Young Researchers

A rapid evidence review of practical independent research projects in science

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A Rapid Evidence Review of Practical Independent Research Projects in Science

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Executive summary

1. Practical independent research projects in science (IRPs) are open-ended research investigations undertaken and led by a student, often with the support of a teacher and/or an adult researcher from a university or industry. For older students, especially post-16, the outcome of the investigation is typically unknown by the student and their teacher.

The focus of the review

2. This rapid evidence review of independent research projects (IRPs) comprised three main strands: a review of the literature, interviews with key informants and five international case studies.

The review methods

Literature review

3. The review of the literature was conducted in accordance with the procedures normally associated with systematic reviews.

4. Four strategies were employed to identify the relevant literature: electronic searches of the standard databases, recommendations made by key informants when they were interviewed, hand searches of recent journals, and literature already known to the review research team.

5. Publications were included in the review if they met a set of criteria drawn up for the review. The overall approach was inclusive, i.e. where publications appeared to offer something of relevance to the review they were included, even if there were insufficient details to enable all the inclusion criteria to be applied.

6. The detailed review and synthesis of the evidence from the literature are based on 39 publications that reported systematically-gathered data on aspects of the impact of IRPs at secondary/high school level on students, teachers and others, such as partner scientists in universities and employers.

The interviews with key informants, including teachers

7. Interviews were conducted with 28 key informants with useful perspectives on IRPs. These included funders of IRPs, people with responsibility for implementing large-scale IRPs, teachers (in schools, colleges, and a University Technical Colleges) and others responsible for the local implementation and running of IRPs. The key informants included people with a range of views about the value of IRPs.

The interviews with students

8. Eight semi-structured group interviews were conducted with students who have participated in IRPs. In total, 39 students aged 11-18 from two schools/colleges were interviewed.

The international case studies

9. Five countries were selected to form the bases of international case studies of IRP work. Three of the countries were chosen based on the literature review: Australia, Israel and the USA. Two were identified through personal contacts: The Netherlands and Singapore.

The evidence on scope and reach

10. IRPs are offered to students in a number of countries, across the secondary/high school age range and in all the major science disciplines. However, evidence from the UK and from the international case studies confirms that it is rare for more than a small minority of students to participate in an IRP.

11. Opportunities to participate in IRP work are offered to students within school in one or more of lesson time, dedicated blocks of timetabled hours and schools science clubs. Outside school hours, students can participate in IRP work as summer schools and camps. Students may also get the opportunity to present their work at science fairs and competitions.

12. There is some evidence to suggest that IRPs work is helping to address the widening participation agenda in science, thought more work in this area would be useful.

13. **The quality of the evidence base on the scope and reach of IRP work is good.** This judgement is based on the evidence from the literature review, interviews with key informants, interviews with students, and international case studies.

The evidence on impact

14. A wide range of features and attributes have been explored, of which the most common are cognitive and affective impacts on students, and teachers' and others' views of the impacts of IRPs.

15. The evidence reveals considerable diversity in the measures used to judge the impact of IRPs, and a pattern of new instruments being developed for each study. It is often difficult to identify sufficient evidence in publications to judge the reliability and validity of the instruments used and the approaches to analysis. It would not be possible to conduct a systematic meta-analysis drawing on the current evidence base.

16. The evidence on impact is extensive, but needs to be set in the following context: (a) reported impact studies are undertaken by people who have been involved in some capacity with the design and implementation of the IRP; (b) those in favour of IRP work predominated in any group of key informants; and (c) the data that emerge from interviews take the form of self-report data.

17. Individually, most studies have a robust design. The frequent involvement of those researching the impact of IRPs in the implementation of the IRP itself does not necessarily adversely affect the impartiality of the design or the reporting of the evidence.

18. The evidence shows positive responses to IRPs from students, gains in students' learning, improvements in students' attitudes to science, suggestions that increased numbers are likely to consider careers in science as a result of their participation in IRPs, and particular benefits for students from traditionally under-represented backgrounds.

19. Students reported that their IRP work had made them aware of a broader range of careers and specialisms available in STEM subjects and STEM-related areas. They also felt that their IRP work had helped them to make decisions about future work and study, and that they had a better idea of the attributes for which employers are looking.

20. The key informants reported that IRPs are challenging for teachers, partners and students, though all groups also felt that the benefits very much outweigh possible drawbacks. The challenges were associated with resource constraints, teacher preparation (both in terms of time and knowledge), teacher confidence in supervising IRPs, identifying potential partners for IRP work, teacher workload and time constraints, and some concern over the potential sacrificing of students' breadth of knowledge for depth in a particular area if students participated in an IRP.

21. Additional benefits for students reported by key information include the development of self-esteem, independence and autonomy, self-regulation, tenacity, time management skills, a spirit of co-inquiry with teachers and a sense of scientific identity.

22. Students reported a number of benefits associated with IRPs that extended beyond the focus of their study. These included presentation skills, confidence, ability to work in a team and employability skills.

23. Students identified challenges associated with balancing their IRP work with their other studies. Some students saw the workload as excessive, with a disproportionate amount of time being allocated to IRPs.

24. An important factor contributing to the success of IRP programmes was organisational culture, structure and support to drive it forward. This might take the form of a structure

within participating schools, such as guaranteed time or a school science club, or an external structure, such as a science competition or fair. IRP schemes undertaken in single schools are rarely reported in the literature.

25. Teachers reported that participation in IRPs provided them with good professional development, personal and professional satisfaction, improved relationships with their students, and a beneficial network of external partners (universities and employers). The importance of a supportive culture in schools was also cited as crucial to the successful implementation of IRPs. IRP providers noted that the opportunities provided by IRPs can enhance teachers' pedagogical skills.

26. **The quality of the evidence base on the measures used to judge the impact of IRPs is fair.** This judgement draws on the evidence from the literature review, which indicates, where detailed information is presented in publications, that the measures used to judge the impact appear to be soundly designed.

27. **The quality of the evidence base on the impact of IRPs is fair to good.** This judgement draws on the evidence from the literature review, the interviews with key informants, the interviews with students, and the international case studies. This judgement has been reached on the basis that the design of individual studies is sound, but this is offset to some extent by the diversity in focus and the wide range of measures used to gather evidence of impact.

Assessment and validity of IRPs

28. **The quality of the evidence base on the assessment and validity of IRPs cannot be judged at this point.** Very few details are provided of assessment criteria for IRPs, and hence measures of validity, in publications. It is therefore not possible to compare the impact of IRPs with that of more conventional approaches to practical work. None of the studies in the review reported on this aspect.

Points for consideration

29. IRP work is often associated with national policy initiatives, and is seen as important and valuable by a range of people with an interest in, or involved in, science education; including teachers, students, educational researchers, scientific researchers, employers, government organisations, learned societies and charitable foundations.

30. This review suggests that there is sufficient evidence to support providing all secondary/high school students with the opportunity to participate in IRP work.

31. A persuasive case will need to be made to those responsible for the formulation of policy if IRP work is to become more widespread. Key aspects to emphasise in such a case

would include the contribution IRPs make to building links between students, teachers, schools and employers, and the emerging evidence of the positive impact IRPs have in relation to widening participation in science.

32. IRPs place particular demands on students, teachers and universities/employers that are not associated with more conventional school practical work in science. This suggests that some form of training/support should be provided for each of these groups prior to embarking on IRP work.

33. Teachers will require support in identifying external partners (universities and employers) willing to participate in and support IRPs. Two emerging networks, the Institute for Research in Schools (IRIS) and the Extended Project Science Investigation Learning and Outreach Network (EPSILON), will have a key role to play in the UK.

34. Successful IRP programmes require a commitment of resource. Whilst there is variation in requirements depending on the nature of the IRP, all require additional time. Many current IRPs also have financial support, particularly where a range of partners is involved. An exception to this is where IRPs form part of an external examination. The resource demands will need to be thought through carefully if schools and colleges are to be given more encouragement to offer IRP work. Current IRP funding in the UK comes largely from charitable bodies. It would be worth exploring the possibilities for increased industrial sponsorship for such work.

35. Strong consideration should be given to bringing together a group of representatives of current funders of IRP work and other interested groups to co-ordinate thinking and take forward the above agenda.

36. The review also points to a research agenda in substantive areas where more data would be useful, and in the nature of research into the impact of IRPs. For example, given the range of benefits for IRPs identified in the short term, it would seem important to explore the possible longer-term benefits, for instance on students who have gone on to take science courses at university.

37. New research into the impact of IRPs would benefit from greater attention being paid to methodological issues. A greater degree of consensus over the areas in which to gather information would be helpful, and more use could be made of existing instruments, rather than many studies appearing simply to develop their own instruments. Equally, more robust research designs that do not rely wholly on self-report data should be adopted.

38. Given the above, and the wealth of experience in other countries, consideration should be given to hosting an international symposium on IRP work.

Section 1: Introduction

1.1 Aims of the review

This Rapid Evidence Review on practical independent research projects in science (IRPs) is intended to cover five areas:

1. Scope and reach: what schemes are available in the UK for encouraging practical IRPs in science, and who uses them?
2. Impact: what effects do practical IRPs have on students' learning and attitudes to science, and on teachers?
3. Assessment and validity: how are students credited for their achievements in practical IRPs?
4. International comparators: what can we learn from practical IRPs schemes overseas?
5. How the reach of IRP projects could be extended, bearing in mind barriers that teachers and others may report?

To cover these areas a systematic review has been undertaken of the published and grey literature, interviews conducted with key informants, including students, and five international case studies produced. The following research questions guided the review:

- What opportunities are provided for secondary school students to engage in IRPs?
- What are the chief characteristics of IRPs?
- How are IRPs organised and assessed?
- What is the impact of participation in IRPs on secondary school students' responses to science?
- How does the impact of IRPs compare with that of more conventional approaches to practical work?
- What opportunities exist internationally for students to engage in IRPs and how do these compare with those available to students studying in the UK?

1.2 Context of the review

The nineteenth century showed the beginnings of the growth of school science as a practical subject in the UK (Jenkins, 1979) with the provision of laboratories and associated apparatus and consumables (e.g. Stonyhurst College in 1808). Since then, the UK has generally been acknowledged as a world-leader in the provision of practical work in school science, largely due to the presence of appropriate support: well-trained science teachers; a culture of practical work; laboratories; science technicians; the requirement for practical work in science curricula; the summative assessment of practical work; and a tradition, at least in biology, of fieldwork.

The nature and purpose of practical work in the teaching of science has been widely explored and has generated an extensive literature (e.g. Abrahams and Reiss, 2012). Such practical work is seen as motivating for students (Wellington, 2005), as part of the identity of science teachers (Donnelly, 1998) and as a way of developing conceptual understanding and certain skills (Bennett, 2003; Millar, 2004). Practical work can take many forms: at one end of the spectrum is the 'recipe' – in which students follow a prescribed set of actions, at the other end of the spectrum is the IRP, where students have a greater degree of control over the focus of the practical work and the way in which the work is undertaken. IRPs are not new, for example, an important component of Nuffield Advanced Levels from the 1970s (Fairbrother and Swain, 1977).

There appear to be two principal motivations for promoting the use of IRP work in schools:

1. Internationally, the last fifteen years or so have seen the development of approaches such as authentic science, problem-based science and inquiry-based science, all of which seek to increase the amount of open-ended investigative work that students engage in, including work that takes the form of IRPs.

2. In the UK, and at upper secondary/high school level in particular, the use of IRPs has been seen as an important means of providing students with an authentic experience of research and motivating students towards further study of science. Indeed, the specification for this rapid evidence review project stated that perceived benefits of IRPs include:

   - giving students an early taste of scientific research
   - motivating students towards further study of science
   - developing skills of enterprise, teamwork and planning more effectively than regular teaching
   - raising the profile of the science department
   - helping recruit students to continued scientific study
   - providing professional development for teachers involved, potentially helping to attract and retain them
   - providing career development for the supporting researchers
   - a genuine contribution to university research projects by school/college students, and
   - building strong links between the school/college and the supporting university.

There are several examples of IRP work in the UK. These include national schemes such as the CREST Awards, the Nuffield Research Placements and the Royal Society Partnership

Grants. Elsewhere, IRP work takes place in more local schemes in and project work undertaken in University Technical Colleges (UTCs).

However, recent policy changes on the teaching and assessing of practical work at GCSE and A-level in England have resulted in a decisive move away from IRPs, and a concern that some of the important learning associated with IRPs will be lost. One example of the effects of the changes is the loss of the IRPs associated with the Salters' suite of A-level projects.

1.3 The review report

The review report has six main sections. Section 2 provides details of the review methods. Sections 3-5 present and discuss the evidence from three sources: the literature on IRPs; the views of key informants associated with IRPs, including teachers; and the views of students who have experienced IRPs. Section 6 considers the evidence from five countries, presented as case studies. Finally, section 7 summarises the evidence and proposes some points for further consideration.

Section 2: The methods employed in the rapid evidence review

2.1 Introduction

This rapid evidence review of IRPs comprised three main strands: a review of the literature, interviews with key informants and five international case studies. The methods employed in the literature review draw on those developed by the Evidence, Policy and Practice (EPPI) Centre (see, for example, Gough et al., 2012).

Although interviews with key informants would not normally form part of a rapid evidence review, it was felt that a more robust evidence base could be generated if information that might not typically be accessible in written form could be gathered from people with experience of IRP activity. Thus the key informants were people who had experience of one or more of implementing, working with, assessing, and evaluating IRPs. They also included students who had undertaken IRPs.

The interviews provided the additional benefit of enabling the identification of 'grey literature', such as reports commissioned by providers of IRPs or unpublished academic contributions.

2.2 Identifying the relevant literature and research studies

Four strategies were employed to identify the relevant literature.

1. Searches were carried out of the standard electronic databases available: the Education Resources Information Centre (ERIC), the British Education Index (BEI), the Social Science Citation Index (SSCI) and PsychINFO. The search focused on 2000 to 2015. Full details of the electronic search strategy may be found in Appendix 1.
2. Key informants were asked to identify relevant publications during their interviews. A list of key informants may be found in Appendix 4.
3. Hand-searches of journals were carried out to identify any very recent publications that may not yet have been listed on electronic databases.
4. In addition, the research team added a small number of other publications of which its members were aware and felt were relevant to the review. This included the identification of a small number of pre-2000 publications which had a clear focus on IRP-like activity, offered important context or related to long-standing IRP activity.

In practice, a major challenge for the review was the identification of the relevant literature. A wide variety of events, approaches and terms may encompass IRP activity. These include: authentic science, problem-based science, inquiry-based science, practical work, investigative work, independent practical work, extended practical work, extended project, science competition and science fair. In addition to this, work may not be reported as science, but within individual branches of science (biology, chemistry, physics).

The diversity of terms that could encompass IRP activity also resulted in a very large number of papers emerging from the electronic searches. Very careful reading of papers was therefore needed to determine which studies focused on IRP activity in a systematic manner.

The research team is confident that the search strategies it adopted yielded the publications relevant to the review focus.

The electronic searches identified 2,324 publications. This was reduced to 1,403 publications after duplicated entries were removed. The key informants, hand-searches and publications identified by the research team added a further 11 publications.

2.3 Defining relevant studies: the inclusion criteria

In order to identify the relevant literature, inclusion criteria were developed for the studies reported in the literature. These were informed by the review research questions.

Studies have been included in the review on the basis of meeting the majority of the criteria listed below. All the studies met criteria 1-4, and 7, 9 and 10.

1. They addressed one or more of the review research questions
2. They focused on students aged 11-19
3. They focused on science subjects
4. They were published after 2000
5. Students were involved in having a major input into the question(s) the IRP addressed
6. Students had the main input to the design of the IRP
7. The IRP involved practical work
8. The IRP took place over an extended period of time (> 10 hours)
9. The IRP involved production of a report or similar output
10. The IRP was assessed or accredited in some form

Projects based solely on the manipulation and analyses of previously-obtained data were excluded as they do not include a practical component. Examples of such projects include those based on data downloaded from websites, such as data from satellites.

More details of the inclusion criteria may be found in Appendix 2.

In practice, the diffuse nature of the literature meant that professional judgements had to be applied when making decisions about the inclusion or exclusion of publications, as there were a number of cases where insufficient information was provided to makes decisions about whether or not some of the inclusion criteria were met. This was particularly the case for student involvement in agreeing the questions to be addressed by the IRP and its design (criteria 5 and 6 above), and the length of the IRP (criterion 8). In many cases, close reading of the text was needed to establish the nature of the possible IRP-like activity, and detailed descriptions were often not provided in, for example, publications reporting on general aspects of implementing an 'authentic science' or 'inquiry-based science' approaches in science teaching. Equally, it was not always possible to fully determine aspects such as the extent of student involvement in identifying the questions for the IRP, the design of the IRP, the length of the IRP, the products (e.g. project report) generated, or the assessment process.

The overall approach was to be inclusive, i.e. where publications appeared to offer something of relevance to the review they have been included, even if there were insufficient details to enable all the inclusion criteria to be applied.

Application of the inclusion criteria yielded 39 publications which formed the basis of the systematic map. A number of other publications provided useful general background material or overviews of provision, without reporting any data in detail. These publications have also been included in this review report, though not in the systematic map.

2.4 Extracting the key information from the literature

A bespoke data extraction sheet was developed for extracting the key information from the publications. This focused on the following information:

- Practical details (author, title, year of publication, source, country of origin, details of the researchers)
- The research questions and aims of the study being reported
- The name (if applicable) of the IRP scheme and a brief description of the IRP, including:
    - aims
    - chief characteristics (compulsory or optional, duration, organisations details, degree of student choice over questions, undertaken by individuals or teams, input from teacher or others, e.g. university researcher, intern)
    - assessment/accreditation details (is the IRP assessed, who assesses it, and does it count towards any qualification)
    - any associated external funding
- Study design, including details of the sample
- Data collection methods and instruments (including reliability and validity checks)
- Data analysis methods (including reliability and validity checks)

- Summary of findings and conclusions (including information about impact on students' learning or affective responses/attitudes, information on students' subject choices/career intentions)
- Any other information worth noting

The two members of the research team undertaking the data extraction (Bennett and Torrance Jenkins) worked closely together on the development of the data extraction sheet, testing a pilot version on a small number of the publications and then fine-tuning the sheet to ensure it covered the key information needed.

A copy of the data extraction sheet may be found in Appendix 3.

2.5 The literature review

The systematic map of the work and the synthesis of the evidence from the literature are based on the 39 publications that reported systematically-gathered data on aspects of the impact of IRPs at secondary/high school level.

2.6 The interviews with key informants

Interviews were conducted with a range of key informants with useful perspectives on IRPs. These included funders of IRPs, people with responsibility for implementing large-scale IRPs, teachers (in schools, colleges and a University Technical College) and others responsible for the local implementation and running of current and former IRPs. The key informants included people with a range of views about the value of IRPs.

2.7 The international case studies

Five countries were selected to form the bases of international case studies. These countries all appeared to have something useful to offer in relation to the provision of IRPs. Three of the countries were identified from the literature review: Australia, Israel and the USA. Two were identified through recommendations from personal contacts: The Netherlands and Singapore.

In addition to the publications that were identified through the electronic searches, a number of additional publications from a variety of formal and informal sources were supplied to the review team by people contacted during the compiling of the international case studies. These publications are not included in the systematic map, but the international case studies draw on information from the publications.

Section 3: Evidence from the literature

3.1 Introduction

The literature encompassing IRP activity is diverse both in the nature of its focus and in the place of publication.

Work is also reported in a wide variety of sources, including international research journals in science education (or individual branches of science), national research journals, practitioner journals, reports, conference proceedings and internet publications.

This review does not include a number of areas of literature linked to IRP work, including: work focusing on the professional development of teacher knowledge and skills related to areas that may include IRP work, such as problem-based learning or enquiry-based learning; work focusing on teachers' views of the nature of science or of a constructivist approach to science teaching and predispositions towards implementing IRP work; detailed conversation analysis of classroom discussions taking place during IRP activities; work focusing on the attributes of university students of involved in IRPs as mentors and/or supporting researchers, or work focusing on the impact of participation on university students of their involvement in IRPs; effects on school students of undertaking summer internships at universities to act as a research assistant in a research laboratory.

3.2 Systematic map

The literature search identified 49 publications from 14 countries that reported data on IRP activity and met the inclusion criteria for the rapid evidence review. On closer scrutiny, ten of these publications took the form of overview articles with little data reported in detail. The systematic map therefore covers the 39 publications from 12 countries that gathered empirical data in the impact of IRPs reported in sufficient detail to gain a picture of the nature of the IRP and its effects.

3.2.1 Countries where research into IRPs is undertaken

IRP work is undertaken in a number of countries across the world, as shown in Table 1. It is likely that there is additional IRP work taking place, as one of the features of the literature was the comparatively high proportion of publications reporting local or regional IRP activity in practitioner journals (see below). The electronic searches only identify publications in English, and it may therefore be the case that that there are additional publications in practitioner journals in other languages that would not emerge in the search.

Table 1 Country of study

Country	*Publications*
Australia	2
Ireland	1
Israel	1
Netherlands	1
New Zealand	1
Qatar	1
Singapore	1
Spain	1
Taiwan	1
Turkey	2
UK	8
USA	17
More than one country	2
TOTAL	39

3.2.2 Source of publication

Publications appeared in a variety of sources, as shown in Table 2 below. International research journals and practitioner journals were the two predominant places of publication.

Table 2 Source of publication

Source of publication	*Publications*
International research journal	16
National research journal	2
Practitioner journal	12
Report	4
Book chapter	1
Conference proceedings	1
Internet publication	2
Private communication	1
TOTAL	39

IRPs can be characterised in a number of ways: the age range of the participating students, the science discipline, their duration, whether participation is compulsory or optional, the degree of autonomy students have over the research question they address and the research design, the relationship to the formal science curriculum, whether the IRP is undertaken by an individual student or by a team, the time allocation, whether it is undertaken within or outside timetabled lessons, whether it is funded, whether it is associated with linked events (such as science competitions or fairs), and whether it involves external partners. Not all this information could be identified in any detail, particularly about degree of student choice over questions and design. The features reported below are those which were included in the majority of the publications.

3.2.3 Student age range

The review focused on IRP provision for the secondary/high school age range, taken to include ages 11-19. Whilst the electronic searches identified a number of accounts of work done at the primary/elementary level, the majority of these did not report IRP work in any detail, but reported on matters such as the fostering of inquiry-based or problem-based science. The investigations that students tended to carry out at this stage of education were small-scale and prescribed by the teacher.

As Table 3 indicates, the IRPs in the publications were most often found at upper secondary/senior high school level, though there were also several examples of IRPs being undertaken by younger students. In some cases, IRPs were offered across the secondary/high school age range, and in a number of cases no indication of the age of the students was given.

Table 3 Student age range

Age of students	*Publications*
Lower high school (age 11-14)	7
Middle high school (age 14-16)	6
Senior high school (age 16-18)	11
High school (ages 11-16)	1
High school (ages 11-19)	7
High school (age not specified)	7
TOTAL	39

3.2.4 Science discipline

The IRPs reported on are undertaken in a variety of disciplines, as shown in Table 4. As students progressed through school, it was more likely that they would engage in a discipline-specific IRP.

Table 4 Science discipline

Discipline	*Publications*
Biology	7
Chemistry	2
Physics	2
Earth science	1
Environmental science	1
Electronics	2
Science	23
Other (EPQ)	1
TOTAL	39

3.2.5 Other characteristics of IRPs

In two-thirds of cases, participation in the IRP was optional (see Table 5) within an individual school.

Table 5 IRP compulsory or optional

IRP compulsory or optional	*Publications*
Compulsory (within school)	12
Optional (within school)	24
Not specified	3
TOTAL	39

Around two-thirds of the reported IRPs involved student participation as part of a team (see Table 6). In a small number of instances, students had choice over individual or team participation.

Table 6 Nature of student involvement

Nature of student involvement in IRP	*Publications*
Individual participation	10
Team participation	20
Choice of individual or team participation	5
Not specified	4
TOTAL	39

Schools operated one of three models for creating the time for IRPs, either during school time, outside school time or a mixture of both, with no one pattern predominating (see Table 7). Where IRPs took place outside normal school hours, they were undertaken in school science clubs, summer camps or in what were described as 'intensive pull-out courses'.

Table 7 Time used for IRPs

When undertaken	*Publications*
Undertaken in normal school hours	12
Undertaken outside normal school hours	8
Undertaken within and outside normal school hours	14
Not specified	5
TOTAL	39

A number of the IRPs were linked with external activities, which were most usually summer schools and camps, or science fairs and competitions (see Table 8). In two cases, the IRP counted towards the formal assessment in a national examination.

Table 8 Linked events

Linked events	*Publications*
Associated with science fair or competition	10
Associated with summer school/camp	5
Associated with requirements of external examination	2
Not specified	22
TOTAL	39

A number of the IRPs were supported by external funding (see Table 9). Typically, the funding came from grants secured by national funding organisations with a focus on science education, or from industrial sponsors. In just under half the reports of IRPs, no information was specified about funding, and it seems reasonable to assume that these IRPs were unlikely to have been funded.

Table 9 Funding

Funding	*Publications*
Externally-funded	15
Unfunded	5
Not specified	19
TOTAL	39

In just over half of the IRPs reported, the projects involved people outside the school (see Table 10). The largest group of external people involved were university science staff and/or university students, acting as advisers and mentors. Around a quarter of the IRPs involved employers. Occasionally, local voluntary groups and parents were involved.

Table 10 Involvement in running of IRP of people/groups external to school (39 studies, not mutually exclusive)

Involvement in running of IRP of groups external to school	*Publications*
University science staff/student involvement	20
Employer involvement	10
Other external involvement	3
Not specified	17
TOTAL	50

The majority of IRPs required the generation of a product (see Table 11). The two most common of these were written reports and presentations, with many IRPs requiring both. Only one report specified that a student artefact was produced, though it seems likely that some of the science fairs and competitions also required artefacts to be produced. Less commonly, students were asked to produce a reflective diary.

Table 11 Student products (39 studies, not mutually exclusive)

Student products	*Publications*
Written report	19
Presentation	17
Artefact	1
Student reflective diary	2
Report for external examination	1
No product required (explicit statement)	1
Not specified	14
TOTAL	55

3.3 Synthesis of the evidence

This section of the report discusses and evaluates the evidence arising from the literature on IRPs.

The systematic map of the literature demonstrates very clearly the diversity in provision of IRPs and in the methods used to assess their impact.

3.3.1 Scope and reach

A very striking feature of IRP work is the diversity in many of its characteristics: the number of countries where it takes place, impetus for the work, the involvement of partners external to schools, the nature and focus of the IRP work and the way in which it is funded.

Table 12 summarises four contrasting IRP models as examples of the diversity the work can take.

Impetus for IRP work

It is clear from the systematic map that schools in a number of countries engage in IRP work. In some cases, IRP work is linked to national policies and agendas. For example, a number of the publications from the USA make reference to policy statements by groups such as the American Association for the Advancement of Science (AAAS) and the National Academy of Sciences, and this has been a contributory factor to securing funding for a local initiative. Examples of such IRP work can be found in Massachusetts (Gibson and Chase, 2002), Montana (Adams et al., 2009), Texas (Sahin, 2013), Virginia and rolled out to other states (Dolan et al., 2008).

Some IRP activities are linked to groups that have a specific interest in prompting IRP work as part of providing young people with an authentic experience of what it feels like to work as a scientist and engage in scientific research. Examples of such IRPs include the CREST awards which operate in a number of locations, including the UK and Australia (Grant, 2007; Moote, Williams and Sproule, 2013; British Science Association, 2014), The Royal Society Partnerships Grants scheme in the UK (Jenkins and Jeavans, 2015), the Nuffield Research Placements scheme in the UK (Nuffield Foundation, 2013), and the Wellcome Trust-funded Authentic Biology Project (Colthurst, 2015; Finegold, 2015). These initiatives normally involve school-university partnerships.

Partners in IRP work

In addition to the examples above, other examples of regional or local initiatives involving school-university partnerships include a number of examples in the USA: Florida (Burgin et al, 2007), Utah (Campbell and Neilson, 2010), Michigan (Schneider et al., 2013), New Jersey (Charney et al., 2007), and across Canada and the USA (O'Neill and Polman, 2004). Other examples include Australia (Symington and Tytler, 2011), Spain (Diaz-de-Mera et al., 2011), and in six European countries [France, Germany, The Netherlands, Norway, Spain, and Italy] (Dijkstra and Goedhart, 2011).

Some IRPs have extended the partnerships to employers and industrial partners, e.g. in Michigan (Duran et al., 2013) and in North Dakota (Welch, 2010). Occasionally, IRP work includes the specific involvement of families, e.g. in Montana (Adams et al., 2009).

School-focused IRP work

In Israel, Zion et al. (2004) report on an IRP initiative that extends across a number of schools. A limited number of publications reported on IRP projects associated with individual teachers in their own school: in New Zealand (Haigh, 2008), in Qatar (Faris, 2008), in Singapore (Chin and Chia, 2004), the UK (Balmer, 2014), and in the USA (Chien and Karlich, 2007).

In one case, the IRP work formed a formal part of a compulsory national science examination for all students aged 15 and 16 in Ireland (Kennedy, 2014), and in another the IRP work could be entered for a national qualification for students aged 16 or over: the Extended Project Qualification (EPQ) in England (Daly and Pinot de Moira, 2010). There are other examples of IRP work forming part of a national examination, such as in the Salters' Advanced Level courses in England[1] and the Extended Essay for the International Baccalaureate (IB)[2], but no formal impact studies of the Salters' IRP work have been undertaken, and none of the evaluations of IB work have focused on science IRP work.

[1] See http://www.york.ac.uk/education/projects/

[2] See http://www.ibo.org/programmes/diploma-programme/curriculum/extended-essay/

IRP work and wider initiatives

IRP work is very often associated with wider initiatives in education or science education. These include authentic science, for example in Israel (Zion et al., 2004), The Netherlands (Bulte et al., 2007), and in the USA (Burgin et al., 2007; Dolan et al., 2008; Rivera-Maulucci et al., 2014); problem-based learning, for example in Qatar (Faris, 2008) and in Singapore (Chin and Chia, 2004); and project-based science/project-based learning, for example in the USA (Krajcik and Blumenfeld, 2006; Schneider et al., 2002).

Focus of IRP work

IRPs take place in a variety of science disciplines (see Table 4), with biology projects predominating. Within this, there is considerable diversity in the science focus. For example, IRPs focused on genetics (Charney et al., 2007), food and nutrition (Chin and Chia, 2004), carbon cycle research (Dijkstra and Goedhart, 2011), plant science (Dolan et al., 2008), environmental work (Faris, 2008), diet (Faris, 2008), biomedical science (Colthurst et al., 2015; Finegold, 2015), electronics (Hong et al., 2013; Welch, 2010), and pharmacology (Sikes and Schwartz-Bloom, 2009).

Duration of IRP work

Some publications were very clear about the time spent on IRP work, whilst others were not. The two predominating patterns were that of IRP work spread over a number of weeks in schools (e.g. Chin and Chia, 2004; Dijkstra and Goedhart, 2007; Faris, 2008, Hong et al., 2008; O'Neill and Polman, 2004), or undertaken in an intensive block such as at a summer school or camp (e.g. Burgin et al., 2007; Metin and Leblebicioglu, 2007), but occasionally run within a school (e.g. Rivera-Maulucci et al., 2014). School-based IRP work appeared to last from two weeks to up to a year (and very occasionally longer), though the number of hours spent on the IRP was rarely specified. Summer camps appeared to last from two to seven weeks. In a limited number of cases, IRPs consisted of an intensive block plus follow-up time in school (Charney et al., 2007).

Funding of IRP work

IRP wok was more likely to be funded than unfunded (see Table 9). Unfunded IRPs were most likely to occur where the work is local to one particular school, or associated with the requirements of external examinations. Where partnerships are involved (with universities, employers and other groups), IRP work is normally funded. The principal sources of funding are government and research council funding, other national funding agencies, charitable funding and industrial funding. Examples include funding from the Scientific and Technological Research Council of Turkey (Metin and Leblebicioglu, 2007), the National Science Foundation (NSF) in the USA (O'Neill and Polman, 2004), the Cosmos Foundation (a charitable not-for-profit funder of charter schools) in Texas (Sahin, 2013), and from BHP Billiton (an international mining company based in Australia (Symington and Tytler, 2011).

The majority of the funding supports local or regional initiatives. However, some of the funding supports national initiatives. Examples of funding in this latter group include the BHP Billiton funding in Australia, and several initiatives funded in the UK such as the CREST awards[3], the Nuffield Partnerships scheme[4], and the Royal Society's Partnership Grants scheme[5].

Events associated with IRP work

The majority of IRP work takes place in normal school time. This can be supplemented with after-school clubs, as is the case in Taiwan (Hong et al., 2013), Texas (Sahin, 2013) Virginia (Brand et al., 2008). Some IRP work is, however, associated with dedicated events such as summer schools and camps, typically of one or two weeks' duration. Examples of such IRPs can be found in Turkey (Akinoglu, 2008; Metin and Leblebicioglu, 2007), and in Massachusetts (Gibson and Chase, 2002).

IRP work can also be linked to, or driven by, participation in science competitions or fairs, for example in Arizona (Yasar and Baker, 2003) and Virginia (Brand et al., 2008).

Widening participation through IRP work

Some IRP activity has been specifically targeted at groups traditionally under-represented in science, with a focus on one or more of gender, socio-economic status and ethnicity. Such work has tended to take place in the USA, and includes studies in Arizona (Yasar and Baker, 2003) New York (Rivera-Maulucci et al., 2014), North Carolina (Sikes and Schwartz-Bloom, 2009), Massachusetts (Sonnert et al., 2013, and south-eastern Michigan (Duran et al., 2013). In two cases (Rivera-Maulucci et al.; Duran et al.) the IRP was associated with a programme specifically for students from under-represented backgrounds.

Other studies have included analysis of their data to enable them to report on the involvement of traditionally under-represented groups with a view to improving participation (e.g. Nuffield Foundation, 2013).

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[3] See http://www.britishscienceassociation.org/crest-awards
[4] See http://www.nuffieldfoundation.org/nuffield-research-placements
[5] See https://royalsociety.org/grants-schemes-awards/grants/partnership-grants/

Table 12 Examples of IRPs

Publication	Burgin et al., 2007	Charney et al., 2007	Chin and Chia, 2004	Hubber et al., 2010
Source of publication	Research in Science Education	International Journal of Science Education	Journal of Biological Education	Teaching Science
Name of IRP	Student Science Training Programme (SSTP)	Waksman Student Scholars programme (WSSP)	No specific name	BHP Billiton Science Awards (forms part of a Commonwealth programme linked to CREST awards)
Country	USA (Florida)	USA (New Jersey)	Singapore	Australia
Student age range	16-17	15-17	14-15	11-15
Science discipline	Chemistry	Biology (genetics)	Biology (food and nutrition)	Science
External groups involved	University: mentor scientists	University (mentor scientist)	None	'External professionals' mentioned
Nature of student participation	Individuals	Teams	Teams	Individual
When undertaken	Summer residential school (7 weeks)	Summer school (4 weeks) plus 25 hours in-school follow-up	18 weeks during school time	During and outside school time over a period of several weeks
Linked events	None	None	None	Can be presented at science fairs
Funding	Charitable grant	National Institutes of Health, the National Science Foundation, industrial funding and funding from partner university	None	BHP Billiton (industrial sponsor)
Number of participating students	18 (including seven females and 7 from ethnic minority groups)	30 (including 17 females, 18 from ethnic minority groups), two followed in detail	39	65
Student product	Research report and presentation	Poster presentation	Team report and presentation	Not explicitly stated
Impact outcome measures	Student interviews Mentor (scientist) interviews Concept maps	Student diaries Assessment of conceptual knowledge Assessment of views of nature of science	Student questionnaire Student interviews Observation, audio and videotapes of group work	Student questionnaire Teacher interviews Student interviews State organiser interviews

Publication	Burgin et al., 2007	Charney et al., 2007	Chin and Chia, 2004	Hubber et al., 2010
Links to wider initiatives	Authentic science	Authentic science	Problem-based learning (PBL)	Authentic science
IRP focus	Students undertake projects on “genuine unanswered questions” in chemistry	Students engage in a variety of open-ended projects linked to genetics research	Students developed projects based on newspaper reports of food and nutrition issues	Students undertake a variety of open-ended science projects
Reported outcomes	Student reported improved scientific knowledge, and this was supported by data from concept maps Four students reported increased interest in pursuing a career in research science	Improved student knowledge, broader awareness of nature of science, promotion of collaborative learning environment.	Most students viewed IRP work positively and enjoyed the freedom to work in new ways Students less confident about making presentations PBL approaches are time-consuming	The majority of students reported increased interest in science Anecdotal data from teachers indicated increased post-compulsory uptake of sciences Teachers felt IRP provided a positive experience for students normally less successful in science

3.3.2 Impact research design

A very striking feature of IRP work is the wide range of aims of the studies reported in the publications. The majority of the work focused on impact on students, and explored areas such as conceptual understanding, practical skills, more general skills (such as collaborative working), attitudes to science, and motivation to study science beyond the compulsory period. Work focusing on teachers and mentors largely gathered their views of the impact of IRPs. Table 13 provides examples of the study focus of the impact research.

Table 13 Study focus of impact research design

Focus	Examples of studies including this focus	Country
Students' conceptual understanding	Burgin et al., 2007	USA
	Krajcik and Blumenfeld, 2006	USA
	Sahin, 2013	USA
	Schneider et al., 2002	USA
Students' views of the nature of science	Metin and Leblebicioglu, 2007	Turkey
Development of students' scientific literacy	O'Neill and Polman, 2004	USA/Canada
Development of students practical and experimental skills	Chien and Karlich, 2007	USA
	Grant, 2007	UK
	Yasar and Baker, 2003	USA
	Zion et al., 2004	Israel
Development of students' use of technology	Duran et al., 2013	USA
Development of students' more general skills, such as collaborative/team working	Charney et al., 2007	USA
	Faris, 2008	Qatar
	Grant, 2007	UK
Students' attitudes to science	Faris, 2008	Qatar
	Gibson and Chase, 2002	USA
	Welch, 2010	USA
	Yasar and Baker, 2003	USA
Students' creativity	Haigh, 2008	New Zealand
	Hong et al., 2013	Taiwan

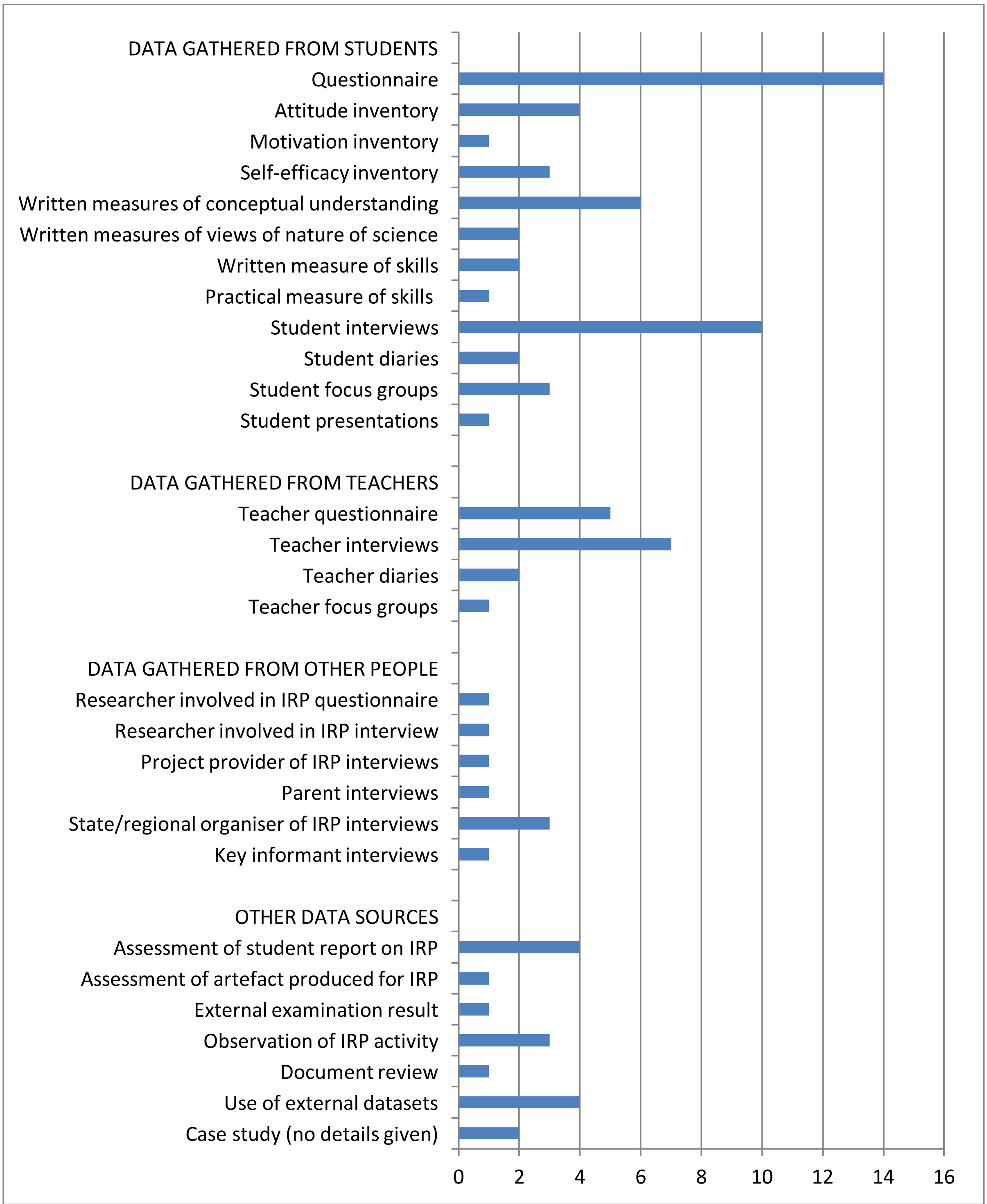
Focus	*Examples of studies including this focus*	*Country*
Student motivation	Moote et al., 2013	UK
Student self-efficacy	Sikes and Schwartz-Bloom, 2009	USA
More general student responses to IRPs	Diaz-de-Mera et al., 2011	Spain
	Finegold, 2015	UK
Barriers to student participation	Nuffield Foundation, 2013	UK
Teachers' view of IRPs	Finegold, 2015	UK
	Chin and Chia, 2004	Singapore
	Kennedy, 2014	Ireland
Views of other people (e.g. science mentors, employers) in their participation in IRPs	Symington and Tytler, 2011	Australia
Exploration of effects of participation in IRPs of traditionally under-represented groups	Duran et al., 2013	USA
	Rivera-Maulucci et al., 2014	USA
	Sikes and Schwartz-Bloom, 2009	USA
	Sonnert et al., 2013	USA
	Yasar and Baker, 2003	USA

3.3.3 Approaches to data collection and research instruments used to judge impact

A total of 89 outcome measures were employed to judge the impact of IRPs, as shown in Figure 1.

The wide variety of outcome measures points to one of the most prominent features of research into the impact of IRPs, which is the comparatively uncoordinated and unsystematic approach to the judge the impact of IRPs.

Figure 1 Impact outcome measures



There were no examples of randomised controlled trials in the publications included in the review. Nine studies adopted some form of experimental design whereby comparisons were made between participants in an IRP and non-participants in an IRP (Finegold, 2015; Gibson and Chase, 2002; Jenkins and Jeavans, 2015; Krajcik and Blumenfeld, 2006; Moote et al., 2013; Sahin, 2013; Schneider et al., 2002; Welch, 2010; Yasar and Baker, 2003). The remaining thirty studies gathered data only from students (and others) participating in IRPs. Given that IRP work is very often localised and very intensive in nature, this is not particularly surprising. However, the fact that IRPs are also optional in the majority of cases does suggest that more use could be made of comparator groups when gathering data, as study designs could incorporate a control and experimental group.

There is variability in the publications in the amount of detail used to gather data on the impact of IRPs. Full reports contain more detail, particularly in relation to the instruments, while journal papers provide much less details. (This is a feature of educational research more generally.) With very few exceptions, each of the publications gathered data through instruments that were developed for the purposes of the study being reported. Exceptions to this included the use of data from state test instruments (Krajcik and Blumenfeld, 2006) or national test instruments (Schneider et al., 2002; Daly and Pinot de Moira, 2010), and the use of existing instruments to measure student attributes such as motivation (Moote at al., 2013).

The diversity of data collected has already been noted. The primary data sources are students participating in IRPs and the teachers running the IRPs. Within this, the data collected from students focuses on cognitive factors such as measures of knowledge and understanding, and affective factors, such as measures of attitudes to science. A substantial portion of the data gathered from students took the form of self-report data (questionnaires, interviews, focus groups, diaries). Data gathered from teachers also took the form of self-report data, as did data gathered from other groups associated with the IRP work (university scientists/mentors, employers, state/regional organisers, parents).

Other data sources were occasionally used, including information in student IRP reports, artefacts produced for IRPs, external datasets including test and examination results, observation of IRP activity and reviews of documentation related to the IRP.

The majority of studies in the review drew on more than one source of data. There were no examples of instruments used in one study being used in another study. Table 14 provides illustrative examples of the data collected in a selection of studies.

A note on the impact evaluations of UK-based IRP initiatives

There are a number of national initiatives in the UK that focus on IRP work. These are funded by national academies, charitable foundations and industrial sponsorship; for example, the British Science Association offers CREST awards (CReativity in Engineering, Science and Technology), the Royal Society offers a Partnership Grants scheme, and the Nuffield Foundation offers a Research Placements scheme. Appendix 8 summarises the key features of these initiatives, together with other UK-based IRP activities (the Wellcome Trust-funded Authentic Biology programme, the Salters A-level individual investigations, and the national Extended Project Qualification [EPQ] examination scheme).

Table 14 Examples of data collected
(* = more than one data source gathered in study)

Data	*Examples of studies collecting such data*	*Country*
From students		
Measures of conceptual understanding	*Charney et al., 2007	USA
	*Sikes and Schwartz-Bloom, 2009	USA
Measures of views of nature of science	*Charney et al., 2007	USA
Practical abilities	*Yasser and Baker, 2003	USA
Attitude inventory	*Krajcik and Blumenfeld, 2006	USA
	*Grant, 2007	UK
Motivation inventory	*Moote et al., 2000	UK
Self-efficacy inventory	*Sikes and Schwartz-Bloom, 2009	USA
Student self-report data (questionnaires, interviews, focus groups, diaries)	Akinoglu, 2008	Turkey
	*Bulte et al, 2007	The Netherlands
	Daly and Pinot de Moira, 2010	UK
	*Gibson and Chase, 2002	USA
	*Grant, 2007	UK
	*Haigh, 2008	New Zealand
	*Jenkins and Jeavans, 2015	UK
	*Nuffield Foundation, 2015	UK
	*Sikes and Schwartz-Bloom, 2009	USA
	Sonnert et al., 2013	USA
Student presentations	*Faris, 2008	Qatar
	*Sikes and Schwartz-Bloom, 2009	USA
From teachers		
Teacher self-report data (questionnaires, interviews, focus groups, diaries)	*Grant, 2007	UK
	*Jenkins and Jeavans, 2015	UK
	Kennedy, 2014	Ireland
	*Rivera-Maulucci et al., 2014	USA

Data	*Examples of studies collecting such data*	*Country*
From other people		
Researcher involved in IRP self-report data (questionnaires, interviews)	*Jenkins and Jeavans, 2015	UK
	*Nuffield Foundation, 2015	UK
Interview with others (IRP providers, IRP regional/state organisers, employers, parents, key informants)	*Grant, 2007	UK
	*Hubber at al., 2010	Australia
	*Jenkins and Jeavans, 2015	UK
	*Symington and Tytler, 2011	Australia
Other data sources		
Assessment of student report on IRP	*Bulte et al, 2007	The Netherlands
External examination result	Kennedy, 2014	Ireland
Observation of IRP activity	*Bulte et al., 2007	The Netherlands
Document study	*Nuffield Research Placements, 2013	UK
Use of external datasets	*Krajcik and Blumenfeld, 2006	USA
	Sahin, 2013	USA

The three major UK schemes have all commissioned external evaluations of the impact of their work: for CREST awards (Grant, 2007; British Science Association, 2014), for the Royal Society's Partnership Grants Scheme (Jenkins and Jeavans, 2015) and for the Nuffield Foundation's Research Placements scheme (Nuffield Foundation, 2013). The publications arising from these evaluations take the form of detailed reports. This contrasts with the majority of the publications included in the review, which take the form of shorter journal publications. One advantage of research reports is that they typically contain more information than journal articles (e.g. copies of research instruments), making it easier to reach judgements about the quality of the work.

3.3.4 Impact

Almost all publications report benefits to participation in IRPs. These benefits take a number of forms. Much of the work concentrated on impacts on students, and, in particular, their responses to participating in IRPs, improvements to their learning, and their more general attitudes to science as a result of participating in IRPs, including attitudes to pursuing a career in science. The impacts on teachers and other participants (university scientists and employers) were also reported in a number of the studies. A further strand of the work focuses on aspects of the widening participation agenda.

A note of caution: while it is rare for the authors of a publication to state specifically their relationship to the work being reported, it is likely that research into the impact of an IRP will often be conducted or funded by those associated with the funding, development or running of the IRP. This was the case in the majority of publications, with the exceptions tending to be the externally-commissioned evaluations (e.g. Grant, 2007; Jenkins and Jeavans, 2015.)

The frequent close association of the publication authors with the IRP research risks selection bias in impact research. In practice, and where it was possible to identify information about the research design and data analysis, there were no examples of inappropriate designs being used, or of designs being used that would limit that nature of the data collected to the point where they were unlikely to reflect an unbiased judgement of impact. Having said this, it was very rare to encounter in the publications details of reliability and validity checks undertaken with research instruments and/or data analysis.

Ten illustrative examples from the twenty-nine studies are provided below, covering the range of dimensions on which studies reported.

1. Adams et al. (2009) in the USA reported

   - improved content knowledge and appreciation of practical skills (improved understanding of aspects of air pollution and respiratory health, and improved awareness of the importance of record keeping and the need for systematic data collection)
   - two-thirds of the group undertaking the IRP (around 80 students) reported increased interest in becoming a scientist.
2. The British Science Association (2014), reporting on the CREST programme in the UK, indicated that the awards:

   - are highly rated by students and teachers
   - promote teamwork and creativity skills
   - improve attitudes to STEM education and careers
   - improve practical and technical skills and understanding
   - are recognised as valuable by universities
   - improve employability skills
   - are equally attractive to both male and female students, and
   - have higher than average take-up by students from lower socio-economic groups.

3. Daly and Pinot de Moira (2010) report that EPQs in the England, Wales and Northern Ireland (a qualification for students aged 17+, some of which focus on science IRPs) probably encourage students to be more motivated and creative about their learning, and that success in EPQs was linked strongly to prior achievement. However, student engagement with EPQs was independent of prior achievement, suggesting that EPQs improve participation.

4. Haigh (2008) in New Zealand reported that participation by senior high school students in biology IRPs fostered their creativity, provided the IRPs were carefully planned by teachers.

5. Hubber et al. (2010) in Australia reported that students participating in IRPs felt positive about the experience.

   - Three-quarters of the sample group (around 50 students) reported increased interest in science.
   - Half felt they got better marks in science after participating in the IRP.
   - Anecdotal evidence from teachers suggested that IRP participation improved post-compulsory levels of uptake. Teachers involved in the IRPs felt that their students valued the autonomy and freedom, felt the IRPs were an authentic reflection of scientific activity, and valued the links with science professionals. The competitive environment and the opportunity to showcase their work were also seen as benefits.

6. Jenkins and Jeavans (2015), reporting on the Royal Society Partnership Grants scheme, noted high levels of satisfaction amongst teachers and participating partners (universities, employers). The benefits for students included enjoyment, confidence, increased knowledge of STEM subjects, positive perceptions of scientists and engineers, first-hand experience of research environments, and inspiration - ‘it could be me’. Teachers valued involvement in IRP work for the satisfaction gained from the perceived benefits to their students, networks they built up, being able to participate in something through choice, improved management skills, and enhancing of career progression. Partners in the IRP work enjoyed their involvement and the opportunity to work with young people. Scientists felt it gave them a new perspective on their research, and employers felt they got to know their future employees at an early age and to know more about the education system.

7. Krajcik and Blumenfeld (2006) in the USA reported:

   - statistically significant learning gains on external tests of achievement, and

- students' attitudes to science remaining positive over the lower high school years, rather than declining.

8. The Nuffield Foundation (2013), reporting on the Nuffield Research Placements scheme, indicated that students acquire a much better understanding of what it means to be a scientist, and a much better knowledge of the range of jobs in which scientist engage. This was particularly the case for students from disadvantaged backgrounds. Students also learned important skills about conducting investigations, such as the need for precision and to engage in creative thinking. The report also notes that there were less obvious impacts on students' learning and skills.

9. Rivera-Maulucci et al. (2014) in the USA reported that authentic IRPs improve students' achievement in science and provide students with a greater sense of agency (i.e. what they know about science and how scientists work with others to construct knowledge). They further report that such projects enhance how students see themselves in relation to science, and found that five of the group of six in their projects joined after-school science clubs in the year following their participation in IRPs.

10. Schneider et al. (2002) in the USA reports that students who participated in IRPs performed significantly higher on more than half the items on a national test of educational achievement of knowledge, skills and application than groups who traditionally did well on the test. They report that open-response items demonstrated differences in the quality of thinking. These findings lead them to conclude that participation in project based science activities does not disadvantage students in national tests of achievement.

Relatively few negative notes were sounded. Where these were raised, they tended to focus on practical matters, such as the time-consuming nature of the work (Faris, 2008) or the negative impact on time available for completion and teaching of course subject to external examination (Kennedy, 2014). Sikes and Schwartz-Bloom (2009) also noted a slight decrease in interest from students in under-represented groups in taking science courses after participation in IRPs.

Drawbacks to participation included some teachers viewing the demands of IRP work as discouraging students from further study (Kennedy, 2014); some teachers viewing the demands of IRP work as having a negative impact on a school's ability to meet the demands of external regulatory inspection (British Science Association, 2014; Jenkins and Jeavans, 2015); low teacher confidence in running IRPs (British Science Association, 2014; Jenkins and Jeavans, 2015); and difficulties in finding partners (Jenkins and Jeavans, 2015)

3.3.5 Assessment and validity of IRPs

The evidence on assessment and validity of IRPs is not easy to judge, mainly because so few details of assessment criteria for IRPs, and hence measures of validity, are provided in publications. This also makes it difficult to compare the impact of IRPs with that of more conventional approaches to practical work. None of the studies in the review reported on this aspect.

3.3.6 The quality of the evidence base

Scope and reach

The quality of the evidence base on the scope and reach of IRP work is good. This judgement is based on the number of studies that have been undertaken, and the degree of consistency in the findings. Whilst provision is diverse, the evidence indicates that there is support for such work in a number of countries, that it is often linked to national policies initiatives, that it is believed to offer students a valuable and valid insight into the way in which scientists work, that it is of interest to a range of people involved in science education (including teachers, educational researchers, scientific researchers and employers), that it is offered to students across the secondary/high school age range and in all the major science disciplines, that it is rarely associated with external examinations, that it is typically undertaken within school hours or in summer schools and camps, that it can be associated with external events such as science competitions and science fairs, that there are links to the widening participation agenda in science, and that initiatives normally require funding unless they are very small in scale.

Impact: gathering the evidence

The quality of the evidence base on what should be measured to ascertain the impact of IRPs and the appropriateness of measures used to ascertain the impact of IRPs is fair. This judgement has been reached on the basis that the design of individual studies is sound, but this is offset to some extent by the diversity in focus and in measures used to gather evidence of impact. Additionally, it is often difficult to identify sufficient evidence in publications to judge the reliability and validity of the instruments used and the approaches to analysis.

This diversity in the data gathered, coupled with so much IRP work being provided locally or regionally, poses a challenge for the systematic collection of impact data that might provide a solid evidence base that would lend itself to meta-analysis.

There are, however, some relatively straightforward steps that could be taken to increase the quality of the evidence gathered. First, it is desirable for those wishing to undertake impact research to look more closely at previous work, both in terms of its outcomes and the methods used to gather data. More use could be made of existing instruments, rather than many studies appearing simply to develop their own instruments. Even if existing instruments are felt to be limited in their usefulness, a greater degree of consensus over the areas in which to gather information would be helpful. It is very noticeable in the publications reporting studies that the justification for undertaking the work is most frequently made with reference to national policy initiatives and/or the desire to provide students with an experience that mirrors that of practising scientists and/or a belief that IRP work will stimulate interest in science. Rarely are studies set in the context of other research into the impact of IRPs.

Secondly, studies should give consideration to the nature of the data they gather. Better studies are likely to rely on more than one data source, and not rely exclusively on self-report data, even if there is more than one source of such data (e.g. both students' and teachers' views). Better studies would also draw on comparison groups, and more use of could be made of external data sets in identifying the sample for studies.

Impact: the evidence base

Given the issues identified with impact focus and the methods used to gather data, the quality of the evidence base on the impact of IRPs could be described as fair to good. Individually, most studies have a robust design, even if there are questions about the nature of the impact research as a whole. The frequent involvement of the researchers in the design and implementation of the impact research does not adversely affect the impartiality of the design or the reporting of the evidence, except where studies are reported by enthusiastic advocates of IRP work who, have, perhaps, comparatively little experience of using research methods in the social sciences.

Studies report positive responses to IRPs from students, gains in students' learning, improvements in students' attitudes to science, suggestions that increased numbers are likely to consider careers in science as a result of their participation in IRPs, and particular benefits for students from traditionally under-represented backgrounds. Similarly, the responses of teachers and others involved in IRPs are positive.

Assessment and validity of IRPs

As noted earlier, the evidence on assessment and validity of IRPs is difficult to judge due to the lack of evidence.

Section 4: Evidence from the interviews with key informants

4.1 Introduction

This section reports on information gathered through interviews with a total of 28 key informants. These included funders of IRPs, people with responsibility for implementing large-scale IRPs, teachers (in schools, colleges and a University Technical College) and others responsible for the local implementation and running of IRPs, curriculum developers, representatives of examination boards, examiners, those involved in teaching science at the undergraduate level, and scientists. 22 of these informants were identified at the project outset, while a further six were recommended made by the initial group of interviewees. The group included one teacher who had stopped running IRPs.

Several publications, internal reports and other sources of data were identified through the interviews for inclusion in the literature review, the evidence from which is detailed in Section 3.

The interviewees were asked comment on various aspects of the organization and impact of practical IRPs in science. More information about the aspects probed is provided in Section 4.2 below.

4.2 Methodology

Semi-structured, qualitative one-to-one interviews were carried out with each of the key informants talking with one of four researchers (Dunlop, Knox, Reiss, and Torrance Jenkins). The informants were chosen based on their experience being involved with IRPs directly, or because one or more of their roles and responsibilities affords them a view on practical project work. Care was taken to include informants expected or known to represent a range of types of practical IRPs, as well as a range of perspectives on their benefits, drawbacks and overall value. A list of the key informants interviewed is included as Appendix 4.

Each interview was tailored to the particular role of the key informant; an example interview schedule can be seen as Appendix 5. Questions covered organisation and access, assessment and credit, benefits and drawbacks for students and educators, and further people or sources we should consult, addressing the considerable ‘grey literature’ in this area and helping to identify publications that would not emerge from standard search procedures.

Each interview lasted between 30 and 80 minutes. The interviews were audio-taped. The interviewer summarised the content in notes following the interview, and these were passed to the interviewee for checking and/or clarification. In all but three cases it was possible to reach the interviewees and obtain confirmation that the meaning of their comments had been correctly understood.

The notes arising from the interviews were initially reviewed by two researchers working independently to generate narrative answers to the relevant subset of the research questions, with one researcher focusing on the first three research questions and a second researcher addressing the fourth and fifth questions. These researchers then worked together to combine their analyses into the information presented in this section.

4.3 Findings

4.3.1 Opportunities for secondary school students to engage in IRPs

The opportunities that are provided for UK secondary school and college students to engage in practical IRPs are summarised in Appendix 8.

The opportunities available are:

- Extended project qualifications (EPQs)
- International Baccalaureate (IB) Extended Essay
- Salters' Chemistry/Physics investigations (last examination in 2015/16)
- CREST awards
- Nuffield Research Placements
- Royal Society Partnership Grants
- Authentic Biology
- CERN@School
- National Science and Engineering Competition
- BT Young Scientist and Technology Exhibition
- University Technical College projects

In terms of equity of access to IRPs, several key informants noted that while IRPs were relevant to all students regardless of prior attainment, not all young people are able to participate in them. In some institutions IRP work is incorporated into the design of programmes, in others it is offered as an additional or enhancement activity, and in some cases it is not offered at all. For some students, the opportunity to participate in IRPs was an important factor in selecting their school. Some programmes which operate outside of schools are oversubscribed; one factor cited as limiting the number of students accepted was the number of participating host institutions from industry or academia.

Great variability also exists in terms of the quality of the experiences that students can access, not only within schools and colleges, but also through external providers, where access may be limited to small numbers rather than entire cohorts of students. Key informants reported concerns that some teachers do not have the skills or experience to enable IRP work to happen, with some suggesting that the shift of initial teacher education from higher education institutions (HEIs) to schools may be likely to compound this. A tension also exists between a desire to provide opportunities which are well aligned with the interests of teachers and students or which draw upon personal contacts, and needing to offer projects which allow students to meet assessment criteria associated with, for example, external examination requirements.

4.3.2 Chief characteristics of IRPs

Interviewees described IRPs as distinctive and potentially transformative experiences for students. IRP work was distinguished from other experiences in terms of its authenticity, the degree of ownership and independence that students have over the question and methods used, the creativity required, and the type of competencies that are required and rewarded. Engagement with the unknown is a further key characteristic of a well-designed IRP. For most key informants, these characteristics of IRPs formed the basis of many powerful benefits of participating in IRPs because they allow students to develop a different relationship with science to that which develops through conventional science lessons, allowing them to understand how it works and how it relates to them as individuals.

4.3.3 Organisation and assessment of IRPs

The assessment mechanisms for each of the IRPs considered are summarized in Appendix 8. Some IRPs lead to national qualifications, for example the EPQs, while others lead to awards offered by the providing institution, for example the Bronze, Silver and Gold awards of the CREST scheme. The University of Kent is developing a research methods module for undergraduate credit, which will be available for some students undertaking IRP work in schools.

Some interviewees described assessing and rewarding the *process* of the IRP work as desirable, as well as the final *outcome* which is typically assessed *via* the submission of a written report. One example of rewarding process was described for the IB extended essay, which assesses against “engagement criteria”; students participate in three mandatory reflection sessions, a report on which will be submitted with the final essay produced.

In terms of organisation of the projects, several factors believed to facilitate a successful experience for all involved emerged from the interviews; these factors are summarised in Table 15 below.

Table 15 Summary of the factors that emerged from interviews which are believed to facilitate a successful IRP experience

Relevant party or entity	*Factors believed to facilitate the success of IRPs*
Project	Authenticity, appropriate duration, continuity from one cohort to another
Individual student	Possess and/or demonstrate characteristics such as: determination, resilience, tenacity, conscientiousness, dedication to project and people, good time management and organizational skills
Teacher	Possess and/or demonstrate characteristics such as: enthusiasm, research experience, strong supervision skills, confidence, useful contacts
Institution	Culture of valuing questioning and thinking, culture of support, appropriate thought given to timetabling and staffing, sufficient budgetary resources
Society	Support from external partners in academia or industry, knowledge of and access to funding streams

4.3.4 Impact on students

All interviewees identified benefits for students afforded by participation in IRPs, as well as challenges associated with IRP work. These have been categorized here according to five themes:

- learning of science and development of transferable skills
- attitudes towards science
- career aspirations
- external recognition and assessment
- personal development.

Learning of science and development of transferable skills

With respect to learning science, interviewees identified that IRP work has a positive impact on students' learning of scientific ideas, practical skills and understanding of how science works.

Interviewees described IRPs as demanding for students. This demand was perceived to be derived from the conceptual knowledge required to generate research questions and design appropriate experiments, as well as the research skills required to deal with evidence, and to make decisions based on interpreting evidence in a real-life context. One interviewee questioned whether students of school age have a sufficient knowledge base to perform these tasks, and others identified that it is challenging for students meeting open-ended investigation for the first time towards the end of secondary education to adapt to a new way of working in science, especially where it has previously been highly directed and strongly guided. The process of adapting takes time, and is frequently difficult.

In terms of incorporating IRP work into existing A-level specifications, a number of key informants felt that inclusion of a requirement for IRP work comes at the expense of breadth of coverage, not only in terms of conceptual knowledge but also practical skills. For example, interviewees perceived that in an IRP, students may develop expertise in one practical technique but not in a wide range. Whilst it was identified that this could support the development of practical skills and appreciation of concepts required to meet assessment criteria, interviewees felt there were unanswered questions from HEIs about expectations of students entering further study, and indeed what is expected of recruits by scientists in academia and industry.

Interviewees identified a range of general research skills that students develop through participation in IRPs in contrast with carrying out conventional practical work. These include searching literature, reading and reviewing sources, selecting and using appropriate methods to collect and analyse data accurately, referencing, proofreading and formal presentation of results in oral and written form, for example in written reports, research articles or at conferences, and to different audiences including learned societies, charitable trusts, children, adults, and academics. Some interviewees discussed examples of students for whom the experience of having to present their work to expert audiences had been transformational in terms of student confidence.

A range of science-specific research skills were also thought to improve through IRP work, such as: designing experiments; generating hypotheses; making observations; use of specialist equipment; materials and analytical techniques; and the ability to make decisions, to work iteratively to make sense of data and to overcome problems experienced in the laboratory. There was also a view amongst key informants that students learned how to interpret and make sense of a large quantity of accumulated evidence and to be precise and organised in their approach, from experimental design through to data collection and analysis. One interviewee explained that the IRP enabled students to go “beyond awareness that a procedure exists towards an understanding of its mechanism and the conditions under which it behaves a certain way and to making decisions about its application to a problem.”

However, some key informants were not convinced that IRPs were the best way to develop students’ practical skills. Although most believed that the experience of developing expertise in a narrow field prepared students for laboratory work in further work or study, some interviewees believed that students would be better prepared by practicing a broad range of practical skills. Some interviewees also felt that the demands of IRP work can have a negative impact on the time students are able to devote to their other studies.

Attitudes towards science

Most key informants identified that IRPs had the potential to engage young people with science and stimulate their interest and enjoyment of the subject. Although many key informants were able to provide examples of the impact of IRPs on students' attitudes towards science from personal experience, many were unaware of research evidence on the impact of specific IRPs on students' attitudes. A number of interviewees were of the opinion that at their best IRPs can be a transformational experience, and at worst are no better than standard instructional activities. Several instances of students displaying average attainment and interest in science being switched on to science as a result of the unique demands placed on them by participating in an IRP were noted. A number of interviewees identified that some students run the risk of becoming so involved in their IRP work that they can lose track of their other studies.

Further study and career aspirations

Interviewees reported that there was insufficient research evidence on the relationship between IRPs and the direction of future study and employment. However, many interviewees shared the stories of individual cases where IRPs had a particular role to play in stimulating the interest and engagement of students with research and students who had gone on to further study in STEM subjects as a result of this. Interviewees also noted that IRPs provided the opportunity for students to become aware of the engineering sector. One school with established physics IRPs was reported to account for 2% of all girls who enter university to study physics.

Anecdotal evidence was provided suggesting that students who had taken part in practical IRPs were better prepared for university-level studies, partly as a result of developing the range of general research skills described above. This is consistent with the perspective to that reported to be held by educators working in higher education in the UK, who have indicated that they felt that students who had completed an extended investigation as part of their A-Level studies were better equipped for practical work at university (Grant and Jenkins, 2011).

External recognition and assessment

Interviews with providers of IRPs highlighted the importance of providing opportunities for students to be afforded external recognition, for example through student presentations, participation in competitions, or assessment. These are not always enjoyable for students at the time, and can be stressful, but they are thought to be seen by students as an important challenge, and to be valuable ways to develop confidence. Furthermore, interviewees reported that students valued making a contribution to a wider field, and gaining recognition for this.

Inclusion of IRPs into A-level specifications presents a challenge. Although this provides a way in which students can obtain credit for project work, it can feel like students are disadvantaged in the short-term compared with those studying a more traditional syllabus owing to the increased workload and differing demands of IRPs. However, this could be offset by the longer-term advantages to students, and some teachers involved in IRPs explained that they felt more confident in the practical skills of those students who had been involved with IRP work.

Assessment of IRPs also presents challenges. Interviewees identified a risk that constraining IRPs to predetermined outcomes, such as those demanded by inflexible assessment regimes, limits the extent to which students have ownership of their project, and therefore changes its very nature. Indeed, some key informants took the view that research is at its best when not part of a formal qualification.

Personal development

Interviewees reported that IRP work develops and rewards a different set of characteristics from standard practical work in science. These characteristics were identified by key informants to include:

- self-esteem
- independence and autonomy - especially in cases where teachers were not experts in the field and students took the lead in advancing the project
- self-regulation - students are given control and decide how much effort to invest and when, in order to reach the goals they set for themselves
- tenacity
- a developing scientific or academic identity.

A number of interviewees also said that it was important for students to develop time management skills so that they did not overcommit in relation to their IRP. Students had reported to some of the interviewees that they had developed a different relationship with teachers and other supervisors through IRP work - one which was collaborative and established in the spirit of co-enquiry, and which was sustained beyond the project.

4.3.5 Impact on teachers

Several key informants identified benefits to teachers deriving from the benefits for students, including increased interest and engagement with science. A number of other benefits were also identified, relating to:

- teachers' professional development
- teachers' professional satisfaction
- the nature and quality of relationships with students.

The challenges for teachers that were identified were primarily associated with:

- workload
- school culture
- resources
- teacher preparation for research supervision.

Professional development

Key informants identified a range of ways in which IRPs can support the professional and personal development of teachers, for example through the learning of new practical skills, the development of knowledge in a specialist area, development of pedagogical skills for enquiry-based learning, and exposure to a greater range of contexts for teaching scientific concepts in the curriculum. Some interviewees reported that IRPs helped them to "bring the curriculum to life." In supporting IRPs there is a need for teachers to work as part of a team with technicians, students and external partners, which can also be developmental.

Professional satisfaction

For many teachers, supporting students to carry out IRPs provides them with a teaching experience that aligns with some of the reasons that led them to pursue a career in teaching. Teachers described supporting students' IRP work as "refreshing" and "stimulating" and described deriving a sense of fulfilment from seeing students reach their goals and become more motivated towards science as a result of being involved in the challenge and excitement associated with scientific research.

Relationships

The supervisory relationship was described by interviewees as different to that which tends to develop in the course of normal teaching. In IRP work students and teachers work as co-enquirers and interviewees reported that in this way IRPs provide a unique opportunity for the development of productive relationships between students and teachers. The quality of these relationships provides teachers with insights into their students' academic capabilities and who they are as a person, something which has value beyond the scope of the research project.

Interviewees also considered relationships with external partners in academia and industry to be important. These relationships can support the development of project ideas, the sharing of expertise and can provide an external critical perspective. The relationships again can have benefits beyond the scope of the project, for example they can lead to access to work experience placements for students.

Teacher workload

One of the key barriers to IRP work identified by interviewees was teacher workload. Informants identified that IRPs require a significant investment of time and resources, particularly if students are given considerable freedom in selecting the topic of their project. The time demand derives from the supervision of projects, from planning, managing internal deadlines, organising space and equipment and managing health and safety in the laboratory over a sustained period of time, as well as from assessing the completed projects (where this is a requirement). One IRP provider noted that although this initially deterred teachers, once involved, they tended to remain so for a long time. It was recognised that there was some scope through EPQs to ensure that practical IRP work in science was recognised and resourced within institutions.

School culture

Being part of a school culture that supports and celebrates IRP work was seen to be important to the success of IRP work. In smaller schools or colleges in which there are few teachers involved in IRPs there is a risk of isolation. It was recognised by IRP providers that it can be difficult to offer experiences for students from ‘hard to reach’ backgrounds, and even where teachers are enthusiastic about carrying out IRP work, support from senior management is an important factor in establishing a successful project.

Resources

Interviewees recognised that IRP work could be costly in terms of teacher workload, space and resources, and argued that it was important for institutions to recognise and support this work, for example by ensuring that governors allocate adequate funding to ensure all young people have access to IRP work, or by timetabling IRP work. The required resources include laboratory, preparation and storage space and equipment. Although some key informants pointed out that IRPs did not always involve new materials and equipment, interviewees identified that lack of resource can constrain the types of project that institutions offer and the level of student choice of research topics that can be accommodated. It was identified that some support exists for teachers, for example ‘starter’ materials for different types of investigative work within the curriculum.

One teacher explained that a lack of laboratory space had essentially ruled out any extended practical work, and that this had constrained the choice of curriculum specification for sixth-form students.

Research supervision

The interviewees identified the demands of supervising IRP work placed on teachers who have not previously been involved in academic or industrial research as a significant barrier. Interviewees observed that not only do many teachers lack confidence in or experience of research supervision, many did not experience substantial investigative work during their degree studies. Their understanding of research is likely to have developed in the final year of their degree, during their initial teacher training, or on the job. Where teachers' understanding of research has developed in a professional teaching context, interviewees observed that their understanding of the investigative process was likely to have been derived from the demands of assessment criteria rather than an understanding of scientific research processes. One interviewee suggested alternative approaches might be more appropriate for encouraging students to be critical and to use and evaluate evidence.

Supervising IRP work was seen by interviewees as demanding a different way of teaching, involving shifting the locus of control away from teachers and towards students. This requires teachers to work in a more facilitative and less directive way, which can be unsettling to teachers, particularly for those with little research experience. The quality of project supervision was seen by many interviewees as key to successful IRP work, and several viewed it as important to encourage university science and education departments to collaborate on teacher education and continuing professional development in this area.

Networks seeking to provide teachers with the support they need in this area are emerging, including:

- The Institute for Research in Schools, which provides consultancy and online resources for those interested in involving students in school-based scientific research with a view to building a more sustained interaction between schools and universities; and

- EPSILON (the Extended Project Science Investigation Learning and Outreach Network), which met for the first time in February 2015 and which aims to pool expertise amongst universities and teachers to encourage wider involvement with practical IRPs.

4.4 Summary

The key informants tended to describe IRPs as challenging for both educators and students, but that provided they are implemented in congruence with their aims, they are worth the effort involved. Benefits to students included learning in areas beyond the standard science curriculum. Teachers had a chance to get to know their students in a meaningful way and to develop professionally. For some students, the impact was described as transformational.

Challenges involved in offering IRP work that emerged during these interviews included resource constraints, teacher preparation and confidence for supervising research, and participation of external hosts and partners.

Section 5: Evidence from the interviews with students who have undertaken practical independent research projects

5.1 Introduction

This section reports students' views of the impact of their participation in IRPs on their responses to science, and on how the impact of IRPs compares with that of more conventional approaches to practical work in science.

5.2 Methodology

Eight semi-structured, qualitative group interviews were conducted with students who have taken part in IRPs. The students selected for the group interviews were identified by their teacher in consultation with a research team member (Dunlop). The interviews were conducted by Dunlop in October 2015. A total of 39 sixth-form students from one school (21 students) and one college (18 students) were interviewed, drawn from both Years 12 and 13. All students were engaged in IRP work at the time of interview. The institutions chosen were known to have strong IRP programmes.

Each interview was tailored to the particular IRP the students had taken part in; an example interview schedule can be seen as Appendix 6. The interviews covered organisation and assessment of the projects, perceived benefits and drawbacks and the support received by the students. Each group interview lasted between 30 and 60 minutes and was audio-taped. The interviewer summarised the content of the interview in written notes following the interview. The notes arising from the group interviews were reviewed by the researcher who conducted the interviews to generate narrative answers to the research questions listed above; the resulting analyses are presented below.

5.3 Findings

5.3.1 What is the impact of participation in IRPs on secondary school students' responses to science?

All students who were interviewed reported that they had been interested in science before undertaking the IRP work, and some stated that this had driven their application to a school that offered research projects as part of their provision. Most students interviewed described participation in IRPs as an overwhelmingly positive experience, although a number of challenges were identified. The perceived impacts of carrying out IRP work that students discussed have been grouped here in terms of their relationship to:

- students' academic studies in science
- learning about 'real' science
- attitudes towards science

- career aspirations
- students' confidence.

Students' academic studies in science

Participation in IRPs was seen by many students as an opportunity to reinforce and expand their scientific knowledge and to develop practical expertise in a scientific field. Students also reported gaining confidence in data collection and analysis, and in using specialist equipment and instruments.

Some students felt a synergy between their project work and their studies and believed that they were performing better in their academic work as a result of their involvement in an IRP. However, it appears that workload can be an issue and a number of students highlighted the challenge of balancing the demands of their project work with other academic studies. At times, they needed to put project work on hold to enable competing academic demands to be met, and conversely, IRP work sometimes involved missing lessons owing to intensive periods of data collection. However, these students reported that they were able to catch up and did not believe that their grades had suffered as a result.

Some students, in contrast, perceived their IRP to be less important than, and sometimes irrelevant to, their studies, and felt that a disproportionate amount of time was allocated to project work. These students were highly motivated by university applications, and although they appreciated the intrinsic value of IRP work as well as its utility for their personal statement, they were highly focused on Universities and Colleges Admissions Service (UCAS) points. Although many IRPs do not carry UCAS points, some students recalled peers receiving a lower offer from universities as a result of their involvement in IRP work.

Learning about 'real' science

A common view amongst students was that their IRP provided them with an authentic experience through which they learnt how science is done, and what it is like to be a scientist. Students highlighted exciting activities such as working on live and topical problems with experts in the field, manipulating specialist equipment and interpreting raw data. However, they also discussed challenges, frustrations and failures that they had experienced, and some of what they described as the less glamorous activities. These included cleaning, setting up equipment and ensuring health and safety issues were adequately addressed, and spending long, repetitive days in the laboratory, sometimes for little or no tangible result. They reported that they felt they had experienced science in its "bare" form, as well as the process of learning from their mistakes when things don't go according to plan.

Students also identified that through their IRP they had been involved in a communal experience that they described as being more in line with how science really works, identifying that scientists tend to work in research groups rather than in the individualised way they are used to working in school.

Attitudes towards science

The students all possessed positive attitudes towards science before undertaking their independent research project. Students described their IRP work as stimulating and exciting, as well as fun, enjoyable and interesting. In particular, they valued being around other people who love science. However, it was not always possible for students to access projects in the discipline of interest to them.

Career aspirations

All students described their IRP work as influential in their future career and study choices. Of the students interviewed, all except one expressed an intention to enter work or further study in a STEM field. For many, practical IRP work had confirmed their desire to study science. One student explained that they had learned through carrying out their IRP work what ‘doing science’ involved and as a result had been able to make an informed decision not to study science further.

Students reported that their IRP work had highlighted some of their misconceptions about careers in science and had made them aware of:

1. a broader range of careers and specialisms available in STEM subjects, although these specialisms were limited to the fields in which IRPs were available
2. non-science careers in scientific industries, for example management and sales
3. the contribution of scientists working in fields such as international development
4. the different gateways into scientific careers
5. the interdisciplinary opportunities available, for example in bioinformatics or as a computer programmer working within a specific scientific discipline; and
6. everyday life in industry.

Not only did students report that IRP work had helped them make decisions about future work and study, they also reported that they felt they had a better idea of what employers are looking for, and that they were better able to communicate professionally with employers. Some students reported that they were aware of university admissions tutors making lower offers to students with extensive IRP experience.

Students’ confidence

Students reported increased confidence in their scientific knowledge, practical skills and communication skills as a result in participation in IRPs. This was particularly the case for

IRP schemes in which students have the opportunity to progress to a leadership role, or where opportunities were provided for students to talk about their project to an external audience.

Students viewed sources of external recognition as important for helping them to believe that their work was valuable. Most students interviewed discussed their use of (or intention to use) their independent project work during the university applications procedure, either in their personal statements or at interview. Some had been able to carry out additional work to qualify for an EPQ in science, and others intended to use their IRP work to contribute towards the Duke of York Award for Technical Education. A small number had contributed to scientific articles that would be published in peer-reviewed journals, and many had presented in fora with undergraduates or experts in their discipline, and reported increased confidence as a result of being able to hold their own in these situations.

Some students felt they were changing the culture of science, challenging the idea that students cannot participate in authentic research, and that scientists cannot communicate. However, they reported that many of the benefits they have experienced as a result of participation in IRPs are not immediately obvious, and took an extended period of time to develop and appreciate.

5.3.2 The impact of IRPs compared to more conventional approaches to practical work

Interviews with students who were currently engaged in IRP work revealed a range of ways in which IRP work can be contrasted with conventional practical work, the main ones being:

- the extent to which they had freedom to explore
- the contrast between individual and group work
- the extent to which they developed expertise in practical work
- the development of networks.

Freedom to explore the unknown

Many students described their IRP as incomparable to practical work, contrasting the freedom, ownership and excitement of their IRP, in which outcomes are unknown, with conventional practical work, which they described as “tired”, “boring”, “failsafe” and “foolproof”, giving a false sense of what science is about and designed to confirm ideas that had been discovered centuries ago. They felt that their IRP gave them access to contemporary science at the frontier of a field that involved learning “a different type of knowledge that was useful and which cannot be examined in a test paper” or “found at the back of the book.” One student commented: “If that [standard practical work] was the limit, I don’t think I would be interested in pursuing science.” It was important to students that they were able to develop IRPs in fields they were interested in.

Students were sometimes required to learn difficult topics, sometimes to second year degree level. Students reported a challenging transition from their year 11 (GCSE) work to being able to understand the methods and concepts required to participate in an IRP. This was described as daunting and scary, but satisfying once overcome. Some were concerned about the transition to university in that they feared they might not be expected to carry out research immediately and were concerned that they might feel a lack of stimulation.

Teamwork

Students contrasted “individualistic” school science with IRPs in which research is carried out in groups of people with a range of skills and experience working on component parts of a larger problem. Students identified that IRPs could be distinguished from standard practical work in that there was a requirement to lead a group of people, to identify individuals’ strengths and weaknesses, to manage and direct projects, to motivate and coordinate people and to delegate tasks. Where this worked well, students spoke of the satisfaction associated with learning as part of a community of peers and academics with a shared love for science. However, group work was not always unproblematic, and students identified difficulties associated with motivating others and organising their research groups, planning group meetings around timetabled lessons and managing time spent on the project so that it did not interfere with academic studies.

Students explained that through their IRP they needed to adapt to new environments and to work with people both within and outside of school with whom they would not normally interact. Although this was identified as a challenging feature associated with IRP work, students identified that they had learnt to appreciate different skills and that through the team work they had forged new friendships.

Development of expertise in practical work

Some students described conventional practical work as decontextualized and that it was possible to perform it correctly with little understanding. They contrasted this with the practical work associated with an IRP, in which it is essential to understand what is happening and to be able to solve problems if things do not go according to plan, particularly when using new equipment with which the supervising teacher may have limited experience.

Students discussed gaining experience of activities related to experimental design, for example identifying all of the factors that can affect the outcome of an experiment and attempting to control these in real systems, learning to deal with unexpected results, and working iteratively to improve their experiments. They described having to gain new skills within a short time scale, for example learning to code so that they would be able to access, process and interpret their data. They contrasted this with standard practical work, which they considered to lend itself to following instructions.

Some had noticed that the equipment that they had been using was common in university laboratories, and felt that their IRP had prepared them well for further study. They described being able to surprise university admissions tutors with their knowledge gained from IRP work and all reported drawing substantially on their research projects in their UCAS personal statements.

Development of networks

IRPs were viewed by students as an important way to develop professional and personal networks. Students valued their teachers' knowledge of industry and university and that they had the contacts to be able to secure funding for the research projects. They also valued their teachers' use of feedback on projects and the way in which they were organised.

In addition to support from teachers and technical support provided by their school, students identified peer support networks as important. This support took a variety of forms:

- within projects, where students in the year above would share expertise with the cohort below including help with experimental techniques
- between projects, where groups would draw on the knowledge and expertise of others in their cohort, for example in data analysis or coding; and
- between schools, for groups working on the same project.

These peer support networks were seen as important to the students as they were also able to discuss non-project related matters such as subject and university choice and UCAS applications.

External sources of support included academics, doctoral and postdoctoral researchers at universities and research institutes, scientists at CERN and NASA, industrial partners (including technicians, research scientists and managers), funders, non-governmental organizations, charities and STEM ambassadors. Students noted that the support provided by these networks extended beyond the scope of the projects, reporting tangible benefits such as securing work experience placements and internships.

Students reported that it could be challenging to learn enough to be able to talk about the subject of their IRP with external contacts, but that achieving this was highly rewarding. They explained that it seemed they were not always taken seriously at times, and felt that they had to convince people that they were worth listening to, but that they gained a sense of satisfaction if they were able to achieve this. Some felt that this would be less of a problem if school-based research was more widespread.

5.4 Summary

The students interviewed at both schools displayed a high degree of commitment to and engagement with their IRP work. The students reported that they had learned a great deal through participating in an IRP, including in areas and relating to skills falling outside of the standard science curriculum. They reported feeling tremendous satisfaction when they overcame difficulties.

The students considered participating in an IRP to be challenging. Notable challenges involved in IRP work that emerged during these interviews included difficulties faced by students with respect to balancing their IRP work with their other studies and in managing team dynamics.

The students also made several references to the relationship between IRP work and the university admissions process in the UK.

Section 6: Evidence from the international case studies

6.1 Introduction

This section of the report considers the evidence from five case studies of IRP provision in other countries: Australia, Israel, The Netherlands, Singapore and the USA.

6.2 Case study 1: Australia

6.2.1 Background

Australia has a very high level of enrolment in tertiary education; in 2012 (with data adjusted to omit the 18% of students who were international) it was ranked the second highest on this measure among OECD countries. However, at the other end of the education spectrum, only 3% of three-year olds are enrolled in pre-primary education, compared with an OECD average of 70% (Bolognini, 2012).

The current Australian Curriculum (ACARA, not dated) for science comprises three approaches or ‘strands’: ‘Science Understanding’, ‘Science as a Human Endeavour’ and ‘Science Inquiry Skills’. Within the first strand, ‘Science Understanding’, students are taught via four ‘sub-strands’ of science: biological sciences, chemical sciences, earth and space sciences, and physical sciences. The second strand, ‘Science as a Human Endeavour’, comprises the two sub-strands ‘nature and development of science’ and ‘use and influence of science’, which develop an appreciation of the nature of science and scientific knowledge, and how its application to life affects people, their work and society.

Relevant to this research is the third strand, ‘Science Inquiry Skills’, in which students are taught to identify and pose questions, plan and conduct investigations, analyse and interpret evidence and communicate their findings. During the investigations, “ideas, predictions or hypotheses are tested and conclusions are drawn in response to a question or problem. Investigations can involve a range of activities, including experimental testing, field work, locating and using information sources, conducting surveys, and using modelling and simulations” (ACARA, not dated). There are five sub-strands through which these inquiry skills are taught: questioning and predicting; planning and conducting; processing and analysing data and information; evaluating; and communicating. There has been “from time to time, at different levels, and in different Australian states, curriculum requirements for open investigative work” (Symington and Tytler, 2011) and in the current Science Curriculum open investigative work has greater prominence.

However, the science curriculum has received criticism for dealing only with inquiry skills, and not teaching about the broader philosophical aspects of inquiry learning; it therefore becomes the teacher’s role to “marry inquiry skills with inquiry learning” (Lupton, not dated).

Inquiry learning is becoming more widespread (Bushby, 2012; Lupton, not dated; Touhill, 2012). It is also worth noting that The Australian Academy of Science's Primary Connections programme (Hackling et al. 2007) has provided teachers of primary science with curriculum resources and professional learning to enhance the teaching of science by inquiry, and these are reported as having positive impacts (Hackling & Prain, 2007).

6.2.2 Case study: BHP Billiton Science Awards

The BHP Billiton Science Awards are a competition, funded by BHP Billiton and administered by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The competition is organised by the Australian state science teacher associations and CSIRO's CREST initiative and has been running since 1983. There are three categories: the Science Student Awards, the Science Teachers Awards, and the School of the Year Award. The Science Student Award is open to primary or secondary students who must submit a research project in one of four categories (biology and microbiology; chemistry and biochemistry; physics, engineering and technology; and environmental and earth science) either as individuals or in groups of up to three students. They must demonstrate an understanding of the selected topic, tackle the problem imaginatively, present findings clearly, discover new facts and demonstrate the practical value of the topic. Authors of the four best projects receive $1,000 and a place at the BHP Billiton Science Camp, and the next 12 finalists receive $100 each and may also attend the camp. One of the aims of the BHP Billiton Award scheme is to encourage students to continue their study of science.

An evaluation of the BHP Billiton science awards found much evidence that the awards were effective in fulfilling their aims and had a positive impact on participating schools and their students. There is much anecdotal evidence of "very impressive … and enthusiastic teachers and schools" (Tytler et al., 2009:5), and it was reported that the awards encourage these teachers and schools to "move beyond normal practical work, which is often described as predictable … rather than representing scientific experimentation" (ibid.). For instance, it was found that the competition entry requirements affect what some schools adopt in their formal curriculum. Although only a minority of schools participate, in those that do, science investigation work is increased. The drive to participate is often instigated by enthusiastic teachers who help to develop a culture which embraces other teachers. For schools whose participation is long-standing, a system of "supporting students with investigative skills including critical thinking and communication" (ibid.) has grown. The evaluation also found that "[s]ubstantial professional learning is required" (ibid.) to organise and administer research projects, and that this tends to occur at a local level (via sharing of expertise); therefore, there is the opportunity to tap into this teacher expertise more formally so that it is sustained within professional development. Although the evaluation could not provide quantitative evidence to demonstrate that participation improved student engagement in science courses and careers, there was “universal agreement supported by substantial anecdotal evidence” (ibid) that this was the case.

Hubber et al. (2010) report that participation in the science awards “led to improvement in numbers undertaking Science at the tertiary level” (2010:8). Furthermore, 75% of students reported that taking part in the STA (Science Teacher Associations)/CREST science awards increased their interest in science, and 52% thought that it helped them achieve better grades in science subjects at school. Teachers cited several reasons as to why the experience of participation is educative: that students have ownership of their work; they regard the investigations as authentic; and links are forged between science professionals and the school, which are beneficial. In addition, the award schemes provide opportunities for students to showcase their work, the competitive environment is educative, and the scheme recognises the quality of the students’ work. Another effect of participation was that it altered students’ expectations of school science and their general orientation towards the subject, for the better. This was particularly notable for ‘fringe’ students who were not previously considered as being particularly gifted scientists: the investigations “provided alternative, more accessible and successful learning experiences for students who may not normally experience success” (Hubber et al., 2010:9). The researchers provide much anecdotal evidence of previously disenfranchised students making great achievements and significantly shifting their attitudes and orientation towards science for the better. The researchers conclude by asking why, if there is evidence indicating that there are “significant benefits for students arising from open investigation activity … such activity is not more widespread in schools”? (Hubber et al., 2010:11).

Symington and Tytler suggest that, despite the “range of positive outcomes” (2011:8), open investigative work can be challenging for teachers and this explains why in Australia “to date, relatively few schools are seriously involved in this form of activity” (ibid.). In those schools that were successful, there was more than often a process in place and an established culture which supported students in open investigative work, usually “driven by enthusiastic teachers, to establish the practice within the curriculum” (Symington and Tytler, 2011:11). Furthermore, the researchers found that commitment to open investigation was linked to experience with “collaborative pedagogies” (ibid.). The supportive schools had approaches that were “varied and pervasive” (ibid.), including supporting written resources, a structured inquiry curriculum that scaffolded students through the inquiry process, and a mentoring system. They had a history of practice that included a catalogue of past projects, and inducted students into investigative practices both formally via the curriculum and informally via support targeted on quality outcomes. Finally, the awards schemes and science competitions themselves were very often key to the sustenance of this work.

6.3 Case Study 2: Israel

6.3.1 Background

Education in Israel is highly respected and the population well-educated (OECD, 2014), based on its higher-than-average percentage of 25-64 year-olds participating in tertiary education: 46% compared with the OECD average of 32%. Furthermore, 83% of the population has an upper secondary education compared with an OECD average of 75% (OECD, 2014).

Educational research in Israel reflects a global interest in a pedagogical shift towards more open-ended, investigative and inquiry-based teaching, and its effect on both procedural and epistemological understanding among secondary and high school students (Zion et al. 2004). To date, research in Israeli schools has generated a number of findings of relevance to IRP work. For example, an examination of the effects of using problem-based learning (PBL) intervention to teach science to low-attaining pupils with a low expected outcome found that "scientific-technological PBL elevated pupils' motivation and self-image at all levels and achieved significant affective learning" (Doppelt 2003:254). Another research project demonstrated that "open inquiry students used significantly higher levels of performances" in two categories of dynamic inquiry criteria: "'changes during inquiry' and 'procedural understanding'" (Sadeh and Zion 2009:1137).

Zion and Mendelovici (2012:383) argue that "an educational shift entails a fundamental cultural change in the epistemology of science learning in schools … from 'instructionism' to social constructivist learning". This has led to the development of a model for implementing inquiry teaching, consisting of several components, which has been implemented in Israel's high school biology teaching since 2000. The model provides a framework, comprising several components, to support teachers and educators who take on the "complex challenge" of "moving from the structured to the open inquiry teaching approach" (Zion and Mendelovici 2012:384). The programme is designed to support this shift by leading teachers (and their pupils) from structured inquiry lab exercises to guided inquiry fieldwork, and finally onto an open inquiry project. Each component has been shown by independent research to be fundamental to inquiry-based teaching. The programme has been developed collaboratively by teachers, science education professionals and ministry of education staff over a period of several years. It can be implemented in several modes, including workshops for new and veteran teachers, is facilitated by programme leaders and supported in various ways, for example, via conferences, online fora, an open resource database, and a National Centre for Supporting Inquiry.

6.3.2 Biomind and BioInquiry

A specific example of an IRP in Israel is the biology-learning curriculum for Israeli high schools. The first version of the curriculum is known as ‘Biomind,’ and the programme began in 2000 with 316 students, and by 2014 had 2,400 students, 60 teachers and operated in 45 schools. From 2015 the new version of the Biomind curriculum, called BioInquiry began which is a compulsory curriculum for high school students in in their final two years (ages 16-18), specialising in biology and studying toward matriculation examinations in this field (34,000 students in 1,300 schools). The programme offers an alternative to traditional pedagogy.

Biomind, and the new version Bioinquiry, have two main goals: firstly, to develop understanding of the inquiry process, by developing students’ “cognitive, meta-cognitive, psychomotoric and social skills” (ibid.), and secondly to increase student involvement and interest in biology learning. There are five curriculum components:

Autonomous research is the overall aim of the Biomind and BioInquiry programme. The teacher offers guidance and support, and the students are required to finish within 12 months. In the Biomind programme, the inquiry process explored two logically connected inquiry questions, to be answered by controlled experiment results used in explaining an intriguing biological phenomenon (Zion and Sadeh 2007). The inquiry process in the BioInquiry programme focused on one practical inquiry question and a second theoretical inquiry question raised in the Discussion. In order to ensure that an open inquiry is indeed taking place in the BioInquiry programme, participating students were asked to report on their ‘personal fingerprint’ (personal communication) in the stages of setting up the experiment system and arranging the inquiry design for answering the practical question.

Laboratory work, which aims to impart inquiry and technical skills, and methods of reporting enables students to practise formulating questions and hypotheses, measure accurately, follow written instructions, use software to deal with data, and to work autonomously.

Study excursions allow students to familiarise themselves with wild flora and fauna and their ecological environments systems, and to learn practical skills such as making observations and taking measurements in the field.

The writing of scientific reports is emphasised, and this includes learning how to write notes, excursion reports, and research proposals. Biomind and BioInquiry recognise the importance of allowing students to make mistakes and being able to correct them in order to raise their grade; in this way, “students learn that the one who takes responsibility and makes an effort is rewarded” (Zion et al. 2004a:61).

The inquiry process products were collected into a portfolio, which includes: an inquiry proposal; the open inquiry report and a reflection on the inquiry process; three lab reports and a reflection on the laboratory work; an excursion report and two plant morphology descriptions; summary and a final reflection on the whole portfolio, linking inquiry findings from the field and the lab to theories, central concepts and fundamental principles in biology.

A particular feature of Biomind and BioInquiry is its requirement for students think reflectively, and link their findings to a theoretical context, which "opens the way for students to create new and unique meanings for biological concepts and ideas" (Zion et al. 2004:65). However, it is "not an easy" (ibid.) programme to implement, and relies on a significant contribution from teachers. 'BioInquiry on the web' is an experimental new programme emerging from BioInquiry. 1,100 students and 45 teachers from 30 different schools currently participate. Pairs of students cooperate on an open inquiry project with another pair of students working in another school, or studying under a different teacher in a different class in the same school. The inquiry process concludes with a joint written report. The cooperative effort is conducted using online digital tools and recorded on a portal set up especially for the 'BioInquiry on the web' initiative. Participants learn and experience dynamic open inquiry, cooperative teamwork with colleagues of varied discourse cultures, and the use of digital media for communication, as somewhere for a learning process to occur, and as a platform for evaluation and assessment.

6.4 Case study 3: The Netherlands

6.4.1 Background

The Netherlands has a high level of educational attainment: an average of 32% of Dutch 25-64 year-olds have a university degree, significantly higher than the OECD average of 24% (Marin 2014:1). Only 7% of young people are not in education, employment or training (NEET) which compares favourably with the OECD average of 15%. The education system is more complex than that in the UK, with students being offered more choice earlier on. Primary school begins from age four (but is compulsory at age five) and lasts for eight years, when students are around 12 years old. As of spring 2015, students are assessed in their final primary school year and the outcome is used to help determine which of the four different types of secondary school they may attend, which vary in type and specialisation:

- VMBO – a further four years of school, which is a preparatory system for vocational secondary education. Graduates must continue in education until they are either 18, or obtain a basic qualification.

- MBO – secondary vocational education, varying from one to four years, which prepares students either for work or for professional studies.

- HAVO – a five-year senior secondary education from which graduates gain access to higher professional education in 'vocational universities'.

- VWO – pre-university education lasting for six years, which prepares students for undergraduate studies at a research university.

VMBO students who receive the highest level of attainment can enter HAVO studies (EP-Nuffic, 2011:5).

It is reported that amongst upper secondary school students there is "very little enthusiasm" (Marin 2014:1) for a career in science: in 2011, only 23% (compared to an OECD average of 37%) pursued a scientific profession. Only 16% of students took science subjects at university, comparing unfavourably to the OECD's average of 37%. One possible cause for this is the "current age profile of many teachers of science" (Osborne and Dillon 2008:24) who tend to be older.

In the late 1990s, the course Algemene Natuurwetenschappen (General Natural Sciences) was developed to increase participation in science: it is compulsory for all grade 10 (age 16-17) students, even those who had elected to discontinue science studies. This course "has been contentious" (Osborne and Dillon 2008:22) and undergone consequential transformations. When evaluated, it was found that "pedagogy was still dominated by a focus on content rather than developing an understanding of science itself", a conclusion that other researchers have concurred with (ibid.).

6.4.2 'Profielwerkstuk'

In their final year of VMBO, HAVO and VWO, students are required to carry out a 'Profielwerkstuk'; a research project performed independently on in small groups. It has two purposes: to deepen theoretical knowledge about a topic of their choice, and to learn research skills such as formulating research questions, devising a method, collecting and analysing data. Each student works on their 'Profielwerkstuk' for 80 hours. The topics must be related to one of the following four subject clusters: Nature and Technology; Nature and Health; Economy and Society; Culture and Society. Over half of the pre-university students choose to situate their research in the Nature cluster, resulting in almost 20,000 science-related investigations each year. The majority of investigations are carried out at school, and some at universities. It is common for students to present their work at school for other students or parents (H. Eijkelhof, personal communication, August 2015).

Each year, the Dutch Royal Society organises a competition[6]. Eijkelhof is involved in the selection of the best 12 Nature and Technology projects, and although reading through approximately 100 submissions may incur a heavy time-load, it is "very rewarding as it shows

[6] See https://www.knaw.nl/en/awards/prijzen/knaw-onderwijsprijs?set_language=en)

what some boys and girls are able to do” (Eijkelhof, 2015 personal communication). Similar competitions are also organised by universities. Schools often use the Profielwerkstuk as the end of a research learning progression line at secondary school, to help prepare students for higher education. Interestingly, it has resulted in more open investigative programmes at university level, as first year students were surprised by the closed nature of most practical work at undergraduate level (ibid.).

6.4.3 Junior College Utrecht (JCU)

The JCU was established in 2004 as a specialised science-enriched secondary school. Entrance is competitive, and acceptance is held in high regard; this status acts as a “means of attracting more able students” (Osborne and Dillon 2008:22). Students are taught by both secondary teachers and university staff, and this collaborative teaching approach is essential: not only do secondary teachers teach the regular VWO syllabus, they are more experienced than university staff at preparing students for national VWO exams. The enrichment activities and student research projects are supervised by university lecturers. The teaching pace at JCU is accelerated, and students are expected to learn minor material independently. It has three curriculum characteristics: “accelerated pace, research-context focused and enriched programme” (Valk and Eijkelhof 2007:1). Students are provided with the research context of subject matter, for instance via trips to university research groups. “Much lesson time is spent doing lab work in university laboratory facilities” and, importantly, “students do investigations” (ibid.). Students are required to carry out two major investigations, to produce a ‘pre-thesis’ and ‘JCU-thesis’ under the guidance of Utrecht University researchers. The theses may be considered IRPs, as “other issues that are thought by the students themselves can be investigated as well” (Valk and Eijkelhof 2007:5). Via these theses, students fulfil the research project requirement set out by the regular syllabus, although they are expected to achieve an undergraduate performance level. JCU curriculum characteristics may be summarised as follows (adapted from Valk and Berg 2006:4):

JCU curriculum characteristics			
Topics from syllabuses		**Topics beyond syllabuses**	
Accelerated	*Comprehensive*	*Curricular coherence*	*Enriched*
- exam topics taught in 60% of regular time - ½ year left for other topics	- lab work in University labs - guest lectures - excursions, for example to CERN	- investigations - modelling - projects e.g. GPS	Academic modules e.g. - modern physics - nanoscience - biophysics

Students are not taught according to a conventional timetable either: on Monday mornings they study Biology and Chemistry, on Tuesday mornings, physics and mathematics, and the rest of the week is spent back in their VWO School. Lab work, lectures and projects are carried out on Monday and Tuesday afternoons.

For participating secondary teachers, the JCU experience was challenging: although feasible, the partnership was complex in organisation and required co-operation with university teachers. However, the teachers “have been inspired to change their teaching in their own schools and to inform their school colleagues about their experiences” (Valk and Berg 2006:8). This project was initially trialled for three years; the positive evaluations it has received from students, partnership schools and the university have led to the decision that “JCU will continue in the years to come on a regular basis” (ibid: 9).

6.5 Case Study 4: Singapore

6.5.1 Background

The education system in Singapore is centralised, with a national curriculum that the vast majority of schools adopt. This curriculum is composed of three ‘circles’: the inner circle comprises non-academic subjects and teaches students ‘life skills’; the middle circle focuses on ‘knowledge skills’, and develops students’ thinking, process and communication abilities through Project Work; and the outer circle consists of content-based subjects in the categories of Languages, Humanities and the Arts, Mathematics and Sciences (Ministry of Education, Singapore (MOE), 2015). Singapore’s performance in international comparative assessments has been described as “excellent and sustained” (Gilbert 2014:298). The country has held strong positions in TIMSS (Trends in International Mathematics and Science Study) and PISA (Programme for International Student Assessment).

In 2000, the science curricula for primary and lower secondary science placed the concept of ‘science as an inquiry’ as “the core emphasis in guiding curriculum design and the way science should be taught” (Wong and Lau 2014:90[7]). MOE replaced the one-off science practical assessment with a “continuous school-based mode” emphasising “the process of scientific thinking and inquiry” (Hoe and Tiam, not dated: 2). To cope with this pedagogical shift, the MOE dedicated a significant part of teachers’ professional development to providing them with good pedagogical models, and the knowledge and skills to foster an inquiry-based learning environment in science lessons. It also provided five professional development courses to ensure lessons were truly inquiry-based, and contributed to the development of theme-based science text books, as well as other appropriate materials, resources and

[7] See http://www.moe.gov.sg/education/syllabuses/sciences/ for the most recent copy of the science syllabus

professional development. Teachers were trained in implementing the new school-based Science Practical Assessment. Such changes to the aims, approach, content, and pedagogy that this significant shift to inquiry-based education made could be described as “drastic” (Gilbert 2014:298).

In 2008, science as inquiry received further emphasis when “inquiry was identified as the guiding pedagogical framework for science education change” (Tan et al., 2014:115). This gave formal and explicit direction for the primary science syllabus to be inquiry-centric, declaring that the “the inculcation of the spirit of scientific inquiry” (Science Syllabus Primary, 2008:1) was central to the curriculum framework, and that teachers were to lead, nurture, and sustain the interest of students in the inquiry process. Consequently, Singaporean educational policy now strongly emphasises the development of key scientific skills, for instance the control of variables and using “proportional reasoning and deductive and inductive reasoning” (ibid.). The new syllabus is organised around five themes: cycle, systems, diversity, energy and interaction, and provides activities and inquiry processes rooted in science’s roles in life, society and the environment.

Currently, students spend approximately 1.5 hours a week studying practical science, and carry out “independent inquiry research” (P. Lim, personal communication, 22 September, 2015) during their Project Work in both secondary schools and junior colleges. One of the aims of Project Work is that “[s]tudents will be able to learn on their own, reflect on their learning and take appropriate actions to improve it” (MOE, Project Work). During Project Work, students learn to “synthesise knowledge from various areas of learning, and critically and creatively apply it to real life situations” (ibid.). However, it is not clear how much of the work carried out in Project Work is driven by student choice and thus truly independent.

Despite the benefits that the MOE hopes that an inquiry-based learning pedagogy will provide for students, recent research has shown that this inquiry-based focus in Singapore has had associated challenges: it was commonly found that “teachers perceived their main responsibility as one that is to help students obtain good test results even though they believed the need of inquiry in science education” (Tan et al. 2014:129), and that teachers believed inquiry science “was impossible to implement in countries such as Singapore where there are usually large class sizes and a strong focus on preparing students for national examinations” (Poon and Lim 2014:139).

6.5.2 Physics by Inquiry

In 2005, the Physics by Inquiry (PBI) curriculum, developed by the University of Washington’s Physics Education Group, was introduced in Singapore to assist teachers “teach physics in a way that emphasises the development of fundamental concepts and reasoning skills through first-hand laboratory-based experiences” (Wong and Lau 2014:89).

Over 1,000 students were involved in the three-year project which aimed to leave a lasting legacy in Singaporean physics teaching. In 2012, a programme evaluation concluded that the PBI "curriculum materials have been effective in providing structured guidance to students to promote their learning of Science through evidence-based reasoning, problem solving and argumentation" (Wong *et al.* 2012:1).

6.5.3 Science Centre Singapore

The Science Centre Singapore (SCS) has a "mission to promote interest, learning and creativity in science and technology, through imaginative and enjoyable experience" (Dairianathan and Lim 2014:251). In addition to over 1,000 exhibits, the SCS works in partnership with schools to run tailor-made programmes, competitions and events. It receives more than a million visitors annually, and over a quarter are students who come to learn science through inquiry-based activities. It includes a problem-based gallery, comprising a pre-visit (in school), a SCS visit, and post-visit (in school). Specialised laboratories provide a range of authentic science "enrichment programmes … to complement the schools' formal science education" (ibid: 254). This includes (amongst others) the robotics learning centre, DNA learning lab, observatory and star lab.

6.5.4 Case study of an IRP: Biology problem-based learning (PBL) intervention, 2010

One example of an IRP in action was an 18-week project undertaken by a group of Year 9 students on the topic of 'Food and Nutrition'. They worked in small groups, with support from mentor teachers. Importantly, the students selected topics that *they* were interested in, and the teacher "integrated students' project work ideas and findings into her lessons" (Chin and Chia 2010:70); thus both the topic and the students' findings had value and meaning. The research projects were carried out in a five-stage process: firstly, the problem was identified, and students read case studies and media articles on topics related to nutrition, such as obesity or dietary and herbal supplements. They made mind maps of the issues of most interest to them, and formulated ideas and questions individually, noting down their thoughts in a log-book. In the second stage, they explored the problem space and designed their project task. During stage three, students carried out the scientific enquiry, and their teacher set up an internet forum so they could contact health-care professionals. Stage four saw the combining of information from various group members and collaborative planning of any further tasks. During the final stage, students delivered oral presentations of their findings, received teacher evaluation and carried out self-reflection.

These students received a high level of support from their teacher, and the study concluded that for such learning to be successful, "the teacher plays an important role in contributing to the success of learning via PBL. If students face difficulties in identifying a problem, she needs to provide 'seed' ideas by posing appropriate guiding questions and giving examples to help them overcome the activation barrier” (Chin and Chia 2010:75). The teacher also helped with organisation and structure by using graphic organisers, guide sheets, problem logs, ‘need-to-know’ worksheets, learning logs and project task allocation forms.

Teaching students how to carry out independent research (posing testable questions, forming workable hypotheses, designing an experiment, collecting data, analysing and presenting findings) in a heterogeneous classroom is a “difficult feat” (Chin and Chia 2010:1) but possible. Not only do “students have the ability” (ibid.), but the opportunities they have to “learn from first-hand interviews … carry out field visits and to analyse real-life data” (Chin and Chia 2010:75) provides students with both a stimulating learning environment and opportunities to “acquire knowledge beyond the given biology syllabus” (ibid.).

6.6 Case Study 5:The USA

6.6.1 Background

In 1996 the United States’ National Research Council established a new set of guidelines, the National Science Education Standards (NSES), for science education from kindergarten to grade 12, comprising a set of goals for teachers to set for their students, and to inform professional development. One area the NSES placed particular emphasis on was the need to move beyond ‘science as process’ and to include inquiry as a fundamental science skill: “Inquiry is central to science learning” (National Research Council 1998:2). The NSES clearly states that there should be “less emphasis on knowing scientific facts and information” and “more emphasis on understanding scientific concepts and developing abilities of inquiry” (National Research Council 1998:113). To this end, teachers were recommended to implement inquiry as an instructional strategy. Although later described as durable and effective, the NSES was updated in 2011 with the Next Generation Science Standards (NGSS), which incorporated a conceptual shift in science standards and reflect the scientific and pedagogical discoveries that had been made in the intervening 15 years. It states that “students must be engaged at the nexus of the three dimensions” (NGSS release, 2013:1): engaging in the practices, concepts, and core ideas of science and engineering. Students are provided with the opportunity to “actively engage in scientific and engineering practices” (ibid.), and consequently, the standards include project design, research problems requiring student-led solutions, and collaborative investigation.

US-based research into ‘authentic’ science inquiry projects demonstrates that teaching this way has several benefits: it significantly improves students’ achievement in science; provides students with a greater sense of science agency (what they know about science and how they work with others to construct knowledge); affords students opportunities to gain expertise; has the potential to challenge students’ understandings of science; and enhances how they see themselves in relationship to science. Furthermore, students are more likely to choose to participate in science-related activities in the future (Rivera Maulucci *et al.* 2014).

6.6.2 Science Fairs

The USA has a strong tradition of extra-curricular science competitions and fairs; indeed, during the literature review for this report, the majority of documentation relevant to IRP findings was consequently from the USA. On the whole, participation in science fairs and competitions has been found to have a positive effect on the engagement and motivation of students (Dolan *et al.* 2008, Duran *et al.* 2013, Rivera Maulucci *et al.* 2014, Sikes and Schwartz-Bloom 2009). Interestingly, Blenis (2000) found that student attitudes were particularly affected by the conditions of science fairs: whilst the award structure (whether there is an outright winner, 1st, 2nd or 3rd place, or corresponding grades) made little difference to attitudes, students participating in non-competitive fairs had significantly higher interests in science. In the study, a surprising finding was that there were no voluntary entries to non-competitive fairs, and it is suggested that this may be due to teachers' lack of enthusiasm, or lack of inclination to carry out extra work. In summary, Blenis' research found that removing the competitive aspect of academic competition focuses students on the project, rather than the award.

6.6.3 Motivational and attitudinal effects of IRPs in USA

The following three examples illustrate the positive effects that IRPs have on the motivation and attitudes of participating students.

Montgomery County/Virginia Tech Robotics Collaborative (MCVTRC)

MCVTRC is a year-long secondary school robotics programme, which seeks to motivate students' interest in STEM subjects. Students have the opportunity to apply their science and mathematics skills to robotics design through a series of short courses and to participate in an international robotics competition, For Inspiration and Recognition of Science Technology (FIRST). Over the course of the year, students construct various robot prototypes in addition to the human-sized robot specifically designed for the FIRST competition. At the time of publishing (2008) the programme was in its ninth year. Brand et al. (2008) found that the opportunity to work with peers and mentors from the university, and to participate in FIRST, motivated students and also increased their interest in pursuing careers in STEM subjects. By the end of the ninth year, the outcomes for the MCVTRC programme had been consistently positive. These results were evident in students' discussions of increased comfort level with the STEM applications in the course and in these programs beyond high school.

Summer Science Exploration Programme (SSEP)

Gibson and Chase (2002) examined the longitudinal Impact of SSEP, an inquiry-based science programme, on middle school students. SSEP provided students with the opportunity to explore different biological and health-related subjects through inquiry-based learning. Students who participated in this program learned how to formulate their own questions, which could be addressed experimentally or through observation. Students designed experiments and practised laboratory and field techniques that could be used to answer their questions. They also analysed data through examining their own experiments and those of others. In addition, college science labs provided students with the opportunity to engage in study that went beyond that which the students experienced in their science classes.

The comparison between students who applied but were not accepted and students who went to camp indicated that over the years, SSEP students maintained a positive attitude towards science and a high interest in science careers. In contrast, students who applied and were not accepted showed a decrease in attitude towards science and interest in science careers over time. Attending SSEP contributed to students' high interest in science, and helping to sustain them through science courses in high school that they did not like. Students who participated in SSEP were actively engaged in science using a hands-on, inquiry-based approach. The interviews suggest that it was this pedagogical approach that made science not only enjoyable but also interesting for students. Students stated they prefer hands-on, inquiry-based science, and this active approach is more engaging to them than sitting and listening to teachers.

Launch into Education About Pharmacology (LEAP)

LEAP is an inquiry-based science enrichment program designed to improve understanding of biology and chemistry and enhance motivation in science careers, particularly for under-represented minorities. During the course, 16-18 year-old students, who opted to participate, study "how drugs work, how they enter cells, alter body chemistry, and exit the body" (Sikes and Schwartz-Bloom, 2009:77). During the summer, students participated in an intensive three-week course in the fundamentals of pharmacology, following the '5E' constructivist learning model: Engage, Explore, Explain, Elaborate, Evaluate. This was followed up by a mentored research component during the school year, during which students pursued their own research question. The LEAP students developed their research "in the role of graduate students; they learned how to read the literature, choose an experimental method to test their hypothesis, write a research protocol, decide what supplies needed to be ordered, and consider dose, concentration, and time in their experiments" (Sikes and Schwartz-Bloom, 2009:79). This process was supported by teachers and university post-graduate and under-graduate students, who mentored the students one Saturday each month for six months (a total of between 35-40 hours contact). Their final research paper was presented at the American Junior Academy of Science competition, and assessed by a panel of judges.

The findings showed, unsurprisingly, that knowledge of basic biology and chemistry concepts improved. Interest in science was high before programme participation, and this may explain why there were no changes in levels of interest after participation. Although under-represented minorities showed the same level of interest in taking science courses as their peers at the completion of the program, they did not actually take more compared to their peers. Interestingly, the second cohort of students showed greater improvements in interest, and this was attributed to fine-tuning of LEAP programme. All students demonstrated an "enhanced awareness of the career activities of academic research scientists, including the rigor and rewards of discovery science" (Sikes and Schwartz-Bloom, 2009:82).

6.6.4 Learning gains resulting from participation in IRPs

The following two mini case studies provide examples of IRPs in the USA which point to significant learning gains for participating students.

The Fostering Interest in Information Technology (FI^{3}T) Program

The FI^{3}T program aims to "increase the opportunities for underrepresented and underserved high school students" (Duran *et al.* 2013:3) in urban communities in South-eastern Michigan to learn, experience use IT "within the context of STEM" (ibid). These underrepresented groups include African American, Latino and female students. FI^{3}T designed and implemented projects that engage youth, educators and community members in STEM-rich learning experiences via inquiry- and design-based collaborative learning experiences. The programme was organised in two phases, delivered over 18 months. During phase one (9 months) it aimed to increase knowledge and skills in IT-/STEM-related fields and students received 54 hours of instruction at the participating university. They then spent an average of four hours per week on their projects. In phase two, the programme facilitated student activities in inquiry-based authentic projects and culminates in a science fair.

FI^{3}T was shown to have a positive impact on students' learning and technology skills, "such as using computers, internet, productivity tools, and Web 2.0 tools. In most cases, the FI^{3}T program also improved urban high school students' frequency of common and advanced IT/STEM technology use when those technologies are available to them" (Duran *et al.* 2013:16). Students' understanding of IT and STEM professions increased. Attitudinal responses varied: increased interest in mathematics and technology was observed. In general, "findings suggest that study participants have limited aspiration for a career in mathematics or science, but fairly strong aspiration for a career that uses a lot of technology" (Duran *et al.* 2013:16). Furthermore, more than half of the students showed an increased or sustained interest in the area at the end of the programme. However, 13% showed a decrease in interest, and it was not clear to the researchers why the remaining 35% were not influenced.

Centre for Learning Technologies in Urban Schools (LeTUS)

The LeTUS programme adopted a project-based science approach, which incorporates five key components:

- Students are presented with a driving question, a problem to be solved.
- Students explore the question by participating in authentic, situated inquiry – processes of problem solving that are central to expert performance in the discipline. As students explore the question, they learn and apply important ideas in the discipline.
- Students, teachers and community members engage in collaborative activities to find solutions to the question. This mirrors the complex social situation of expert problem solving.
- While engaged in the inquiry process, students are scaffolding with learning technologies that help them participate in activities normally beyond their ability.
- Students create a set of tangible products that address the question. These are shared artefacts, and publicly accessible external representations of learning.

Students engaged in project based science (PBS) showed statistically significant learning gains on 'curriculum-focused' pre- and post-tests, and on Michigan State tests when compared with a matched group (Krajcik and Blumenfeld, 2006). This was attributed to fine-tuning of approach and professional development. Importantly, students' attitudes remained positive (as opposed to decreasing) over middle school years: "This is an important finding, considering that the literature reports that students' attitudes toward science typically decrease substantially during the middle school years" (Krajcik and Blumenfeld, 2006:16). The researchers also noted that in order to scale up, more explicit and developed curriculum materials were required, resulting in the activity being more closed that originally intended in PBS.

6.6.5 Incorporating IRPs into pedagogy

For IRPs to be beneficial, they must be run successfully, and it is worth mentioning US-based research into teachers' relationships with this type of pedagogy. Brown and Meleaur (2006) analysed the relationship among secondary science teachers' preparation, their beliefs and their classroom practices after completion of a course designed to provide authentic inquiry experiences. It investigated links among inquiry-based experiences teachers had had in their training, secondary science teachers' beliefs about scientific inquiry and their use of scientific inquiry in teaching. Teachers participated in a course called 'Knowing and Teaching Science: Just Do It'. The course provided opportunities to experience similar frustrations to those that their students would possibly encounter. They valued experiencing scientific inquiry in the same way that they would teach their classes, even though they struggled with the open-inquiry style of the course.

All teachers reported that participating in an inquiry-based science course was valuable, as it gave them the opportunity to experience scientific inquiry as their students would. However, those teachers who described themselves as student-centred were not; they were in fact teacher-centred, and two teachers who described themselves as teacher-centred were actually more student-centred (Brown and Meleaur, 2006).

The study concluded that teachers' beliefs and behaviours were not consistent with the type of inquiry-based learning they experienced on the course. First-year teachers remain mostly teacher-centred in their beliefs and behaviours. Thus, the researchers remain cautious; this type of course cannot solely bring about change in teachers' attitudes, beliefs, and actions. "In conclusion, we find the inquiry-based science course experience necessary, but not sufficient in bringing about belief and behaviour change with secondary science teachers" (Brown and Meleaur, 2006:960).

6.7 Conclusions

Four main conclusions can be drawn from the five international case studies of IRPs. IRPs may be undertaken either as part of the formal curriculum or as a supplement to it. IRPs can be highly motivating for students and enhance knowledge, understanding and skills in science. IRPs require an organisation (e.g. one responsible for the school curriculum or for out-of-school science clubs / fairs) to drive them forward. It is rare but not impossible for more than a small minority of students in a country to undertake IRPs.

Section 7: Discussion and conclusions

7.1 Introduction

This section of the report draws together the findings from the review of the literature, interviews with key informants and the five international case studies. Some points for consideration are also identified.

The judgements on the quality of the evidence base have been made with reference to criteria applied in systematic reviews of research literature, and take into account factors such as the declared aims, hypotheses and research questions of impact studies, the sampling strategies, the appropriateness of the data-collection, the appropriateness of the analysis methods, the extent to which the conclusions draw on the data gathered, and the relevance of the study to this rapid evidence review.

There is little doubt of the support for IRP work. It is often associated with national policy initiatives, and is seen as important and valuable by a range of people with an interest in, or involved in, science education, including teachers, educational researchers, scientific researchers, employers, government organisations, learned societies and charitable foundations, as well as students themselves.

7.2 Scope and reach

The quality of the evidence base on the scope and reach of IRP work is good. This judgement is based on the evidence that comes from the literature review, the interviews with key informants, the interviews with students, and the international case studies.

IRPs are offered to students in a number of countries, across the secondary/high school age range and in all the major science disciplines. The nature of IRP provision is diverse, though always linked to the belief that it will result in positive outcomes for students in terms of their learning and/or attitudes to science, and to positive outcomes for other groups, including teachers, scientific researchers and employers. Opportunities to participate in IRP work are offered to students within schools/colleges in one or more of lesson time, dedicated blocks of timetabled hours and school science clubs. Outside of school hours, students can participate in IRP work as summer schools and camps. Students may also get the opportunity to present their work at science fairs and competitions. A further dimension of IRPs work is to address the widening participation agenda in science.

Key informants felt that there were equity issues in relation to participation in IRPs as they were relevant to all young people, but not all were able to undertake an IRP. The international case studies confirm that it is rare for more than a small minority of students in a country to participate in an IRP, although there were several examples of IRPs that targeted students from traditionally under-represented backgrounds.

7.3 Impact

7.3.1 Impact: gathering the evidence

The quality of the evidence base on the measures used to judge the impact of IRPs is fair. This judgement is based on the evidence from the literature review.

A wide range of features and attributes of IRPs have been explored, of which the most common are cognitive and affective impacts on students, and teachers' and others' views of the impacts of IRPs. The evidence reveals considerable diversity in the measures used to judge the impact of IRPs, and a pattern of new instruments being developed for each study. Moreover, it is often difficult to identify sufficient evidence in publications to judge the reliability and validity of the instruments used and the approaches to analysis. It would not be possible to conduct a systematic meta-analysis by drawing on the current evidence base.

7.3.2 Impact: the evidence base

The quality of the evidence base on the impact of IRPs is fair to good. This judgement is based on the evidence from the literature review, the interviews with key informants, the interviews with students, and the international case studies.

The evidence on impact is extensive. In considering this evidence, account needs to be taken of issues to do with the nature of the data gathered, the way in which these are gathered, and also the source of the evidence. Typically, reports in the literature of an impact study are undertaken by people who have been involved in some capacity with the design and implementation of the IRP. Equally, it is inevitable that those in favour of IRP work will predominate in any group of key informants, and that the data that emerge from interviews take the form of self-report data.

Individually, most studies have a robust design, even if there are questions about the nature of the impact research as a whole. The frequent involvement of those researching the impact of IRPs in the implementation of the IRP itself does not necessarily adversely affect the impartiality of the design or the reporting of the evidence. The exceptions are reports by enthusiastic advocates of IRP work with little training in research methods in the social sciences.

Studies report positive responses to IRPs from students, gains in students' learning, improvements in students' attitudes to science, suggestions that increased numbers are likely to consider careers in science as a result of their participation in IRPs, and particular benefits for students from traditionally under-represented backgrounds.

The interviews with key informants, teachers and students support these findings, as do the international case studies. A number of benefits to students were perceived by teachers and other key informants. These relate to improved learning of science concepts, to learning of science that extends beyond what would be encountered in the standard curriculum, to improvements in affective factors such as attitudes and motivation, and to improvements in a wide range of practical and research skills. Additional benefits reported include the development of self-esteem, independence and autonomy, self-regulation, tenacity, time management skills, a spirit of co-inquiry with teachers and a sense of scientific identity.

Many of the benefits identified by the key informants were confirmed by students in their interviews, with students reporting that that they had learned a great deal through their participation in an IRP, also identifying learning and skills that fall outside their experiences of the standard science curriculum. The student interviews revealed a high degree of commitment on the part of students to their IRP work, and the feeling of satisfaction students had when they felt they had solved problems and overcome difficulties. Students also spoke very positively of the value of participating in an IRP in relation to applying for a place at university or in the workplace.

Students reported that their IRP work had made them aware of a broader range of careers and specialisms available in STEM subjects and STEM-related areas. They also felt that their IRP work had helped them make decisions about future work and study, and that they had a better idea of what employers are looking for.

The key informants reported that IRPs are challenging for teachers, partners and students, though all groups also felt that the benefits very much outweigh possible drawbacks. The challenges were associated with resource constraints, teacher preparation, teacher confidence in supervising IRPs, identifying potential partners for IRP work, teacher workload and time constraints, and some concern over the potential sacrificing of breadth of knowledge for depth in a particular area if students participated in an IRP.

Students also identified challenges they faced with their IRPs. Typically, these were associated with managing team dynamics and balancing their IRP work with their other studies. Some students saw the workload as excessive, with a disproportionate amount to time being allocated to IRPs.

A feature that was particularly apparent in the international case studies was the need for an IRP programme to have organisational structure and support to drive it forward. This might take the form of a structure within participating schools, such as guaranteed time or a school science club, or an external structure, such as a science competition or fair.

Teachers reported that participation in IRPs provided them with good professional development, personal and professional satisfaction, and improved relationships with their students, and established a network of external partners (universities and employers). The importance of a supportive culture in schools was also cited as crucial to the successful implementation of IRPs. IRP providers noted the opportunities provided by IRPs for enhancing teachers pedagogical skills.

7.4 Assessment and validity of IRPs

The quality of the evidence base on the assessment and validity of IRPs cannot be assessed at this point. Very few details are provided in the literature of assessment criteria for IRPs, and hence measures of validity. It is therefore not possible to compare the impact of IRPs with that of more conventional approaches to practical work. None of the studies in the review reported on this aspect.

7.5 Points for consideration

This review suggests that there is sufficient evidence to support the importance of providing all secondary/high school students with the opportunity to participate in IRP work.

The following points should be considered in taking this agenda forward.

A persuasive case will need to be made to those responsible for the formulation of policy if IRP work is to become more widespread. Key aspects to emphasise in such a case would include the contribution IRPs make to building links between students, teachers, schools and employers, and the emerging evidence of the positive impact IRPs may be having in relation to the widening participation in science agenda. More work in this latter area would be useful.

IRPs place particular demands on students, teachers and universities/employers that are not associated with more conventional school provision. This suggests that some form of training/support should be provided for each of these groups prior to embarking on IRP work. Two emerging networks, the Institute for Research in Schools (IRIS) and the Extended Project Science Investigation Learning and Outreach Network (EPSILON), could have a role to play here.

Teachers will require support in identifying external partners (universities and employers) willing to participate in and support IRPs.

Successful IRP programmes require substantial financial support, unless they form part of a mandatory examination, and this aspect will need to be thought through carefully if schools are to be given more encouragement to offer IRP work. Current funding for IRP activity in the UK comes largely from charitable bodies. It would be worth exploring the possibilities for increased industrial sponsorship for such work.

Consideration should be given to gathering more detailed data concerning the influence of IRP experience on the preparation of students for university study, building upon work commissioned by the Gatsby Charitable Foundation (Grant & Jenkins, 2011).

Strong consideration should be given to bringing together a group of representatives of current funders of IRP work to co-ordinate thinking and take forward the above agenda.

The review also points to a research agenda in substantive areas where more data would be useful, and to a careful consideration of the nature of the data gathered.

For example, given the range of benefits for IRPs identified in the short term, it would seem important to explore the possible longer-term benefits, for instance students who have gone on to take science courses at university or entered employment in science-based industries.

New research into the impact of IRPs would benefit from greater attention being paid to existing work in the area, both in relation to methods used and outcomes. More use could be made of existing instruments; at present many studies appear simply to develop their own instruments. If existing instruments are felt to be limited in their usefulness, a greater degree of consensus over the areas in which to gather information would be helpful. Equally, more robust research designs that do not rely wholly on self-report data should be adopted, and greater use made of control and experimental groups.

Given the above, and the wealth of experience in other countries, consideration should be given to hosting an international symposium on IRP work.

Appendix 1: Search strategy

Focus

Articles, reports and other publications on the use and impact of independent practical research projects

Population

School and college students aged 11-19

Limits

Published in English

2000 to date

Results of searches of ERIC and BEI databases

Search period: 24 July to 3 August 2015

Total records retrieved: 2,324, reduced to 1,403 after duplicated records were removed

Search terms

authentic scien* AND research AND school (158 records)

authentic biolog* AND research AND school (4 records)

authentic chemi* AND research AND school (5 records)

authentic physic* AND research AND school (3 records)

scien* AND practical AND project AND school (384 records)

biolog* AND practical AND project AND school (27 records)

chemi* AND practical AND project AND school (25 records)

physic* AND practical AND project AND school (56 records)

scien* AND investigat* AND project AND school (843 records)

inquiry-based scien* (491 records)

independent research project AND scien* AND school (13 records)

independent research project AND biolog* AND school (3 records)

independent research project AND chemi* AND school (1 records)

independent research project AND physic* AND school (2 records)

problem-based AND project AND scien* AND school (145 records)

practical investigat* AND scie* and school (33 records)

problem-based AND project AND biolog* AND school (18 records)

problem-based AND project AND chemi* AND school (6 records)

problem-based AND project AND physic* AND school (10 records)

extended project AND scienc* AND school (7 records)

scien* competition AND school (49 records)

scien* fair AND school (41 records)

Notes

Use of thesaurus facility in search allowed meant search for ‘school’ included ‘college’.

The Social Science Citation Index and PsychINFO yielded records that duplicated those found in ERIC and BEI.

Additional publications identified though hand-searches and recommendations from key informants were added to those identified through the electronic searches.

All the publications identified through electronic searches were imported into an EndNote database, and from there to a Word document. At that point details of the additional publications were added.

A database was created on Google drive for all the publications included in the review that were available electronically. A small number of publications were obtained in hard copy.

Appendix 2: Inclusion criteria

Studies are included in the review if they address one or more of the review research questions and meet the inclusion criteria.

Review research questions

1. What opportunities are provided for secondary school students to engage in IRPs?
2. What are the chief characteristics of IRPs?
3. How are IRPs organised and assessed?
4. What is the impact of participation in IRPs on secondary school students' responses to science?
5. How does the impact of IRPs compare with that of more conventional approaches to practical work?
6. What opportunities exist internationally for students to engage in IRPs and how do these compare with those available to students studying in the UK?

Inclusion criteria

Studies are included in the review on the basis of meeting the majority of the criteria listed below. All the studies met criteria 1-4, and 7, 9 and 10.

1. They addressed one or more of the review research questions
2. They focused on students aged 11-19
3. They focused on science subjects
4. They were published after 2000
5. Students were involved in having a major input into the question(s) the IRP addressed
6. Students had the main input to the design of the IRP
7. The IRP involved practical work
8. The IRP took place over an extended period of time (> 10 hours)
9. The IRP involved production of a report or similar output
10. The IRP was assessed or accredited in some form

Projects based solely on the manipulation and analysis of previously-obtained data were excluded as they do not include a practical component. Examples of such projects include those based on data downloaded from websites, such as data from satellites.

Appendix 3: Data extraction form

Wellcome Rapid Evidence Review: summary of research report or other document

Author(s)	
Title	
Year	
Source	
Country of study	
Review research questions addressed	
Details of researchers	
Name of IRP programme (if applicable)	
Brief description of IRP (see overleaf for characteristics to note)	
Age of learners	
Aims of study	
Summary of study design, including details of sample	
Summary of data collection methods and instruments*	
Methods used to analyse data*	
Summary of findings and conclusions	
Anything else to note?	

* including details of checks on reliability and validity if details given

Characteristics of IRPs to note

- Name of IRP programme (if it has a name)
- Aims of IRP
- Chief characteristics of IRP programme
    - compulsory or optional?
    - duration (number of hours/days/weeks)
    - how organised? (e.g. organised by school OR organised by an outside body / done in school OR done outside school / done in school time OR done outside school time)
    - how much student choice over questions?
    - undertaken by individuals or teams (and size of team)?
    - how much support/guidance from teacher or other (e.g. university researcher, intern)?
    - how assessed (if assessed), who assesses it, and does it count towards any qualification?
- Any information about impact on students' learning or affective responses (attitudes)?
- Any information about students' subject choices/career intentions?
- Anything else of interest?

Appendix 4: List of key informants

- Booth, K., Senior Manager, Science: Edexcel Qualifications, Pearson
- Buckingham J., Vice-Chancellor and President, Brunel University London
- Canning, P., Head of BTEC Qualifications Product Management, Pearson Education
- Colthurst, D., Science Teacher, Simon Langton Grammar School, Kent
- Denby, D., Science Education Consultant
- Easterfield, A., Director of Science, University Technical College, Cambridge
- Evans, S., Head of General Qualifications Reform, Oxford Cambridge and RSA Examinations
- Flowerdew, B., Science Teacher, York College
- Hall, A., STEM Education Consultant, Design4Ed
- Halton, J., EngineeringUK
- Holman, J., Emeritus Professor of Chemistry, University of York
- Hunt, A., Science curriculum and assessment: author, editor and consultant
- Mathieson, K., British Science Association
- Metcalf S., Programme Head, Nuffield Research Placements
- Mist, R., The Royal Society
- Moote, J., Research Associate, Aspires2 Project, Kings College, London
- Newall, E., Science Communication and Education Consultant, Nuffield Research Placement Coordinator, Greater London and Surrey
- Nurse, P., President, Royal Society
- Oates, T., Group Director ARD, Cambridge Assessment
- Otter, C., Director, Salters Advanced Chemistry, University of York
- Paes, S., AQA Education, Head of Science Qualifications
- Parker B., Director, Institute for Research in Schools, Visiting Professor School of Physics and Astronomy Queen Mary, University of London.
- Raine, D. J., Associate Director, Centre for Interdisciplinary Science, University of Leicester
- Riviere, A. Curriculum Manager, Diploma Programme Development, International Baccalaureate.
- Scott, A., Honorary Visiting Fellow, University of York
- Swinbank, E., Honorary Visiting Fellow, University of York
- Taylor, J., Head of Philosophy and Director of Critical Skills, Rugby School

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- Professor Harrie Eijkelhof
- Professor Mark Hackling
- You Yun
- Dr Michel Zion

Appendix 5: Key informant interview schedule

Preamble

The Wellcome Trust is particularly interested in the impact of independent research projects, i.e. projects that are student-led and involve the undertaking of an extended piece of open-ended practical work.

- Please would you tell us briefly about [name of independent research project] and how you became involved in it / what is your experience in connection with independent research projects?
- How is this/your project organized? Which groups of students have access to the project?
- Could you comment on / have you explored ways to expand access to the project / this type of project?
- How is the project assessed?

We are interested in the impact of the projects on both students and teachers (and any other people supporting the project, such as researchers)

- What would you see as the benefits for students, and what makes you say this?
  Prompt for skills developed compared with those developed through regular classroom activities
  Prompt for learning of science ideas/concepts compared with those developed through regular classroom activities
  Prompt for any influence of project on student choices with respect to employment/further study
  Prompt for emotional and attitudinal responses of students (for example motivation)
- What would you see as the benefits for teachers, and what makes you say this?
- What would you see as the drawbacks for students, and what makes you say this?
  Prompt for skills developed compared with those developed through regular classroom activities
  Prompt for learning of science ideas/concepts compared with those developed through regular classroom activities
  Prompt for any influence of project on student choices with respect to employment/further study
  Prompt for emotional and attitudinal responses of students (for example motivation)
- What would you see as the drawbacks for teachers, and what makes you say this?

Part of our study involves looking at what has been written or presented about the effects of independent research projects.

- Is there anything you would particularly recommend we should look at?

We also want to make sure we talk to key people such as you about independent research projects.

- Who do you think it is essential we consult?

Appendix 6: Student interview schedule

Preamble

The Wellcome Trust is interested in the impact of independent research projects, i.e. projects that are student-led and involve the undertaking of an extended piece of open-ended practical work.

Introduction

- Please would you tell us about the project and how you became involved in it?
- How is your project work organised?
- How/will your project be assessed?

Perceptions of IRPs

- What do you see as the benefits for you of doing the project, and what makes you say this?
- What would you see as the drawbacks for you, and what makes you say this?
- How do you perceive the impact of your independent research project on:
  - skills you have developed compared with those developed through regular classroom activities?
  - learning of science ideas/concepts compared with those developed through regular classroom activities?
  - your choices with respect to employment/further study?
  - how you feel about science?

Concluding questions

- What sort of support did you get from other people (teachers, technicians, university students/staff, parents, anyone else)?
- What advice would you give someone just about to start on an independent research project?

Appendix 7: Summary of Independent research projects (IRPs) offered in the UK

Scheme	Participants	Overview	Reach	Assessment	Student work requirements	Notes
IRPs LEADING TO NATIONAL QUALIFICATIONS						
Extended Project Qualification (EPQs)	Usually taken alongside Advanced levels by students aged 17-19 (sixth form/college students).	To provide students with an opportunity to design and complete an individual project; can be in any subject.	Over 30,000 students take EPQs across all subjects.	Teacher assessment with external moderation.	120 guided hours of work including independent student work, normally over a year.	
International Baccalaureate (IB) Extended Essay	Students aged 16-19 as compulsory component of the IB Diploma. Also offered as a standalone qualification.	To provide an opportunity for students to investigate a topic of special interest to them.	All IB diploma programme students (2795 schools globally; 222 schools in the UK).	4000-word report externally assessed by IB examiner. Awarded a grade from A – E.	40 hours independent study.	Students can complete an Extended Essay on any subject. Approximately 16% of essays are carried out in sciences of which some include an IRP. IB Personal Project for ages 11-16 also offered.
Salters' Chemistry/Physics investigations	Students aged 17-19 as part of the Advanced level chemistry or physics course.	To provide students with a practical experience similar to how 'real research' is carried out.	Over 20,000 students study Salters' Chemistry and Physics at Advanced level.	Teacher assessment with external moderation.	Carried out during second year of Advanced level ('A2').	A-level practical requirements changed in 2015, resulting in changes to the Salters' investigations; last examination in 2015/16.
NATIONAL SCHEME IRPs						

CREST award	Students aged 11-19 with different levels of award (bronze, silver and gold) aimed at certain age groups.	To develop practical and problem-solving skills through engagement with project.	Over 30,000 CREST awards undertaken annually.	Teacher assessment in the first instance, then assessment by the CREST Local Coordinator.	Bronze (age 11-14) 10 hours. Silver (age 14-16) 20 hours. Gold (age16 – 19) 70 hours.	Suitable EPQ work can be put forward for a CREST gold award.
Nuffield Research Placement	Students aged 16-17 in the first year of a post-16 STEM course.	To provide an opportunity to work alongside professional STEM employers.	Over 1,000 students each year.	Some students may exhibit a poster at a Celebration Event.	4-6 weeks during summer vacation.	The selection process considers a widening-participation agenda and features quotas for certain groups. Projects may be put forward for a CREST gold award.
Royal Society Partnership Grants	Students aged 5-18.	To enable students to carry out investigative projects in science, engineering, maths or computing in partnership with a practicing STEM professional.	227 grants awarded since 2010.	No formal assessment.	Not specified.	
OTHER IRP ACTIVITY						
Authentic Biology	Students aged 16-17 in the first year of an Advanced level Biology course.	Students undertake a research project and collaborate with a partner university.	7 schools.	No formal assessment.	Part of Advanced level Biology course.	

CERN@School (a programme of the Institute for Research in Schools)	Typically students aged 16-19, although some schools involve students aged 14-19.	To enable school students to carry out their own particle physics research.	Approximately 50 schools in the UK are involved (with total number of students estimated to be around 700).	No formal assessment, but projects can contribute to the EPQ, CREST award or National Science & Engineering Competition.	Not specified.	
UTC Cambridge Challenge Projects	Students aged 14-19 at Cambridge UTC, alongside their academic studies.	To provide students with an authentic experience of scientific research particularly in biomedicine and environmental science and technology.	At present, approximately 300 students (140 in years 10 and 11, 160 in years 12 and 13).	Variety of assessments including presentations, products, posters and reports, plus feedback from external partners.	7 – 10 hours/week over 8 – 9 weeks. Students participate in 3 – 4 projects/year.	Challenge projects contribute to the assessment for the Duke of York Award.
National Science and Engineering Competitions	Young people aged 11-18 in full-time education in the UK.	To recognise and reward young people's achievements in all areas of Science, Technology, Engineering and Mathematics (STEM).	Thousands involved in heats; 200 projects at the final.	Projects judged at local heats or online and (where successful) at the national final and at international competitions.	Not specified.	Can be carried out individually or as part of a group.

Appendix 8: Publications included in the review of the literature

Adams, E., Ward, T. J., Vanek, D., Marra, N., Hester, C., Knuth, R., Spangler, T., Jones, D., Henthorn, M., Hammill, B., Smith, P., Salisbury, R., Reckin, G., & Boulafentis, J. (2009). The Big Sky inside. *Science Teacher, 76*(4), 40-45.

Akinoglu, O. (2008). Assessment of the Inquiry-Based Project Application in Science Education upon Turkish Science Teachers' Perspectives. *Education, 129*(2), 202-215.

Balmer, D. (2014). An Alternative Energy Career Project at the Warwick School, Redhill, Surrey. *School Science Review, 96*(354), 118-122.

Brand, B., Collver, M., & Kasarda, M. (2008). Motivating Students with Robotics. *Science Teacher, 75*(4), 44-49.

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