the skill or concept in which it was originally learned. For example, if the lesson is about inference from reading a passage about dinosaurs, the practice should be about inference from reading about another topic such as whales. The advocates of Direct

Instruction argue that the failure to do this seventh step is responsible for most student failure to be able to apply something learned.

Hattie (2009) points out that where science teachers received in-service training in inquiry methods, students significantly outperformed students in traditional programmes. Analysis of the data gathered by the Irish Science Teachers Association (Higgins, 2009) shows that one of the essential problems encountered by teachers in Ireland was that no nationwide inservice training was provided to teachers to help them adopt an inquiry-based approach to teaching the Investigations. This training has been left to branches of the ISTA to organise their own annual inservice evenings to discuss various approaches to teaching the Investigations that are sent to schools each year. (The author of this article conducts approximately twelve of these inservice courses each year). A relatively small number of approximately thirty teachers in Ireland are involved in the ICASE/University College Cork PROFILES (Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science) project. These teachers have undergone a programme of inservice training in the area of IBSE with a focus on the PROFILES teaching packages developed for teachers in Ireland.

In summarising the research evidence on Inquiry Based Teaching, Hattie (2009) points out that it could have "powerful effects where students have the cognitive capacity to think critically but have not previously been encouraged to think in this way. Overall, inquiry-based instruction was shown to produce transferable critical thinking skills as well as significant domain benefits, improved achievements, and improved attitude towards the subject". In short, the two main advantages of IBSE appear to be an improvement in process skills and an improvement in student attitudes towards science.

CONCLUSIONS AND RECOMMENDATIONS

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 with an emphasis on Investigations to promote Inquiry-Based Science Education. The introduction of this new syllabus has focused the spotlight on the role of practical work in science education and particularly the role of Investigations. The research carried out by the Irish Science Teachers' Association clearly shows that teachers are experiencing considerable difficulties in implementing IBSE in the school science laboratory and in the classroom. Some of these are practical issues such as availability of laboratory space and laboratory technicians. Others are clearly related to the lack of inservice training provided to assist teachers to embrace an IBSE approach to teaching.

Analysis of the data from the survey clearly shows that introducing Investigations into the Junior Certificate Science syllabus does not necessarily mean that teachers automatically adopt an Inquiry Based approach in their teaching. 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. One of the clear outcomes from the research literature is that IBSE approaches to science teaching do result in an increase in the interest levels of students in science. Based on the research evidence outlined in this paper, it does not seem wise to "put all our eggs in the one basket" and promote IBSE as the only approach to effective science teaching. We need to get the right balance between the Direct Instruction approach as interpreted by Hattie (2009) and the IBSE approach as discussed in this paper. The challenge facing science education in Ireland is to ensure that we get the right balance and that our teachers possess the knowledge, skills and resources to embrace IBSE and thus help to achieve many of the objectives of the Junior Science curriculum.

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