Article:

Dunlop, Lynda orcid.org/0000-0002-0936-8149, Knox, Kerry Jane orcid.org/0000-0003-3530-6117, Bennett, Judith Merryn orcid.org/0000-0002-5033-0804 et al. (2 more authors) (2019) Students becoming researchers. School Science review. pp. 85-91. ISSN 0036-6811

Students becoming researchers

Keywords
Independent research project, practical work

Brief description
How practical independent research projects can support young people to become scientific researchers.

Abstract
This article describes the results of a study into students' experiences of independent research project work in science. Independent research projects (IRPs) are projects in which students are supervised (usually by a teacher, scientist or both) to work independently on a scientific problem or question over an extended period. We collected data from 39 young people aged 16-19 engaged in independent research project work using group interviews and found that the projects gave them experience of thinking and acting like a researcher, and had an impact on their aspirations for future study or employment science.

Practical independent research projects
Research into the nature, purpose and effectiveness of practical work in science highlighted the importance of a "minds-on" as well as "hands-on" approach (Abrahams & Millar, 2008). The way in which practical work is used can take a range of forms, from 'recipe' type practicals, where students follow a set of instructions with the aim and procedure determined in advance, to, at the other end of the spectrum, extended projects in which students have greater control over the aims and methods.

Independent research projects (IRPs) are of the latter type. These are understood to be "projects, usually involving hands-on investigations, in which students or groups of students work independently, supervised by a teacher and/or other adults, on a scientific problem over an extended period" (Holman, Hickman & Leevers, 2016, p.3). Students in many countries have the opportunity to become involved in IRP work, for example through science fairs and national schemes such as CREST Awards and the Institute for Research in Schools (IRIS) in the UK and BHP Billiton Science and Engineering Awards in Australia (see box 1 for examples of independent research projects carried out by students in the UK). Recent changes to science specifications at A level in England have resulted in a move away from IRPs, although there exists space for valuing such work through the Extended Project Qualification (EPQ) or Extended Essay for the International Baccalaureate Diploma Programme, as well as outside the formal curriculum.

Box 1: Independent research projects in science in the UK

Authentic Biology (http://www.mbp-squared.org/) features seven schools working on understanding multiple sclerosis, and in particular the role of myelin basic protein in maintaining the myelin sheath around nerve fibres in the central nervous system of mammals. This project engages school students in authentic research in biology using collapsed curriculum days and research afternoons throughout the year. In each school, research teams take responsibility for different strands of the project, and are supported by university staff and students as well as more experienced students from the school.

CREST Awards (http://www.crestawards.org/), administered by the British Science Association, allow students to gain a gold award following 70 hours of work on a research project. This can contribute to an existing research project or can be based on a student's own interests and ideas. CREST Awards are offered by schools, with mentoring (e.g. from a STEM Ambassador) strongly recommended.

Challenge projects offered by University Technical Colleges (UTCs) (http://utc.jtresponse.co.uk/challenge-projects) bring students together with scientists and engineers from industry, universities and non-governmental organisations (NGOs) to work on real-world practical challenges. Examples of projects include surveying rivers to prepare management plans and investigating the optimal shape and size of a hole used to relieve pressure on the brain following a head injury.

In a recent review of research literature since 2010 on practical independent research projects (Bennett et al., 2015) we found that IRPs are carried out for different reasons and that their effectiveness is assessed in a range of ways. These include the impact on students' conceptual understanding of subject content, practical skills, understanding of the nature of science, attitudes to science, and motivation to study. One aim of IRPs is to provide students with an authentic experience of scientific research. In doing research, students have to develop new ways of doing science and being a scientist that are critical for understanding their discipline and becoming a researcher.

Becoming a researcher

IRPs place significant demands on young people, and embody a way of working that is quite different to more typical practical work. In an attempt to find the key concepts that novice researchers must grasp in learning to be a researcher, Kiley and Wisker (2010) carried out interviews with supervisors of doctoral students across a range of disciplines, including the sciences, to find out what distinguished students who were thinking like a researcher from those who were not. They identified number of 'threshold concepts' (Meyer and Land, 2003). These are concepts that result in a shift in thinking about a subject. They are often difficult for students to grasp – but when they do, students can make connections they could not previously make, they have access to new ways of thinking about a subject and are better able to think and act as a researcher. In this sense, they are described as transformative. Grasping threshold concepts can result in students seeing their subject in a new light, and lead to changes in attitudes, feelings or values towards it. There is usually no going back once a student has crossed a threshold – they are usually irreversible. Kiley and Wisker identified examples of threshold concepts associated with doing research to include identifying or shaping *theory* through their research, working within a *framework*, carrying out disciplined, or systematic *analysis* of data, and making an *argument*. Box 2 indicates some of activities that Kiley and Wisker found evident in novice researchers when they have crossed these thresholds to think and act like a researcher.

Box 2: What can students do when they are thinking like a researcher?

- Develop a research question and research design from a broad topic.
- Focus on a conceptual framework, methodology and methods.
- Produce conclusions that deal with concepts, not merely facts.
- Enter into dialogue with experts, including through a literature review.
- Make an argument, supported by evidence.

Although Kiley and Wisker's (2010) research focused on doctoral level research across a range of disciplines (not exclusively the sciences), these concepts are a useful starting point for understanding what young people engaged in IRPs in science need to learn to become a researcher. This marks a different way of understanding learning from IRPs, which has often focused on conceptual understanding, for example about molecular genetics or the nature of science (e.g. Charney et al., 2007). In this study, we were interested in sixth form students' (i.e. young people aged 16-19) experiences of undertaking independent practical research projects and, in particular, finding out whether there was evidence that they were taking part in the type of thinking that is needed to cross conceptual thresholds associated with becoming a researcher.

In addition to learning how to become a researcher, IRP work has the potential to influence young people's aspirations to study science further, or to enter science-related employment. A review of the research literature found some evidence that IRP work can improve attitudes to STEM education and increase interest in becoming a scientist (Bennett et al., 2015). We were therefore interested in how IRP work had shaped the aspirations of the students involved.

Study aim

The aim of this study was to investigate students' experiences of independent research project work in order to inform the work of teachers who are involved, or are considering being involved, in supervising such projects, and to answer the following questions:

- What is the impact of IRPs on students' learning to become a researcher?
- What is the impact of IRPs on students' aspirations in relation to science?

Methods

The study was carried out with 39 young people in years 12 and 13 (age 16-19) in two non-fee-paying institutions: one mixed 14-19 college (C) and one 11-19 selective school (S); these institutions were purposively sampled as both had a strong culture of independent research project work. Teachers in both institutions had established research projects in collaboration with scientists in universities, industry and NGOs. Eight semi-structured group interviews were conducted with a total of 21 students in the school and 18 young people in their college, and from these we extracted the activities that students were engaged in that were associated with becoming a researcher. All students reported an interest in science prior to their participation in IRPs, and for some this was a driver for selecting their school or college. Our findings cannot therefore explore the impact of IRPs on students with no prior interest in science.

The interviews focused on the students' experiences of IRPs, their perceived benefits and drawbacks and the research environment. Each interview lasted between 30 and 60 minutes and was audio-recorded and transcribed. Students had participated in a range of project types across physics, chemistry and biology. All students were involved in IRPs at the time of interview. Group interviews were used to bring together participants with different experiences of IRPs and to allow participants to build on the responses of others (either in agreement or disagreement, and to expand on reasons). Care was taken in the interviews to ensure all students had the opportunity to respond to each question.

Interviews were then analysed using a thematic approach, drawing on Kiley and Wisker's (2010) work on the evidence of conceptual threshold crossing in learning to be a researcher. Data were analysed according to (1) students' experiences of research work and their learning to become a researcher (in particular, in relation to developing research questions, conceptual framework, methodology and methods, and dialogue with experts), and (2) the impact of their IRPs on their aspirations. The following section uses quotations from students to illustrate examples of how students talk about learning to become a researcher. All names are pseudonyms; (S) indicates that the interviewee is in a school and (C) that they are in a college.

Findings: students' experiences of independent research projects

Learning to become a researcher

Students identified features of working on IRPs that they found exciting. These included working on live and topical problems with experts in the field, manipulating specialist equipment and interpreting raw data. However, they also discussed challenges that they had experienced, some of these relating to the routine elements of lab work, but others relating to problems that they had to solve in relation to the intellectual challenge of doing research. In this section, we report on the evidence that students are engaging with the sorts of activities they need in order to cross conceptual thresholds in becoming a researcher. Reports of their experiences are linked to three of the categories of evidence identified by Kiley and Wisker (2010): developing a research question; focusing on a conceptual framework, methodology and methods; and entering into dialogue with experts.

1. Developing research questions

Kiley and Wisker (2010) argue that students are beginning to think and act like a researcher when they are able to "define a research question from a broad topic and then ask questions of the field, their data and themselves" (p.205). This is characterised by students moving from reading that has been directed by others to self-directed and 'owned' reading, and being able to identify a relationship between existing research literature and their own research. In the interviews, we found evidence of students taking ownership of developing research questions. For example, Connor discussed the importance of asking his own question within a larger project:

> *A lot of projects may seem big but there's not a project that does exactly what you want it to do. Change it so it does.* Connor (C)

As well as having the ownership of the question (and knowledge of the area of study in order to be able to ask meaningful questions), Andrew identified the type of questions that he considered important in IRP work:

> *Sometimes when you ask questions and not even the teacher knows the answer. That's what we're trying to tackle. We're finding out for everybody.* Andrew (S)

Contrasting IRPs with the type of practical work that was more common as part of their A level or BTEC studies, several students highlighted that they were looking to create new knowledge, where the answers were 'not found at the back of the book' and to contribute to the field, for example:

> *There isn't necessarily an outcome that you're looking for, you're not told what to get like results that are consistent with something that's been done hundreds and hundreds of times. This is new, exciting stuff and you don't know what you're going to find.* Julia (S)

> *The project makes you go away from the sort of controlled sort of individual nature of that lesson set-up, it is sort of more the university or real world lab sort of set up where you all work as a team and all try and get different parts of research*. Felix (C)

Some discussed seeing themselves differently in relation to science. This included feeling a part of the research environment, and being able to make links between their own work and the ideas of others. For example, Alex had been able identify his position in his field:

> *I did quite a bit of research about other research in that field and it's really quite a small area because this is the first eclipse where there's been new modern equipment so it's been really good to be on the forefront of that and answer a question which most people honestly have no idea about what to expect from it. So it's really good to be at that same level as professors who might have been in the field for half a century.* Alex (S)

This suggests that IRP may enable students to ask a different type of question to those that they pursue in more conventional forms of practical work. In pursuing IRPs, students ask questions that they 'own', and which may not have been asked before. Closely linked to this is the use of reading, which helps students to understand the field in which they are working.

Several students spoke of the importance of wider, self-directed reading to inform their research, for example:

> *We had to like read quite a lot of stuff on it because it goes beyond our syllabus, I'd say it helps our detail, like extract the more important knowledge … like because we've already [read] scientific papers from people like professors or biologists and that so … it helps understanding more advanced stuff.* Connor (S)

> *It does teach you how to research like a scientist. I know where to go if I want to find something.* William (S)

Lachlan outlined the role that doing his own research writing played in making sense of the research literature:

> *Over last year I had to write two, maybe three research papers on our projects that we did … it just helps get the right sense of what you are doing.* Lachlan (C)

The wider work was not limited to reading. Students also talked about the importance of working with and asking questions of scientists in industry, government and academia, as well as more experienced and knowledgeable peers.

2. *Focus on conceptual framework, methodology and methods*

One of the threshold concepts that students grappled with was that of analysis. Kiley and Wisker (2010)found evidence of threshold crossing when students had learnt to work with data at different conceptual levels, i.e. analysing, interpreting and defining findings.

One of the groups discussed the need to be open-minded in the analysis of results, in this case in the discussion of a project on polymers where students discuss interpreting results, thinking about what the data means, and making decisions on the basis of this:

> *You don't know until you've got all the data or seen any trends, or if there are any. You're not going to know if it works or not … you need to think about it.* Ameera (S)

> *And reacting to results. If you get something that stands out you think right, okay, so we would email the university ahead and say 'you need to make things like this, use this as the derivative instead'.* Jon (S)

Several students involved in physics projects found it necessary to learn to code in order to carry out their analysis:

> *A lot of it is computational so there was a point where you just had this massive set of data when we were just starting out on the project and we were, 'Right we need to learn Python pretty quickly!' so we can actually get it out of the file and start manipulating it to get some experimental results.* Poppy (S)

This was often not a feature of their research that students enjoyed: they reported having to learn complex ideas beyond the scope of the physics and computer science specifications at speed. However, all students recognised this learning as essential for analysing and asking questions of their dataset, and being able to describe their findings qualitatively such that they made sense to collaborators and other researchers in their field, all of which presents evidence that these students have crossed a threshold in terms of analysis.

Another way in which students demonstrated that they were made to work with data at different conceptual levels was in relation to methods and methodology:

> *All you have to do [for the A level] is know that you can purify protein from living organisms, but you've got no clue of how until you do the project. You find out there's loads of different ways you can do it, most of them have got different effects on the protein … so, you've got to find the optimal way of doing it.* Darren (S)

This suggests that IRPs allow students to gain not just knowledge as required by exam specifications, but also that relating to procedures and context, such that they can make informed decisions about the materials and conditions they need to conduct their own research.

A further threshold concept important in becoming a researcher relates to theory underpinning or resulting from research. Students contrasted their experience of conventional practical work with IRPs, describing practical work as decontextualised and possible to perform correctly with little theoretical understanding. Discussing a chemistry project on polymer properties, Adam relates the need to understand and interpret theory and apply this to the data:

> *You have to think about it, you have to think logically behind every step. Not many people have done it before and there are not many papers on this specific technique, so every time you move something, tweak something you've got to think how is this going to effect it, and you've got to go through every bit of theory you can in your head and you've got to discuss it properly.* Adam (S)

Many of the students interviewed reported being able to explain how their work fitted into the context of the entire field, and to link their findings to theoretical knowledge in their discipline. For example, Ifor discusses learning about theory through IRP work:

> *It's just given me a heck of a lot more information just on general physics really. Because I know how the chips work, I've learnt a lot more about the nature of radiation and a lot more about the nature of radiation above our Earth, and I think that's quite fundamental really*. Ifor (S)

In common with research that has found that IRPs can help students to develop more sophisticated ways of thinking about science (e.g. Charney et al., 2002), these students were able to link theory with experimental results, and use their knowledge to make meaningful decisions about their research. The next section outlines the role that communicating with experts within and beyond the school environment plays in this.

3. Dialogue with experts

Kiley and Wisker (2010) argue that novice researchers are likely to engage in learning and transformation if they are in research environments where they can access support from peers and those further along the journey towards being a researcher and 'learn the rules' of the research culture. Indeed, in both institutions, IRPs featured as part of the culture in science departments, and peer and professional networks were established from the outset. Students discussed how they had engaged in dialogue with experts in different ways.

In the college, students had to present their findings to experts from industry, academia and NGOs in a variety of ways. Joy describes some steps in her learning:

> *No matter what you are doing, you have to either write a report or present it and I have got a lot better at kind of actually knowing what needs to go on a slide ... and what is going to make people listen to you … and that gives you confidence in your presentation skills as well.* Joy (C)

In their IRPs, communication with experts was seen as an ongoing process. These students were not only communicating their findings to a lay audience, but also to experts, whether peers in their own institution, teachers, or scientists from academia and industry, policymakers and funders, and some were writing a journal article on their findings. Students discussed reaching a point at which they could successfully engage in such dialogue:

> *We were working with experts in the field so there is an element of trying to learn a lot of stuff to get to the level where you can converse about the things you need to converse about with these people. But even that is quite rewarding in itself because you get to a point where you can just talk about it to anyone that.* Anna (S)

This was not always straightforward as they felt that had to work hard to be taken seriously and for their work to be recognised by experts:

> *People definitely do underestimate you in a way, which is – yes which is good and bad because it's nice that they're impressed but then they're not necessarily always going to want to hear what you have to say.* Lizzy (S)

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.

These findings suggest that IRPs can create the conditions for students to work at the conceptual thresholds associated with learning to become a researcher, and that IRPs give students the opportunities to do and think in ways associated with research in science. These include formulating a research question, working with data at different conceptual levels, focusing on a conceptual framework and entering into dialogue with experts. Although students found this troublesome at times, there is evidence in the data that students shifted their perceptions of their subjects, and made connections that they would otherwise not have made as part of their sixth form studies. Table 1 summarises these findings, and identifies some implications for teachers who are interested in providing IRP opportunities for their students. The following section describes different types of impact that IRPs can have on students' aspirations to pursue science further.

Key activities associated with becoming a researcher (Kiley & Wisker, 2010)	**Implications for teachers: what students need to do or access to become a researcher**
Developing research questions	• Freedom for students to follow their own interests within a subject/project area • Opportunities for students to participate in projects where the answers are unknown • Group or team project • Access to research literature • Opportunities for students to write about their research
Focusing on conceptual framework, methodology and methods	• Responsibility for the analysis of results • Ownership of decision making • Responsibility for communicating with related groups and resourcing their research project • Signposting to specialist expertise (e.g. coding, synthesis) • Support, or access to support with experimental design and control • Extended (beyond A level) theoretical knowledge • Knowledge of how analytical methods / detection systems work

Dialogue with experts	• Research group(s) in school/college • Reporting requirements, e.g. provide opportunity to present findings to lay and expert audiences in written and/or oral form • Contacts in academia, industry and NGOs

Table 1: What are the implications for teachers who supervise research projects?

The impact of IRP work on students' aspirations

All of the participants in this study were interested in science before beginning their IRPs. Indeed, for some this had been a driver for selecting the school or college in which they were completing their IRP work. Through their research project work, students reported learning about everyday life in industry, different gateways into scientific careers, a range of careers and specialisms in STEM subjects (specifically in relation to those relevant to their IRPs), non-science careers in scientific industries (e.g. management and sales) and about the contribution that scientists can make to fields such as international development.

Students also discussed the influence of participation in IRPs on their own career choices. For some, it confirmed their choices:

> *I knew I wanted to do a biochemistry degree but I didn't really know the scale of the job opportunities that were available from it so by picking biochemistry- or biology-based projects I have been able to work out that actually I would enjoy doing some of these things because it is an insight into some of the industries that I could potentially be working in … it has just confirmed my choice of degree course.* Jenna (C)

For others, it helped them to narrow down their choices to a specific field:

> *I always wanted to do some area of biology but I didn't really know what until joining the project and getting a good overview of the different kinds. So, I plan to study genetics at university level because of what we've been learning*. Tom (S)

Although most students participating in IRPs intended to undertake further work or study in science, there were some who had made a positive (and informed) decision to change the direction of study, whether to other STEM disciplines such as mathematics (Esme), or in an as-yet-undecided direction (Ellie).

> *When I came I thought I wanted to do physics but through the project found that actually it's the maths I really want to get in to. If you were just doing your A Levels you wouldn't have that opportunity to really find out what it is you actually have most interest in.* Esme (S)

> *That has definitely helped me see what I would be doing if I did go into that career and actually thinking, 'No I don't want to do that'. So yeah, I love science, don't get me wrong but I don't think it will be what my career is based on. It might be part of my career, like I might need science somewhere but I won't be going off to be a researcher.* Ellie (C)

Most students reported that IRPs had helped them make decisions about future work and study, but there were some who found that participating in them had made it more difficult to make decisions about their future:

> *It's made it harder. I've wanted to do medicine for quite a while and now I've been looking into the research and I'm quite interested now in the research side of it as well. So actually it's drawn me apart a bit more.* Mark (S)

Students also reported that they felt they had a better idea of what employers and universities are looking for, and that they were better able to communicate professionally as a result of their research work. Several students reported that they had arranged further work experience and study placements as a direct result of their IRPs.

These findings suggest that although IRPs give students insights into what scientists do, this does not always lead to every student deciding to take science further. However, students are able, as a result of their IRPs, to make more informed decisions about what they choose. For those who decide to study science further, they believe that they have a realistic idea about what future work will involve, they often want to specialise within a discipline, and feel that they are well placed to apply for competitive university places or positions in industry.

Discussion and conclusions

Students from each institution displayed commitment to their research and reported that they had learned a great deal through participating in IRPs. Most students reported their experience as positive, and shared examples of activities that aligned with those associated with crossing conceptual thresholds in becoming a researcher: devising a research question, making sense of data at different conceptual levels, engaging with conceptual frameworks and methodologies, and entering into dialogue with experts. Students also described ways that IRPs had influenced their future career decisions. They felt well informed about the career decisions they were making, whether or not these involved science.

Although limited in scale, and involving only self-report data from students already interested in science, this study suggests that there is value for students in participating in IRPs. The findings might be useful to teachers interested in supervising young people to carry out independent research projects as they suggest opportunities that students need to be given in order to become researchers. These include freedom to devise a research question, ownership over data analysis and decision making, and access to experts, whether in a specific technique (coding or preparation of reagents in these cases) or in the field more broadly.

Future work might focus on the identification of science-specific threshold concepts related to becoming a researcher and the application of these to the construction of marking criteria for formally assessed research project work. Further work on how learning experiences can be designed to 'nudge' students across conceptual thresholds through IRPs has the potential to be useful to supervisors of such projects. Although this study has focused on learning to become a researcher, this is just one perspective on what independent research project can offer.

> *I'd say the entire process of doing research in the project is completely different to a lesson because in lesson we do, we just carry out a practical and then you might write up about it whereas, and that is just with the intent of teaching you what is on a course, whereas in a project we learn skills like the division of labour, we learn who has got to do what roles and we learn how to actually get from hearing a task all the way to having a report that can be written up and doing that as a team.* James (C)

Acknowledgements

This work was supported by the Wellcome Trust and conducted during a rapid evidence review of independent research projects.

References

Abrahams, I. & Millar, R. (2008) Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education*, *30*(14), 1945-1969.

Bennett, J., Dunlop, L., Knox, K.J., Reiss, M.J. & Torrance Jenkins, R. (2015) A Rapid Evidence Review of Practical Independent Research Projects in Science: Final Report to the Wellcome Trust, October 2015. York: University of York. Avilable at https://wellcome.ac.uk/sites/default/files/review-of-practical-independent-research-projects-in-science-wellcome-apr16.pdf.

Charney, J., Hmelo-Silver, C. E., Sofer, W., Neigeborn, L., Coletta, S., & Nemeroff, M. (2007) Cognitive apprenticeship in science through immersion in laboratory practices. *International Journal of Science Education, 29*(2), 195-213.

Holman, J., Hickman, M. & Leevers, H. (2016) *Young Researchers. Reflections from Wellcome on the impact of doing research projects.* London: Wellcome Trust.

Kiley, M., & Wisker, G. (2010) Learning to be a researcher: The concepts and crossings. In Meyer, J.H.F., Land, R. & Baillie, C. (Eds.) *Threshold concepts and transformational learning* (pp. 399-414). Rotterdam: Sense.

Land, R., Meyer, J. & Smith, J. (Eds) (2008) *Threshold Concepts within the Disciplines*, Rotterdam: Sense.

Meyer, J. & Land, R. (2003) Threshold concepts and troublesome knowledge: linkages to ways of thinking and practising within the disciplines. In Rust, C. (Ed.) *Improving Student Learning – Ten Years On* (pp. 412-424). Oxford: Oxford Centre for Staff and Learning Development (OCSLD).