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Teaching Research - Evaluation and Assessment Strategies for Undergraduate Research Experiences (TREASURE)

Resources Handbook: Nuggets from the TREASURE Trove, 2014

Lead Institution: **Australian National University**

Partner Institutions: **University of Western Sydney**

University of Canberra

Project leaders: **Susan Howitt**

Anna Wilson

Team members: **Denise Higgins (Project Manager)**

Pam Roberts

Betty Gill

Pauline Ross

Gerlese Åkerlind

Report authors: Susan Howitt, Anna Wilson and Denise Higgins

Website: <treasure.edu.au/project/>

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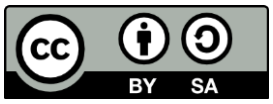

Requests and inquiries concerning these rights should be addressed to:
Office for Learning and Teaching
Department of Education

GPO Box 9880,
Location code N255EL10
Sydney NSW 2001

<learningandteaching@education.gov.au>

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List of acronyms used

ALTC	Australian Teaching and Learning Council
ANU	Australian National University
AQF	Australian Qualifications Framework
ASC	Advanced Studies Course (ANU)
ASP	Advanced Science Project (UWS)
ATAR	Australian Tertiary Admissions Rank
GSM	Global Social Movements (UC course)
HEI	Higher Education Institution
ILO	Intended Learning Outcome
LMS	Learning Management System
MOI	Methods of Inquiry (UC course)
OLT	Office for Learning and Teaching
PQF	Prompt Question Framework
TEQSA	Tertiary Education Quality Standards Agency
UC	University of Canberra
URE	Undergraduate Research Experience
URSSA	Undergraduate Research Student Self-Assessment
UWS	University of Western Sydney

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Introduction

This resources handbook has been produced to accompany the final report for the OLT project, Teaching Research - Evaluation and Assessment Strategies for Undergraduate Research Experiences (TREASURE). This project aimed to improve both:

- the learning experiences and outcomes for undergraduate students engaging in research activities, and
- the visibility of this learning to both academics and students.

To achieve this, we developed and implemented structured reflective journals for students to reflect on their experiences of research as described in the final project report. These journals were designated Learning Logbooks, with structure being provided by the Prompt Question Framework, a set of reflective prompts for students on aspects of doing research and learning about research. An important component of the TREASURE project was to develop an evidence base that would be useful to others wanting to include undergraduate research in the curriculum. This handbook contains a set of resources that form the evidence we have assembled so far. In keeping with the name of the project and the theme of the final report, each resource is designated a nugget from the TREASURE trove.

Nuggets 1-6 are products of a phenomenographic approach to investigating the range of student understandings, expectations and learning about research or our reflections on issues that became important during the project. We have used the Learning Logbooks from subsets of participants to generate these analyses. They do not represent an exhaustive analysis of all data collected but focus on issues that were of particular interest to us or that emerged as important during the project. Because the project was initially implemented in science, the analysis is inevitably focussed more on science than other disciplines. Analysis is continuing and we aim to add to these resources through further publications and our website.

Nuggets 7-14 have been developed to assist others interested in implementing Learning Logbooks and the Prompt Question Framework. They include the Prompt Question Framework, different ways in which to consider intended learning outcomes for research experiences and whether they have been met, a sample guide for students using Learning Logbooks and a collection of practical guides for staff on different aspects of implementation.

Nugget 1: Students' Expectations of a URE

One key factor that may constrain the learning that occurs or is recognised as occurring in UREs is the expectations that students themselves have of what the URE will provide. The Project Leaders' prior research on the experiences of students undertaking apprentice-style research projects suggested that if students expectations are limited to the acquisition of content knowledge and technical skills, they are less likely to recognise and possibly develop more sophisticated understandings of research as a process, for example (Wilson et al, 2013). The First Post questions included in the PQF were intended to both reveal the range of student expectations and to prompt students to consider what they might learn from their UREs and how this might differ from learning in conventional coursework, and hence also to encourage them to view their UREs as experiences in which they might expect to learn something different.

Analysis of the First Post responses in Phase 3 of TREASURE is still underway. However, an analysis of the First post responses for students undertaking apprentice-style projects in Phase 2 has been carried out. The initial results are shown in the table below. The questions students responded to were:

- Why have you chosen to do a research project and what are you expecting to get out of it?
- Have you undertaken a research project previously? Describe it.
- What are you expecting to be different in this research project experience from your normal coursework?

As can be seen, the students' expectations as revealed in the Learning Logbooks varied over a number of different dimensions, reflecting the prompt questions and what they drew students' attention to. In addition, they exhibited a range in terms of sophistication, with some students aware of richer opportunities than others.

A better understanding of what students are expecting as they embark on a research project might also be useful for supervisors, who can use their student's responses to address any early misconceptions and to highlight factors that students may be unaware of. This could also contribute to better scaffolding of learning during a URE or other research experience.

Table 1: Students expectations for their URE

	Not related to disciplinary content or research	Related to discipline-knowledge rather than research skills/experience	Related to research but not anticipating different/ new of thinking/learning	Related to research and anticipating different/new way of thinking/ learning
Reason for taking unit	• Requirement • Count towards major/sub-major/minor • Final semester • Timetable	• Broaden knowledge • Increase knowledge	• Interest in field (want more depth to prepare for future research)	• Chance to actually answer a research question • Possibility of contributing to new knowledge • To experience research as a taster for Honours*

Anticipated learning gains		• Content-knowledge/technical skills (more of the same as in previous coursework but more focussed/personalised) • Integration of previously learned concepts/skills • Learn *more* (because of more effective learning environment – either self-directed or one-on-one)	• Put previously-learned concepts/skills into practice • Discipline-specific technical research skills • Time management skills/self-discipline	• Improved trouble-shooting/problem-solving skills • Analytical/interpretative thinking • Critical thinking • Learn what it's *really* like to do research/nature and practice of research • Learn how a scientist thinks • Better understand own capacities
Anticipated differences to normal coursework (nature of experience)	• Greater workload • More satisfying/fun • Interest-driven • Sustained focus • More flexible (in terms of timing etc) • Own opinion valued • More lonely – no peer group	• More writing • More fieldwork • Different structure (no lectures) • Different learning environment (self-directed, one-on-one) • Different form of assessment (no exam) • More personalised learning outcomes • Increased ownership/ emotional investment due to personal interest (rewards and frustrations) • Integration of practice and theory	• Independent learning (more of the same) • Real world applications of theoretical knowledge (application of knowledge/concepts to solve a real problem) • Personal/professional relationships with supervisors	• Independent learning (new types of concept/ways of thinking) • Generate genuinely new knowledge • Generate new knowledge which may be of benefit to others • Structured around a problem/ seeking answers • More potential for creativity • Potential for the unexpected • Challenging/intimidating because requires new type of learning

* although most students who wrote this were not explicit about differences, this answer implies that they anticipate something not experienced so far

Nugget 2: the Skills needed for Research: Initial Views of Science, Arts and Social Science Students

For many of the students who participated in TREASURE, the research experience undertaken was their first. Despite the focus on research-led education at all three institutions and the fact that these were largely later year students, it is evident from answers to the first post questions that students exhibited a wide range of conceptions of research. Answers to these questions are providing us with an approach to surfacing different understandings of research that may allow the development of better strategies to introduce students to research and overcome their misconceptions.

One question students were asked in their initial post was 'What skills do think you need to be a good researcher?' This question was added in Phase 3 of the TREASURE project when it became evident from the existing questions that students held a wide range of conceptions of research (Nugget 1 on students' expectations). The extra question was intended to provide more information on how students perceived research and their understanding of the kinds of skills they might be developing. In answering this question, students demonstrated a wide range of interpretations of what was meant by 'skills' (something we also noticed in the last post questions – see Nugget 13). Answers ranged from lists including generic and specific skills, competencies and/or personal qualities to more sophisticated discussion of the nature of research, leading to identification of qualities and skills needed for success. This question was asked in all logbooks, regardless of the discipline. Initial analysis showed that there were few differences between the students in arts, sciences and social sciences so all logbooks have been analysed together. Some differences are noted and their implications discussed below.

Analysis of the answers to this question led to the identification of two dimensions of understanding within the answers (Figure 1). The first dimension related to the nature of the qualities required, ranging from generic skills – that are widely accepted as graduate attributes – to personal qualities that may be seen as outside the range of what is taught at university. Both generic skills and personal attributes can contribute to success in research so a balanced view on this dimension would be in the middle. Generic skill can be considered more as procedural while the personal attributes indicate agency and confidence. It was clear from many responses that the skills identified were derived from the student's conception of research and thus the second dimension related to conceptions of research ranging from the view that research was a 'certain' activity where a successful outcome simply required adequate planning to the view that research involved uncertainty and therefore required skills relating to judgment and evaluation. In contrast to the first dimension where the two possibilities are equivalent, the second reflects an increase in sophistication, with the more complex view often also including the need for organisation. Not all students' answers covered both dimensions.

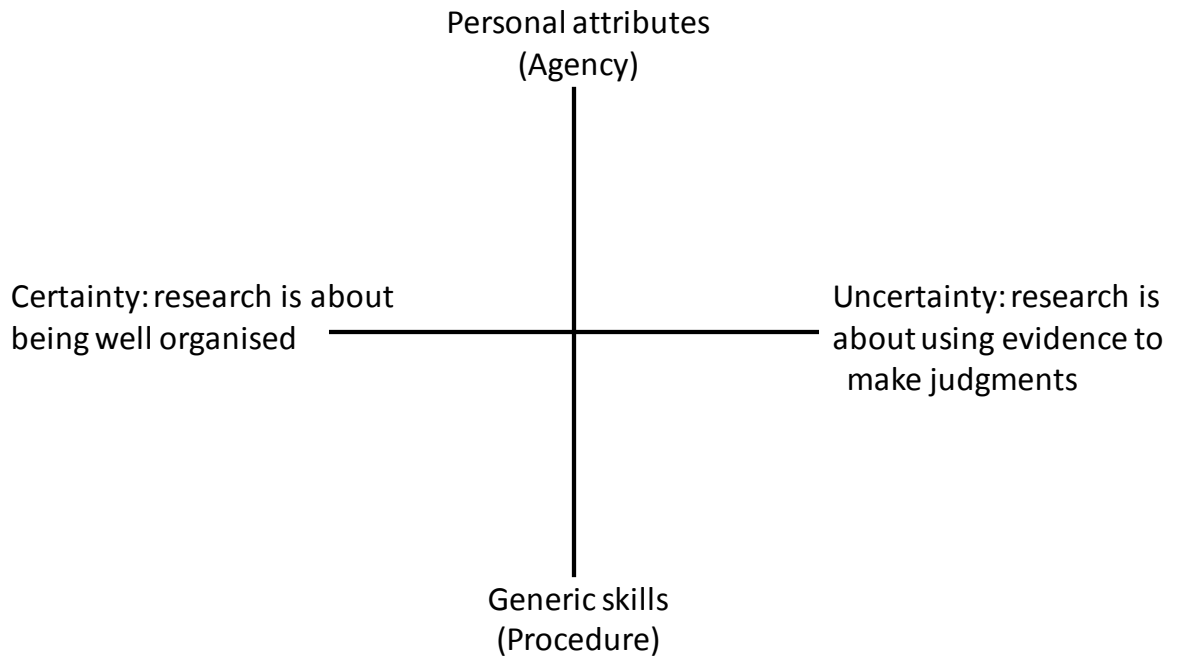

Figure 1. The dimensions of students' expectations of skills needed for research

The skills and attributes dimension
Table 1 shows the classification of the skills and qualities listed in student answers into the two categories spanning this dimension. A list of generic skills was the most common form of answer to this question, although many such answers did include one or more of the personal qualities listed.

Table 1: Skills and qualities needed for research

Generic skills	Personal attributes
Communication skills (oral and written) Analytical skills/critical thinking Interpersonal skills Independence Awareness of ethical issues Integration/synthesis Quantitative skills Ability to find and interpret literature	Passion Curiosity Perseverance/persistence Creativity/imagination Patience Leadership Self-discipline Openness to new ideas Confidence Observant Ability to cope with failure Ambition Honesty

Three examples of responses providing lists with a focus on generic skills are shown below.

'Not afraid to ask the questions, good communication skills, reflective listening, analytical skills, research into various concepts/literature, data analysis and writing skills.' Social science

'I believe a good researcher needs curiosity; good listening skills, analytical skills, observational skills, good people skills, good organisational skills, teamwork skills, networking skills, the ability to systematically organise large amounts of data, the ability to

synthesise information and form opinions, information technology skills, project management skills, good writing skills, time management skills…..' Social science

'I think a good researcher needs to have rigorous analytical and reasoning skill, need to be hard-working and good at time management, have a very good in-depth understanding of the theoretical problem being examined, and be efficient and realistic when it comes to planning out and conducting different experiments.' Science

The personal qualities listed most frequently were passion, curiosity and perseverance and these were evident across all disciplines. While these were most commonly presented in addition to generic skills, there were some students whose response included only personal qualities, as shown here.

'I imagine that to be a good researcher the one thing you need above all else is a lot of enthusiasm and love for what you are working on.' Science

The conception of research dimension

Some student responses included an explicit exposition of what they felt research included and therefore what skills would be needed. Other answers implied particular conceptions of research by the skills that were and were not included. Because different answers may reflect differences in interpretation of the question more than different conceptions of research, we cannot be sure about the conceptions of research held by some students. However, the majority of answers showed little or no evidence of a conception of research that includes the need to evaluate evidence and make judgments. This is consistent with other work showing that many students enter scientific research with the conception that the research process is well-defined and orderly (Cartrette and Melroe-Lehrmann, 2011). Such answers also tended to focus more on generic skills than personal attributes. Thus, those students for whom research was a certain activity saw that what was needed was largely procedural, ie the ability to apply generic skills. Those whose view of research incorporated uncertainty were more able to see a need for a more personal involvement, including agency and evaluation. Table 2 shows the types of qualities and skills that were used to classify conceptions of research.

Table 2: Words and phrases used to indicate each conception of research

Certainty: research is about being well organised	**Uncertainty: research is about evaluating evidence**
Following a plan Time management Awareness of previous research Knowledge of methods Attention to detail	Critical thinking Criticism of self and own views Awareness of two sides Looking for counter evidence Questioning assumptions Checking for mistakes/validity Asking the right question Choosing/evaluating methods Awareness of bias/objectivity

This dimension reflects a continuum from the view that good organization is the main requirement for successful research to a more complex and inclusive view that recognises the uncertainty of research and the need to make choices. Many answers focussed on organizational skills but contained some indication that more complex skills might be required. Answers that showed no evidence the student recognized the roles of judgment, evidence and uncertainty in research were found in all disciplines. Two typical responses are shown below; both are consistent with the view that, provided a researcher is organized and puts in the necessary time, there will be a successful outcome.

'Good time management, being able to always stay on track of research topic, keeping track of data analysis and to know how to present it in a good format.' Social science

'This in some ways reflects what I think it takes to be a good researcher; persistance and a great deal of time dedicated to getting great results, as well as learning new techniques to apply them to problems in your field in a timely fashion.' Science

Intermediate views commonly recognized one or more aspects of a more complex view of research. In the two quotes below, both an Arts student and a Science student recognize the need to choose appropriate methods or approaches, which requires more than just organizational skills – abstract thought and creativity in these particular cases. However, there is no indication that these students see roles for these qualities in other aspects of research or have considered the need to draw conclusions from the data generated by the chosen method.

'To be a good researcher I think one needs to be disciplined and organised to get the work done, methodical to ensure the research is of good quality but also good at abstract thinking to look for wider and more original approaches to their work.' Arts

'I think a good researcher needs to be extremely organized, lab book entries for each lab must be logged with preciseness and can be followed by others. A good researcher not only need to be creative as he/she is required to come up with an experimental plan that could address a problem, but also should be practical enough to carry out that plan in actual events and obtain reliable results.' Science

In the next quote, there is recognition that evidence may be contradictory but this is seen as an opportunity to be thorough and unbiased, rather than recognizing the need to evaluate opposing views. Again, this illustrates some recognition of the complexities of research but is not a complete understanding.

'*I feel to be a good researcher you need to be able to collect research objectively. Depending on the topic or what your researching there will often be two sides to the topic and I believe it is the researchers job to collect research that can show evidence of both sides. A good researcher also needs to be able to collect information from a variety of sources in order to validate the opinion of the topic*.' Arts

There were a small number of answers that showed a high level of understanding of the nature of research, explicitly recognizing that since the outcome is unknown, extra dispositions and abilities are required to develop approaches and draw conclusions. These students showed evidence of having thought deeply about research and then considering the skills needed to address the complexities identified. These answers could be found in all discipline groups, as illustrated with the quotes below.

'I think that the key skills needed to be a good researcher are the ability to know questions to ask to solve a problem and how to find and then understand the answers to these questions, even if they are not what is expected or what will solve your initial problem. Creative thought is important to a researcher, as being able to interpret new results in a new light is important to making new discoveries. Precision and technical ability are also important to being a good researcher, as experimental work forms allow for the basis of new information although the ability to interpret this experimental data is, I think, more important. In my mind however, the most important quality of a good researcher is curiosity, the drive to learn more and breach the unknown, always asking questions can allow these questions to them be addressed and new knowledge can be gained.' Science

'I think perhaps most importantly, good researchers are inquisitive, motivated/enthusiastic and open-minded. They have to question everything, even things they already know ('re-'search), ask questions about things that seem obvious to most, ask questions that other don't dare to ask – this comes from being open-minded too. They have to want to find the answers to their questions. If that happens, then that's half the battle. Then finally they have to be prepared to learn, to have their mind reshaped, altered, their reality changed.' Arts

'A good researcher needs to maintain an open mind and constantly question the credibility and reliability of information. The researcher should be willing to consider alternative ideas and should have patience and persistence. A researcher should be prepared to test theories and if necessary conclude that they are wrong or that their theory cannot be supported based on the data gathered. There is not always a right answer in research and a researcher should be prepared to support any claims made with case studies and data.' Social Science

Differences between science, arts and social science

Analysis of the answers to this question also included comparing different disciplines to determine if research was perceived differently by students in different areas. This was complicated by the fact that the Arts and Social Sciences courses all involved embedded research components whereas the science courses were full apprentice-style UREs. Students in the Arts and Social Sciences courses were therefore exposed to the views of a course convenor since part of each course involved classes covering research and/or research methods. Science students interacted mainly with their supervisors and therefore shared very little common experience within their research course. Despite this, the similarities in students' answers were much more noticeable than the differences. As outlined above, the full range of conceptions of research and identification of necessary skills was found in all three discipline areas. In particular, a naïve conception that views research as simply a matter of good organization and time management was evident in multiple students in all courses. Previously, this view has been associated with science students (Cartrette and Melroe-Lehrmann, 2011) and linked to a simplistic view of scientific method. The data we have obtained from Learning Logbooks suggest that this is a more general view of research that spans all disciplines.

Two areas where differences between the disciplines might be expected have been chosen for further discussion.

Awareness of context and bias

Students in the arts and social science courses displayed a much greater awareness of the broader context for the research, for example, cultural relativity, the need to meet community expectations, personal bias or ethical considerations. Such considerations were very rarely mentioned by science students. The three quotes below illustrate different aspects of ethical and cultural implications but all show an awareness of the need to meet community expectations.

'I will need to seek the approval of my course convener and academic staff to ensure that my research methods are ethically sound and suitable for the case study that I will be analysing.' Social Science

'I believe to be a good researcher you need to be able to locate and synthesise relevant information. Furthermore you must be able to apply said information within a broader context, whether it be cultural, social, political or a combination thereof.' Social Science

'A good researcher needs to be able to communicate their research in simple but not simplistic ways to the community. They need to have some understanding of cultural relativity.' Arts

This broader awareness extended to the recognition of bias and the impact of the researcher's own views, which was also more common in arts and social science students than in science students. In the first quote below, the student recognizes not only the need to be aware of bias but also that this can be difficult. Others, as in the second and third quotes, simply recognized the need to avoid bias.

'I think you would have to be able to set aside your own biases in order to think more objectively about issues. This requires you to first be aware of what your biases are which is not always easy.' Social Science

'I think it is important for a researcher to be objective, as this will ensure a clear outcome that has not been impacted by an opinion or bias that the researcher may possess.' Social Science

'Much of the research in the humanities and social sciences involves people, necessitating a certain degree of people skills. A good researcher should nevertheless try to maintain discipline and approach their research clear and open minded, free from bias and prejudice.' Arts

A small number of science students showed some awareness of bias. While the student quoted below does recognize that bias exists, there is an implication that correct use of scientific method will eliminate problems due to bias. It is not clear whether this student has considered broader implications of personal views on research approaches and results.

'Finally, Rationality is important for more than just research, science and the scientific method requires rationality to reduce incorrect data through human biases and bad experimental design. As a researcher, I think you would need to look beyond your own thoughts and feelings and try to be as dispassionate as possible when viewing the big picture.' Science

Communication and collaboration

Students wrote about the need for communication skills in different ways, as detailed in the Table 3. While it might be expected that significant differences would arise because of the different public perceptions of different disciplines, this was only sometimes the case. The importance of communication skills in the presentation of research was frequently recognized, demonstrating that most students see the presentation of their findings and conclusions as an essential part of the research process. There was considerable variation in the recognition of the value of communication skills for other aspects of research, however. We have identified two further levels of awareness of the value of communication skills; practical benefits where communication with others is seen as necessary to the progression of the research, and intellectual benefits, where the student recognizes that ideas and understanding can be generated and improved through interaction with colleagues. The latter was seen in only a very small number of students (although for many students this changed as a result of the research experience as shown in Nugget 3 on students' views of collaboration). The main differences between the disciplines occurred where communication was seen as necessary to the research, ie in the practical benefits domain and this was often related to the type of research undertaken. The table below shows the different levels of awareness of the role of communication illustrated with exemplar quotes.

Table 3: Communication and collaboration in research as seen in students' initial posts

Aspect of communication or collaboration	**Where it is observed**	**Exemplar quotes**
Ability to present research	All disciplines	*Furthermore, one needs to be good at communicating, both in speaking and writing.* Science *You need to have excellent communication and writing skills, so that you can present your research piece effectively.* Arts
Practical benefits of communication skills in doing research	Interacting with colleagues: all disciplines but more common in science	*Researchers should also be able to work both independently and in a team, as collaboration is often necessary.* Science *Networking and Team-working skills – building relationships and networks, working in a team, and giving and receiving feedback.*

		Social Science
	Interaction with subjects of research: arts and social science only	*Depending on the type of research, people skills could be quite important in knowing how to frame questions, noticing when a person is beginning to feel uncomfortable with a certain topic, predicting what responses and issues you may come across.* Social Science
Intellectual benefits of collaboration	Found in all disciplines but rarely	*Moreover I believe that a good researcher must be surrounded by like-minded people as well as people of other disciplines and schools of thought as this sort of dialogue between both similar and different people may offer previously un-thought-of understandings.* Arts *An even better way of expanding insight would be to simply talk to researchers, especially those who have worked in the field and have significant experience to notice instances that a rookie may miss.* Science

References

Cartrette, D., and Melroe-Lehrman, B. (2012). "Describing Changes in Undergraduate Students' Preconceptions of Research Activities." *Research in Science Education*, 42(6), 1073-1100.

Nugget 3: Student Views of Collaboration in Research

While the list of intended learning outcomes generated from interviews with supervisors and convenors of science projects was both wide-ranging and ambitious, one common realisation that was not explicitly anticipated by staff was the essentially collaborative nature of science. From comments in the Learning Logbooks, it became clear that many students realised, perhaps for the first time, that research progresses through discussion and collaboration, and that it is in this mutually trusting exchange of ideas that problems can be solved and the seeds of future inspiration sown. In this nugget, we focus on this realisation rather than the students' appreciation of a collaborative environment as supportive of their current learning.

As we saw with the intended learning outcomes described in Nugget 10, the ways in which students came to appreciate the role of discussion, collaboration and trust in scientific research varied widely. So, to, did the sophistication with which they made inferences and drew out connections and implications for the wider research process.

What students noticed

The following quotes provide illustrations of some typical ways in which students realised that scientists are not solely responsible for all their successes and progress.

Realisation	Example excerpts
That personal understanding is deepened through discussion:	
Through directly-related discussion with supervisors	*"When reading papers I have find that sometimes I have put a lot of energy into reading them, and have read them first, then tried to summarize them and analyze the information I have gained, to see where it fits into the picture that I already have. These are typically where I have gotten more subsequent questions from, that I have asked my supervisors, which has led to discussions which have been as just as helpful as reading the paper initially, if not more."*
Through directly-related discussion with peers	*"I have also found the benefits of discussing themes, concepts and thoughts with other people. Discussing research is something that is not commonly employed within our undergraduate degree."*
Through reflection on the questions asked by others	*"The aforementioned seminar … was not only educational in itself, but the questions asked by the audience really alerted me to the extent to which an experiment with all its controls and strategic decisions had to be thought out. In fact, my own work on designing controls for this experiment, and subsequent realization that I had missed a few was also an eye-opener."*
That researchers can get practical help from their community	*"After hours of searching the published literature and the web, I finally found an answer to my question on an online forum that directed me to the supplementary pages of a particular published paper. I had never come across supplementary materials that are downloaded separately to the main paper before, so would never have guessed to include that in my search.* *From this experience I learned: (1) to keep an eye out for the supplementary material in published papers; and (2) online forums*

	can be a useful resource – not to use information learned directly from a forum but instead use it to locate the published information of interest, as in this example"
That we can learn through observing the practice of others	*"What I really didn't expect was how much the success and failure of my peers would lead me to tweak my own experiments, even though their field of work was completely unrelated to my own."*
That a friendly environment is important because it facilitates communication	*"I think the lab I am working in is excellent. It has an extremely conducive working environment; everyone is friendly with each other, are supportive of each other, and has something that they can offer. The friendliness and cheer of the members of the lab allows free flow of ideas and communication which prevents it from being awkward"*
The need for trust	*"I learned that in research it may be necessary to take certain results and techniques on faith since there can never be enough time to fully understand all of the results and techniques employed."*
That methods and ideas evolve through discussion and collaboration	*"I see research as a much more collaborative endeavor than before I started this project. This has come about from seeing how discussing recent research in the field with people in the research area exposes you to new approaches. In addition I have witnessed the collaboration between people in the lab/research group"* *"To work through this problem, I often conferred with [S] as to what level of discrimination she was using … I see the research environment as being very collaborative. Nearly every time that I am in the lab, [S] joins me and we complete our work together ([S] is completing a similar project to mine, but with a different focus, on the same data). We often discuss our progress and any issues that arise. We regularly meet with [R] and [B], who are always interested to discuss our newest results and are helpful in suggesting what steps to take next."*
That disciplinary knowledge develops through discussion and collaboration	*"I remember for one of my science exams at high school I had to write about the importance of collaboration in science, and thought it was a little ridiculous to be wasting part of an exam on a waffly question like that. In retrospect, I think I didn't recognise the significance of collaborating. In doing this project now, I have been helped by several people outside of the lab I am working in. I have also seen how my supervisor will show someone from another lab how to do a particularly specific procedure, and others will also show him a procedure from their own lab. I think it's wonderful and shows how science works to share knowledge for the pursuit of benefitting all. It's also fun to share frustrations or successes with others in your lab; I like how with research you get your own space but you can also interact with others as much as you like."* *"While writing up some of the motivation for the experiment in my report, these links between different areas of physics became even more apparent, and I could see how research can flow from one experiment to another and between researchers. The contrast between real experimental physics and the limited lab experience we can usually get in undergraduate life is quite significant, and gives me a better understanding of how experimental physicists operate, learning about other researchers and testing their own limits, rather than the slightly insular feel of undergraduate labs"*

Opportunities missed

Of course, not all students experienced the unalloyed joys of teamwork and cooperation. In some cases, the Learning logbooks allow us to see when more discussion, collaboration and trust would be helpful, as in the following examples:

"When I am unsure about something, there is no-one around to ask, and often, even with all the sources available, I cannot answer these questions. For example, several statistics analyses that I will be using in my report are new to me, and I had trouble understanding them at first sight. Then, later, [D] had left and [A] was un-contactable and I could not have these questions answered. Eventually I was able to answer these questions, but it costed me time and effort which could have otherwise been spent on other portions of my research."

"This week I also discovered that although lab work is interesting, pipetting 9 hours a day is not something that appeals to me. I found the fieldwork much more enjoyable and like being outside and with people; wet work is a very lonely job."

Although several supervisors described wanting their students to feel (at least temporarily) part of the research group or community, this was usually positioned in terms of providing a pleasant working environment or destroying the myth that scientists are dry, dull and rather cold, rather than explicitly highlighting, for example, the importance of discussion in idea generation, the essentially collaborative nature of scientific research and the degree of (considered) trust that implies. The fact that so many students remarked on the importance of discussion and collaboration later in their Learning Logbooks but not in their initial posts (see Nugget 2) suggests that they have not been led to appreciate this through their more conventional coursework studies – something that is not altogether surprising, given the tendency of coursework to focus on what *is* known, and to emphasise a small number of great names and scientific heroes rather than the network of human actors that comprises the successful scientific community.

Fostering an understanding of collaboration

The excerpts above suggest that supervisors who see an understanding of the importance of collaboration in research as a valuable learning outcome for students might identify opportunities to bring this to the fore. This could be done by, for example,

- discussing examples of successful collaboration in their own experience or from the history of their field;
- relating anecdotes about times when discussion would have been beneficial, e.g. in preventing someone going down the wrong track or reinventing the wheel;
- identifying moments in discussions with students and other lab members where a creative approach has been developed, and stopping to reflect on and critically analyse how that happened;
- explicitly asking students to consider how discussion and collaboration has helped them deepened their own understanding or improve their approach; or
- explicitly discussing how decisions are made on what (and whom) to take on trust, especially when building on prior work, and when/why it is necessary to test out the claims of others.

Nugget 4: The Value of the Student Voice

Complex learning outcomes, particularly those relating to generic skills and disciplinary ways of thinking, can be difficult to assess. This is inherent in their complexity; as was evident from the Learning Logbooks, students often described their understanding of research in ways that intertwined several different learning outcomes (Nugget 10). This also arises because research requires a response to an ill-structured problem. A simple problem may require a simple, often linear problem-solving strategy while an ill-structured problem might require multiple attempts and iterative approaches.

Part of the aim of the TREASURE project was to consider ways in which assessment might better reflect the varied and complex learning outcomes generally attributed to participation in a URE. Our conclusion is that there is considerable value in listening to the student voice, as revealed in the Learning Logbooks, rather than using existing diagnostic or assessment instruments or trying to develop new ones. Such diagnostic instruments may be more convenient to administer but can be simplistic because they test for acquisition of particular views (which may not always be appropriate) and do not adequately represent the complexity of student thinking or show how the students develop ownership of their learning. For example, there are numerous instruments for assessing students' understanding of the nature of science – also a complex learning outcome - but these have led to considerable argument about their validity and value (reviewed in Lederman, 2007). Similar criticisms can be made when any complex learning outcome is being assessed because student views may be highly context-dependent and students may vary in their ability to generalize from their own experience to the broader disciplinary context. We will consider the potential contribution made by Learning Logbooks to understanding student attitudes and fostering complex learning outcomes as an alternative.

More general concerns about the overly authoritarian approach used in much science teaching (Hodson 1999, Aikenhead 1996, Wallace 2012) support the view that the student voice should be heard more often. Wallace argues that too much science teaching is approached from a content and product model of education, where the emphasis is on the student receiving and reproducing expert knowledge. This can lead to the development of a reductionist view of science, as a collection of facts and prevent an understanding of the process of scientific research. She suggests that, instead, a process and development model should be adopted. This would value thinking and reasoning skills in the context of science content and aligns better with research in cognitive psychology on student learning than the traditional approach to science education. Successful learning is then defined in a more open-ended manner than simply correctly answering an exam question. Wallace recognizes that such a model will be harder to implement and assess because it recognizes more complex learning outcomes and allows content to be used in more individual ways. However, it does value the student voice, allowing students to develop in their use of scientific language, ways of thinking and identity.

Our philosophy in developing Learning Logbooks has similar aims in that the logbooks allow students to discuss what they are learning and doing in the context of an authentic project. The value of the student voice is that it illustrates the development of the student's own views of the way in which research is done, rather than testing for conformity to a particular view. Learning Logbooks can provide a window into student thinking that allows us to monitor and assess such development, leading to consideration of approaches that might make UREs more effective. Because multiple entries are made during the project, changes in a student's thinking can also be traced over the semester. The logbooks also provide opportunities for helping students to develop their thinking and solve problems, although not all staff viewed them during the semester. Further analysis could also examine the role of key incidents in prompting changes in views of research. While use of the student voice is perhaps more novel in the context of science, our experience with Learning Logbooks in other disciplines suggest this approach is valuable in many areas.

Some students are able to generalize their experience beyond their project
The way in which students are developing higher order analytical and critical thinking skills is often evident as they discuss specific examples from their projects. The three students quoted below are grappling with issues relating to collection and interpretation of data. Their concern is clearly related to their own projects, rather than being an abstract discussion of the scientific process. All three recognize that the methods used are not always standard and require that judgment is exercised. They also all see that the conclusions drawn are dependent on decisions made during the research process, recognizing that small changes in methods can have considerable implications. This attitude is consistent with a sophisticated understanding of the interplay between experimental design, data analysis and conclusions but is framed within the context of their specific experience. However, all also show the ability to generalize from their own experience, with the first two students stating that they would now be more critical in analyzing methods of scientific papers, demonstrating that they have understood that the process they have undergone is a feature of research and not just of their experience. The third student makes a further extension, linking the importance of definitions to her studies in law. The ability to generalise, as well as linking different aspects of their experience, is one of the hallmarks of those Logbooks showing highly sophisticated understanding of the nature and practice of research. These excerpts are, therefore, atypical and represent some of the deepest understandings of research that we observed.

'Also, it was difficult to draw links between studies measuring similar things. The standard units of measurement change with time and between journals (e.g. recent papers measure variation using standard error, while older papers use standard deviation), and so do terms used to describe biological processes such as 'aerobic scope' (can also be described as 'metabolic power') or 'resting metabolic rate' (can also be described as 'routine metabolic rate'). In terms of temperature measurement, it was also often not specified where the temperature was taken from (at which depth/water or air temperatures), which is problematic as we are unsure if we are comparing apples with apples. …… As the methods section of a paper may be often overlooked, this experience has definitely made me more aware of the impact methodologies can have on the results obtained.'

'Another thing I had a lot of trouble with while doing the work was the subjectivity of the experiments. A lot of the experiments required me to subjectively assess qualitative results then present them in a quantitative way, such as the histology lung scoring of pathology (Figure 6 and Appendix 4). I know, because I am less experienced at it I am more likely to make more mistakes and inconsistencies in my evaluation. However, still, because of the subjective and qualitative nature of these experiments it makes me a bit more sceptical when I view data that is portrayed in a quantitative way that is obtained from qualitative means. The way data is portrayed as well has made me a bit more sceptical about science and the papers I read.'

'After getting through the issue of inconsistently defining parental arrival time, I have a new found appreciation for definitions! I had been struggling to see the importance of such, seemingly minute differences in a definition in a couple of my law courses. For instance, in succession law, why separately define a 'domestic partnership' and a 'domestic relationship'? When serving court documents on a party, why should the 'end of the day' be 4pm rather than 5pm? I have learned while such things may seem trivial, they can have an impact beyond what is clearly apparent at face value. In my research project, the importance of parental arrival time stems from the fact that I am considering nestling response to the parents presence – if the point at which the parent arrives is defined incorrectly, nestling responses will also be improperly characterised. This is despite the fact that the change in definition often only impacted 1 to 2 seconds of the parents visit. Since realising this I have actually looked into the rationales for some of the legal rules which I could not see a clear reason for having. This has helped me to better understand the provisions of the legislation I am studying – hopefully this will come in useful for exams!'

Some students' changing views are limited to their discipline
While some students do generalize from their own experience and link different learning outcomes as shown in the quotes above, this is not always the case. The three quotes below, from the final reflections of students doing ecology projects, recognise the uncertainty in their own research but suggest that this is especially typical of ecology. While the first two start with more general statements, both go on to privilege ecology. The third student shows no recognition that 'things are rarely black and white' in disciplines other than ecology.

'For science as a whole, especially in ecology and evolution, time is always a limiting factor in general as there are always so many more questions posed after answering a few in a research project.'

'Research is not as easy as it seems. There are always problems when conducting a research project, especially when doing behavioural ecology. It is unpredictable and we do not always get what we want/ the data we want. In my case, the lizards stopped showing any response because the weather got so cold out of a sudden.'

'At the end of whole process, though, putting together the data was an eye-opener. It's very exciting to finally get back results after so long slaving away at the scanner, blindly hoping that the results will be worth it. Ecology is hard though, because things are rarely black and white and it can be very hard to distinguish between any number of variables at play. To really get any meaningful results you need many replicates, many different species. And you need to control every variable which you can, which was an issue for me at times.'

In contrast to the students quoted in the previous section, these students don't demonstrate an ability to generalise into thinking about their approaches to the science that is reported by others. They are, however, clearly identifying the uncertainty of their own research, recognising that it may never be complete because the answers might not be definitive and there are always more questions to ask.

Conclusion
The quotes shown clearly illustrate that the development of more sophisticated thinking about the nature of research is inextricably linked to the project experience and also show that students exhibit different abilities to generalise their experiences to understanding research more generally. Students evaluate their own experience and may show sophisticated thought about their own project or within their own discipline area. More sophisticated understanding often appears as an ability to link different aspects of their experience and to generalise to the process of research beyond their own discipline. However, only a small proportion of the Learning Logbooks demonstrated this level of understanding. This raises questions about whether simple diagnostic instruments, which are usually not discipline-specific and may not be suited to complex understandings, would provide an appropriate context for these students to recognize and display their learning. Instead, we would argue that in the context of authentic research, it is more valuable to allow the student a voice to express their own understandings. Of course, this requires some interpretation and sometimes an understanding of the disciplinary context, as can be seen from the quotes above, as well as being more time-consuming to evaluate. However, the purpose of the logbooks in the TREASURE project is to make explicit a wider range of learning outcomes and to allow the student to consider and develop their own views, not to test for particular understandings. As discussed elsewhere in the TREASURE final report, logbooks can be used not just to examine the development of particular students' thinking but also to identify barriers to learning and possible interventions, both at the level of individual supervisors and in scaffolding of other aspects of research-led education.

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Nugget 5: Helping Students Learn

While the main aim of introducing Learning Logbooks was to make existing learning visible, it is also possible that the act of keeping the logbook can enhance the learning that takes place. There is some theoretical basis to think this and the limited feedback that we obtained from students on the value they found in keeping a logbook confirms that the act of writing about their experience can help them process what they are learning.
The theoretical basis for suggesting that simply keeping a Learning Logbook can enhance learning is linked to the role of writing in engaging students in thinking about their subject. Well-designed writing assignments prompt students to think about, and struggle with, relevant ideas and this process can lead to the development of critical thinking skills (Bean). A review of the literature on the value of reflective journals cites many studies showing that reflection can enhance learning (O'Connell and Dyment, 2011). There are two schools of thought on the role of writing in learning science, summarized by Prain (2006). The first holds the view that teaching students to write scientific reports in the appropriate format is sufficient to develop scientific thinking because in order to master the format, the student needs to understand the implicit assumptions and underlying thought. The implication of this view is that a scientific report is a sufficient form of assessment for a URE because the process of writing the report will develop scientific ways of thinking.

Our project is based on the other view, to which Prain subscribes, that just as scientists themselves participate in a wide range of oral and written discourse, it is important that students experience different types of writing about science, addressing different contexts and purposes. A scientific paper deliberately conceals the process of thought that contributed to the discoveries reported (Medawar, 1963) because its purpose is to communicate an outcome, rather than the process through which the discovery was made. Students may therefore need assistance, through other forms of writing and discussion, to understand and value these thought processes. The act of writing is seen as important 'to clarify science concepts and practices, to connect new concepts and meanings to past understandings, and to develop critical perspectives' (Prain, 2006). We hoped that Learning Logbooks would provide a forum for the student to develop a voice and reflect on their learning about the process of research.

The PQF provides a scaffold for reflection, prompting students to think about particular aspects of their project. Thus, in addition to any possible effects from the act of writing, simply directing attention to the types of learning that may occur, or even just the idea that the research experience results in different types of learning, might have beneficial effects. Reflection prompts are commonly used, particularly in areas of professional practice, and the evidence suggests that they are useful in facilitating learning (see for example, Moon, 2006 and references therein).

For example, writing about what was being done in the project might prompt metacognition as a student attempts to clarify their thoughts and what they have learned from their project. Although only a small number of studies have investigated links between metacognition and an understanding of the nature of science, it appears that development within these two domains is linked (Zohar and Barzilai, 2013). Improved metacognitive understanding may enhance the nature of science understanding and *vice versa*. It is possible that, by prompting students to think about what they are doing and why, the Learning Logbooks generate deeper understanding of both the nature of science and the way that particular student learns. Students have been found to find writing for a non-expert audience more useful than writing for a teacher because in order to explain concepts and terms, they first need to understand them themselves (Wallace, 2004). Writing for yourself in a reflective journal could easily serve a similar function.

Analysis of the Learning Logbooks is currently being undertaken, with the aim of illustrating different types of learning, noting what students say about their learning and identifying barriers to learning that students may experience. In this nugget, we examine what students tell us about their learning processes.

Learning about learning when doing research
The feedback we obtained from students at the end of semester supported the view that keeping a Learning Logbook was helpful for learning; however, as noted in our final report, the response rates to the final surveys and attendance at focus groups were low. Most students who did respond were positive about the experience, with some typical responses below.

'I got a lot more out of my actual project because it [the Learning Logbook] encouraged me to engage with the process and think about my actions throughout it.'

'I found the learning logbook project really beneficial for solidifying and consolidating what I'd been learning over the past few months.'

'Mainly I got enjoyment from exercising my rusty writing skills. I think also that the process of writing helped to shape and focus a 'world view' of scientific research that was formerly fragmented (at least in my head).'

'…it helped me reflect upon science research and the different aspects to it such as skills, problems, learning etc. In this way it surely did affect the way I went about my project.'

A small number of students commented in the Learning Logbook that keeping it helped them with various aspects of their learning. For example,

'…… through my last two years at uni I have been pretty quiet when it came to asking questions about assignments and about asking other students what their projects were based on, what they found was easy in their write up and what they found particularly challenging. The logbooks I think helped with this as well because without having a milestone of where my thoughts were and are about the assignment I wouldn't of thought to seek out other students ideas as I did.'

'Thank you for providing the framework for reflection, I've found it very useful and rewarding.'

'I have completed many learning reflection pieces of the course of my study. They always seem to be easy times when included in assessment, but prove challenging when you actually sit to write something. I have rediscovered this week that taking the time to reflect on what you have been doing and why is always invaluable. It allows you to process what has been happening and see some progress in your learning and development. This helps my learning and reinforces that what I'm doing is worthwhile.'

Not all were positive, however, as shown by this quote.
'I also believe that this 'learning logbook' hasn't really contributed to my learning in any significant way and still am unsure why I have to do this every couple of weeks. Particularly when I have had several assessment pieces due this week and honestly this is the last thing I really want to do.'

Several PQF questions directed student attention to what they were learning. While some asked about specific aspects of particular courses, for example collaboration in those that included group work, others were more general. Many responses about learning more generally were elicited by three questions,

- What have you learned about your research topic, science and research, or your own

learning? (PQF cycles 1 and 2, answered by 66 of 109 students)

- What have you learned about your own learning? (PQF, cycle 3, answered by 73/110 students)
- What have you learned from undertaking this research project? (Final post question, answered by all students)

While the most common responses to the first and last question included lists of skills associated with the project such as mastering specific laboratory techniques or methods of analysis, it was clear that doing a project and/or the Learning Logbooks prompted some students to consider their own learning styles. To help direct students into thinking about their own learning, we separated the alternatives in the first question above into separate questions (Nugget 7). This appears to have been successful because even though the question used in cycle 3 was restricted to learning about learning, the proportion of students answering this question stayed the same. We cannot tell from the TREASURE data whether it was doing the project or the act of writing in their Learning Logbooks that prompted these thoughts. Either way, consideration of learning is often linked to the more self-directed aspects of project work, where the student takes greater responsibility for managing their time and workload; time management was especially likely to be noted as an improved skill, or at least something that needed improvement. The following quotes illustrate some of the aspects of learning commented on by students.

'This project has reinforced to me that I work best with deadlines, and find that I tend to get off task when there is a lot of time to complete an assignment or part of a project. …..Therefore having self-imposed deadlines to complete different parts of this project has helped me to be more organised in completing tasks. This has not only helped me in this courses, as having to actually stop and reflect on my own working style, I have started writing essays for my other courses earlier than I typically would.'

'I have learnt that I need to write a list and make sure that every bit of the research project is completed on time and in a timely manner.'

'In a nutshell, science and research is not easy. We get better only by experience. Experience means making mistakes and learning from them. I realize I have my own weaknesses and that I have to manage them the next time I take research.'

'I have learnt throughout the research project about my own learning style. It is clear that I learn best when I make notes on the articles in my own writing. It is not beneficial for me to highlight the articles when reading, I must write the important point in my own writing. I have also found the benefits of discussing themes, concepts and thoughts with other people. Discussing research is something that is not commonly employed within our undergraduate degree.'

All of these students have learned something about themselves as a result of undertaking a research project. For several, there are clear implications of gaining transferable skills that will lead to improvements in their study more broadly.

Scaffolding of learning about research in courses with embedded research components
The courses including an embedded research component that participated in TREASURE did aim to scaffold research experiences and appeared to do this effectively for many students, as judged by the Learning Logbooks. In each of these courses, there was also a lecture or seminar component where relevant theoretical background and methods were explained and discussed. This allowed students to better understand the context and to develop skills in analysis that they would use in their research projects. It also gave them a broader perspective on why particular methods are chosen for particular research questions. The assessment for the research project was only one component of the total course assessment and built on earlier assessment items in the course. Students valued the structured approach to research and the opportunities to obtain feedback from tutors and

their peers.

'Through talking with the other students and [my tutor] I realized that my literature review was focused too narrowly and that is why I was struggling with the methodology section. The information that should have been in the methodology section was in the literature review, hence why I did not understand what needed to be in the methodology.' And later in the semester, *'I think that the most important thing that I am learning about research is that it is a process, and not a linear one at that. I have a growing appreciation of the need to be constantly revising my research plan. I have discovered that I need to be flexible and that it is essential to have an open mind, instead of pre-formulated expectations of what I will find, both in the existing literature and from my own research.'*
'Yes, my understanding of what research is, and how it is carried out has definitely changed since starting working on this research at the start of the semester. With this project, it was the first time that I have been introduced to the idea that your research and research findings must be in conjunction with a particular theory model or models.'

'Recent activities have definitely helped in the construction of my report, for example the analysis activity we did in a seminar a few weeks back when we were learning about the major theories really helped.'

'I've realized how unlinear and fragmented my approach to learning and research is. Because of what we've been discussing in class I've been very aware of the process of our research throughout the project. What has been really obvious is how much time we spend going around in circles, or jumping between ideas and lines of enquiry. It took a lot of this quite disjointed process before we came up with anything coherent. In light of this, I've been thinking about my approach to research in all my subjects and have realized that this is generally true of the learning I do across the board.'

These quotes show that the structure of these courses has assisted students in various ways to understand more about research, ranging from help with specific skill or difficulties to more general understanding of research strategies and processes. With a research project that is more limited in scope than a URE, more directly tied to other course activities and scaffolded through interim assessment items with feedback, it may be more appropriate to assess a wider range of learning outcomes in the final report.

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Nugget 6: Critical Thinking in Science UREs

This nugget takes one of the key intended learning outcomes identified by supervisors of undergraduate research projects – the practice and development of critical thinking – and examines it in more depth. It is based on a submitted book chapter:
Wilson AN, Howitt SM, Higgins DM and Roberts PJ (2014) Making Critical Thinking Visible in Undergraduates' Experiences of Scientific Research. Accepted as chapter in '*Handbook of Critical Thinking in Higher Education*', eds M. Davies and R. Barnett. Palgrave McMillan

First, we'll think about the position of critical thinking in higher education. Then, we'll use the students' learning logbooks to start to answer questions such as:

- What does it look like when undergraduate students practice critical thinking in an authentic scientific research context?
- Do we provide such students with opportunities to show their critical thinking in action—or do we, for the most part, leave it hidden?
- If critical thinking can be made visible, how can we recognize and hence develop and assess it?

Finally, we'll use what we've learned from the students to suggest a framework for describing critical thinking to help supervisors and assessors of undergraduate projects to both identify and evaluate the quality of critical thinking in their students practice, and think about how to structure projects and take advantage of serendipitous opportunities to better foster the development of critical thinking.

What do we mean by critical thinking?

Although "critical thinking" appears increasingly frequently in universities' statements of graduate attributes and generic skills, very few of those statements actually offer a definition. This means that, although policy-makers, academics and students all say that critical thinking is important in university education, it's not at all clear that we mean the same thing by it. Before we go any further, we shall therefore indicate what our own interpretation of this important concept is.

Many attempts have been made to pin down critical thinking as a generic skill. For example, the influential author Stephen Brookfield (1987) described critical thinking as involving four components:

- recognizing and challenging assumptions;
- challenging the importance of the context;
- being willing to explore alternatives; and
- being reflectively sceptical.

More recently, another well-known author in the field of critical thinking studies, Richard Paul, offered the following description of what a critical thinker **does**:

"critical thinking is the art of thinking about thinking in an intellectually disciplined manner. Critical thinkers explicitly focus on thinking in three inter-related phases. They analyse thinking, they assess thinking and they improve thinking (as a result)" (Paul 2005, p28).

Adding another slant, Barnett (1997) identified three different tiers of critical thought, with a widening focus on what one might be critical of:

- 'critical thinking' as cognitive skills, usually involving problem-solving,

- ‘critical thought’ as interchanges, debates and standards within an intellectual field, and
- ‘critique’ as metacriticism, involving the taking of a wider perspective, operating outside the discipline itself and sometimes directed at the rules of the discipline.

While differing in some respects, all these conceptions of critical thinking involve abilities such as analysis and evaluation, together with dispositions such as reflectivity, a willingness to challenge current or accepted thinking or practice, and a desire to seek improvement in one’s own thinking or practice, that of the discipline or profession, or in society itself (Pithers and Soden 2000). It is this mix of critical, analytical thinking skills and a disposition to use them in order to improve understanding that we intend when we use the phrase “critical thinking” in the TREASURE project.

Critical thinking in science

Critical thinking in the sciences is strongly associated with problem-solving, analytical thinking, the application of logic and scepticism. It is also frequently described as a key learning goal within a science degree. For example, drawing on data from a study of WTPs in biology, Entwistle (2009, p60) quotes one bioscientist as describing his/her aims as “[to bring students to] challenge things, to question things, [to ask], ‘Can both these people be right?’ . . . A good healthy dose of cynicism . . . In the end of the day, it’s you and your data, and you make up your own mind what you think.” And, as we saw from our interviews with supervisors and convenors of science research projects, critical thinking was one of the most commonly-cited intended learning outcomes for students taking such projects.

Especially in Australia and the UK, undergraduate science students frequently have the opportunity to undertake smaller scale projects, often in parallel with conventional coursework, in their third year of study. Such projects are likely to be exploratory or open-ended, with a looseness of structure that allows students to encounter surprises, obstacles, problems, ambiguities, uncertainty and contradiction, and where resolution may be down to the student. We therefore expect them to be rich with opportunities for students to practice and develop their critical thinking.

What critical thinking is aimed at

One of the first things that struck us on reading the students’ Learning Logbooks was the variety of different things that they were thinking critically about. In some cases, the logbooks adopted a highly formal voice, in line with what students thought they should write in a formal report, and in such cases it was often the case that critical thinking remained invisible (if it was happening at all) – instead, students appeared to be adopting a highly procedural approach. However, where there was evidence of critical thinking, we saw it directed at:

- The student him/herself (their own knowledge, preparation, abilities, actions).
- The research environment in which the student found themselves.
- Their own data/observations, method and/or research question.
- The data/observations and methods of others, including published work.
- The interaction between question, method, environment and observations.
- The research process as a whole.

What exactly the students were critical of, and how successful their critical thinking was, depended on several factors. In the following we give examples of different types of critical thinking triggered by different aspects of projects, summarised in Table 1. The table summarizes and compares the levels of thinking relating to both these examples.

Example 1: How students responded to problems in their research progress
Most students encountered and commented on some kind of problem during the course of their project. In some cases, their responses to such problems were entirely uncritical – they did not spontaneously notice anomalies in their data, for example, continuing to follow set procedures blindly (and unproductively). In other cases, students lacked the self-confidence to try to solve the problem themselves. Such responses form the first three levels presented in the first column of the table below. However, in other cases, students responded to problems with varying degrees of criticality, as described in the second three levels.

Example 2: What students noticed about the research environment
The academic or cultural research environment in which students found themselves offered another opportunity for critical thought. As described in the second column of the table, three different types of uncritical response were evident in the data. However, some students did engage in a critical appraisal of aspects of the research environment, leading us to identify the three levels presented in the second half of the table.

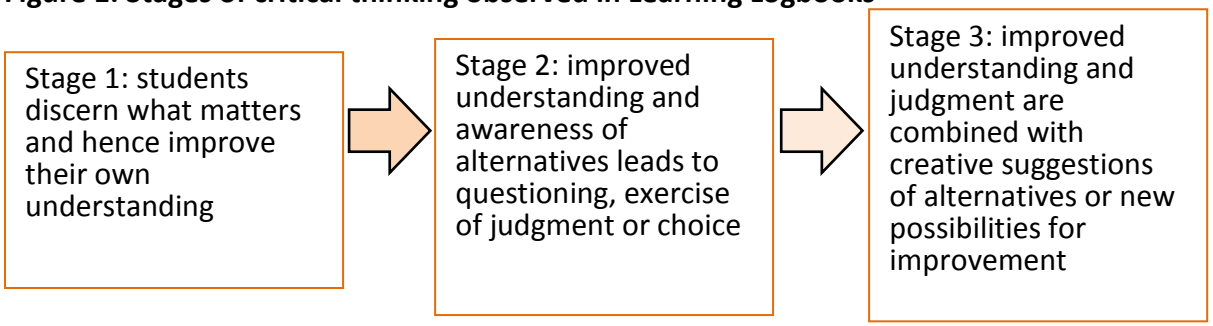
Table 1: Levels of criticality students demonstrate in response to different issues

	Response to problems	**What is noticed about the research environment**
Absence of criticality	Student does not spontaneously notice problematic or anomalous data.	Not considered: not noticed as different from usual study environment.
	Student notices problem or anomaly, blames own practice, knowledge, preparation or ability, or equipment failure, and gives up.	Research/researchers are seen as intimidating. The research environment is seen as complex, not something the student belongs to, requiring an expertise beyond their capabilities.
	Student blames self and/or equipment and turns to supervisor for a solution.	Research/researchers are seen as awe-inspiring, something the student may hero-worship but not be part of.
Exercise of criticality	Student independently identifies and explores factors contributing to failure with a view to finding an explanation or solution.	Research/researchers are seen as expert but not unattainable; participation is an exhilarating challenge to rise to.
	Student suggests coherent explanations, bringing together multiple factors in an integrated way and recognizing causal relations.	Research/researchers are recognized as fallible.
	Student suggests, and where possible enacts, solutions to problems.	Multiple possibilities are recognized, and the role of researcher style in determining research/practice directions is discerned.

Building on these and other aspects of projects where students have opportunities to engage in critical thought (for example, considering their own research design/methodology, scientific process and the evolution of scientific knowledge), we saw a pattern emerge that suggests three broad levels of critical thinking in scientific research projects, corresponding to different stages in the process illustrated in the Figure 1.

Stage 1: Discerning what matters and improving the student's understanding
In the first stage, students think critically about existing disciplinary techniques, concepts or approaches in a way that allows them to discern key features and hence achieve a deeper understanding. They may discern what matters by noticing variation between different circumstances, thus there is an element of comparison (often implicit) and evaluation in this stage. They may also recognize and challenge their own assumptions. However they do not challenge the assumptions or underlying intentions of the research team, or question whether there may be a better approach or way of understanding. This type of thinking may be seen as one that brings the student's thinking closer to that of the discipline.

Figure 1: Stages of critical thinking observed in Learning Logbooks



For example, a variation in a standard procedure leads to this student's realization of the relevance of something she had previously not thought about at all:

"I have picked up little technique tricks in the process, and the logic behind each of them. For example, when using the solvent dichloromethane, it is important to pipette the liquid up and down before measuring the appropriate amount, due to the surface tension which could alter the quantity. Most of the time when working in the lab I am using simple liquids such as water, isopropanol and buffers, so I have never really considered the simple concept of surface tension to have an effect before."

Another post shows a student thinking critically about his data in order to discern a pattern and decipher the message they carry:

"I . . . find it really satisfying playing the detective role with my data, starting with a mish-mash of meaningless numbers and then figuring out what they are telling me."

Another student relates how using a particular method in his project led to critical thinking about his other learning experiences and a better understanding of the real practice of science:

"The biggest shock was the amount of troubleshooting required and tweaking of methods needed to get results. PCR, a reaction that we learn about in first year that seems so simple, proved to be a complex process requiring not only knowledge of how to adjust things when they do not work but also an element of luck. This differed significantly from my experiences in other courses where all the resources are laid out in front of you and the methods have been checked time and again to be successful."

As with the first quote above, this illustrates how research projects offer a context in which students can start to think critically about methods they might otherwise take for granted—but in the first case the student's focus remains on the technique itself, whereas in the second, the student relates his realization about a specific technique to the broader practice of science.

Perhaps the most sophisticated examples of critical thinking corresponding to stage 1 of the figure result in realizations about the way science progresses, as in the following:

"What is interesting when reading papers is that you can see the progression of thought within the scientific community on this question, which is something that is often hard to appreciate from lectures. For the cancer that I am looking into, Burkitt's Lymphoma, it has only recently been suggested that three genetic 'hits' are required for a B cell to become malignant . . . it is hard to imagine that something that is being taught to you as widely accepted now, wasn't always known. This is something that comes through clearly from reading a range of papers, and trying to teach yourself through them. Early papers detail their new discoveries with obvious excitement, whilst the knowledge they are presenting is treated as assumed by more recent papers. In this context it is easy to appreciate how knowledge is accumulated."

In these excerpts, we see an expanding focus from project-specific objects of thought (techniques and data) to what science is really like (trouble-shooting and how scientific knowledge is created).

Stage 2: Critical thinking involving value judgments or choices between existing alternatives
In the second stage, students use their improved understanding to question and make active judgments about existing ideas or practice. These may be judgments of value or standard, or they may be choices involving explicit comparison between alternatives. If alternatives are considered, they are ones that the student has become aware of, for example through reading or observation; that is, they are alternatives drawn from external (usually authoritative) sources.

The blogs reveal students exercising judgment about their own practice and that of others. In some cases, no alternatives are explicitly considered or choices between approaches explicitly made, yet changes are made with the intention of improving outcomes. For example, one student describes his experience of background reading as follows:

"I ambitiously tried to start to read articles on recent clinical trials, it quickly became evident that my understanding on vaccination strategies was required first. This taught me to progress in a logical order and take it step by step. I have returned to some of the articles on clinical trials and it is abundantly evident how much I was missing in the first read through."

It appears that this student's initial judgment of his approach as inappropriate was followed by an immediate, obvious way forward, with no perceived need to consider alternatives.

Other posts reveal students thinking critically about the practice of experts they observe during their projects. In the following example, a student draws a comparison with her own previous observations in order to make a judgment:

"I found the change of environment altered the dynamics of the sessions. We were using a small pediatrics consultation room with a glass wall, which seemed odd, having the bed and such in the background and no real table and chair setup. I felt this made the consults seem less professional and less private."

Stage 3: Critical thinking involving judgment and creativity
In the third stage, students use their improved understanding not only in the exercise of judgment, but also as a basis from which to put forward their own ideas and suggestions. These new ideas are proposed with the intention of improving practice or outcomes. This category adds an element of creativity to the questioning introduced in stage 2.
Most comments belonging to this category focus on the student's project. In the following example, Elizabeth builds on her observations to propose a new research question, and suggests a possible experiment intended to address it:

"It is interesting that chiloglottone was found in high amounts in the sepals of C. seminuda; is it possible that if you remove the sepals, pollination will still occur? Or is it vital to the overall system? I think it would be interesting to remove certain parts of the floral tissues and see the 'success' of the remaining parts that produce chiloglottone, possibly to view the differences, or roles each part plays in attracting a pollinator, or if it is simply a system to which enough pheromone is produced (and concentrated in the appropriate place) such that the pollinator is attracted and pollen is transferred."

In another case, we see a student respond to a surprising aspect of his data with a recognition of how the resulting new knowledge impacted on the method he had been using, and putting forward a revised approach in the light of his discovery:

". . .Theoretically [the surprising factor] shouldn't have made any difference but from the empirical results it clearly did . . . knowing what I know now, if I was doing this again my

approach would be quite different: instead of starting with just one particular metric and looking for broad correlations across a large sample set, I would instead start with just a handful of samples and all of the data points, looking for relationships and correlations and then slowly growing the sample set."

This type of comment shows not only critical thinking about observations and method, but also an awareness of how the two interact with each other. An even more sophisticated awareness of the interaction between observations, methods, hypotheses and research design is evident in the following extract from a student's post describing his evolving project:

"I initially set out to look at the costs and benefits to cockatoos of flocking with corellas . . . from the perspective of the cockatoos. As such I was only gathering data from mixed flock and cockatoo flocks. After a while, however, I began to suspect that the corellas may be benefitting more from the mixed flocking than the cockatoos: they seemed to be much more aggressive than the cockatoos . . . I hypothesized that when corellas associate with a cockatoo flock they may be benefitting from the vigilance of the cockatoos while experiencing a reduced level of aggression from that of their own flocks. Being surrounded by vigilant, non-mating cockatoos may also afford them more safety while they're courting and mating (activities where vigilance seemed especially low). The cockatoos, on the other hand, may be suffering from increased aggression when corellas are present, which may or may not be offset by the increased vigilance the extra birds afford. I decided that it would be interesting to examine the situation from the perspective of both species and see if one species was deriving a greater benefit than the other from the association. Of course, this meant that after a few weeks of gathering only cockatoo data I had to also start recording corella-only flocks ."

Instances of students imagining their own alternatives to the practice of others were much rarer. One of the few examples comes from a similar context to the excerpt about genetic counseling above, where another student not only discerns differences in practice but also relates them to her developing understanding and possible future professional practice:

"I [have become] more observant of the way in which the counselors deliver information and how I think I might have done it. I am starting to be a bit more critical of the different counseling styles, which I think is good because it means I am starting to think more about the way in which information is communicated, which is a key aspect of genetic counseling."

Although she does not explicitly describe what she thinks she might have done, this student's comment implies that she has her own ideas.

Critical thinking and confidence

It is important to recognize that simply placing students in research projects is not in itself a guarantee of opportunities to exercise and develop critical thinking; it has been fairly widely shown that scaffolding and opportunities for self-reflection and metacognition are critical (Pithers and Soden 2000).

A key pattern that emerges from our data is a correlation between criticality and confidence. Students who engage in the exercise of judgment, choice or creative thinking characterizing stages 2 and 3 in Figure 1 appear to have also gained confidence in their own expertise. This confidence provides a basis from which to put forward ideas and opinions that are valid within the disciplinary context, facilitating deployment of a critical approach. This correlation can be seen in the following excerpts, which are taken from the blog of a single student. Early on in her project she recounts responding to a problem as follows:

"I had an E.coli transformation fail, and purified some DNA samples, only to get rather low yields. My initial reaction to this was to blame myself for poor technique and look no further . . ."

Several weeks later, she responds to unexpected results in a radically different tone—note the confident use of sophisticated, technical language accompanying her own hypothesis about what might have happened:

". . . the positive ligation mixture controls did not give the expected PCR bands for EITHER of my recombinant plasmids. I've hypothesized that my digestion of the initial plasmid pYM-N5 failed because the restriction sites were right next to each other. Perhaps my gel showing 'successful linearization' was merely the result of one enzyme working giving a linear plasmid with one compatible and one non-compatible end."

One of the key differences between these responses is a willingness to think for herself—indeed, her initial problem was only solved by turning to her supervisor for help. The apparent increase in her critical thinking is coupled with increased fluency in the disciplinary discourse. It is evident that during the course of her project, she has acquired a substantial amount of disciplinary knowledge and technical expertise, possibly furnishing her with the confidence to make judgments and suggest her own hypotheses.

The shift from an uncritical approach to attempts at criticality, as exemplified in the table above, thus seems to be related to developing confidence. Confidence may also play a key role in determining which stage of critical thinking a student engages in in any given context. Where critical thinking is directed towards elements of the project, students are more likely to consider critically those elements they feel are under their control, or that they are capable of properly understanding/executing. Students who feel less sure of themselves are more likely to focus on highly specific, immediate aspects of the projects as separate tasks that they have to master, and to focus on achieving that mastery or improved understanding: they seek improvements to their own practice, with improvement envisaged as better reproducing procedures and thinking defined by authority. Students who have developed a significant level of confidence with regards to their understanding of the project are more able to critically appraise it as an integrated whole, and seek improvements to its execution and scope for findings. Where critical thinking is directed towards the practice of individuals, the scope of criticality may be related to students' sense of relative equality, and therefore what they are eligible to judge and make suggestions about.

One thing that became clear in developing this framework was that those excerpts which showed significant levels of sophistication in relation to the learning outcomes had two general properties:

They tended to combine several of the learning outcomes, for example showing critical thinking coupled to creativity in responding to a problematic situation or obstacle in the research process, or combining externally and internally-directed critical thinking; and
They tended to successfully link concrete examples of the students' own experiences with broader thinking, for example about the possibilities offered by the project, the nature of science/scientific practice, or the nature of knowledge-generation through research.

Less sophisticated examples tended to operate only on one level – either that of the specific situation of the student or on science as a whole, without linking the two; to illustrate only one aspect of the intended learning; or to be observations of the practice of others, rather than connect with the student themselves.

Whether or not a decision is made to use this type of framework in any summative assessment (a decision that will inevitably be strongly context-dependent), we hope that analysis of students' learning logbooks against such a framework might help supervisors identify areas that can be singled out for praise and encouragement, or for constructive intervention, so that students who are missing some critical element of thought or who have not realised some of the opportunities available to them can be guided towards success. Similarly, supervisors may find that they can identify aspects of their own practice that they could improve.

Development of critical thinking

The learning logbooks have several implications for the provision and assessment of research projects. For one thing, our students may be thinking in surprisingly sophisticated ways about their research projects, but such thinking is hidden in most of our normal assessment processes. Where a final report would most likely start from the hypothesis that the student ended up with, the blogs allow us to see the processes by which hypotheses evolve and change in response to observations and active testing. Trouble-shooting, liable to be unreported in formal scientific writing, is recorded as it happens, enabling us to see whether it has been undertaken in a purely procedural, uncritical way, or whether it has involved students critically evaluating their diagnostic and solution processes. Similarly, students would not typically explain the logic or even choice of standard techniques in a formal report, making it difficult to determine whether they followed them algorithmically or whether they reflected on and understood *why* they were doing what they were doing. Finally, our blogs reveal students reflecting on their own practice and that of others in a way that would be excluded in a report focused on the *results* of the project.

Our findings suggest that supervisors could look for and actively seek to encourage critical thinking directed towards a range of different objects, and at multiple levels. The possibility of students engaging in critical thinking, critical thought and critique could be maximized by deliberate provision of opportunities to see science as more than procedural; by challenging students to go beyond instructions to think about why they are doing what they are doing (engaging in stage 1 of Figure 1); by explicitly inviting them to choose between alternative techniques or approaches, or judge between different suggested interpretations (engaging in stage 2 of Figure 1); by asking them to put forward their own ideas or suggestions (engaging in stage 3 of Figure 1); and by deliberately finding ways to encourage a sense of relative equality, so that they are more likely to feel able to make critical judgments and put forward valid suggestions.

In these ways, perhaps we can provide opportunities for the capacity for critical thinking to be exercised and strengthened, and encourage a propensity to use it as a constructive way of engaging with research. By helping students to see themselves as capable of learning enough to discern what is important, and make their own judgments, in contexts that initially appeared to be beyond them, we may make it more likely for them to believe themselves capable of similar development in future. That is, having gained enough confidence in their own knowledge and ability to analyze a situation or argument to think critically about a new idea/field once, we may hope that students will realize they are going to be able to do this again in other contexts.

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Nugget 7: The Prompt Question Framework

The following table shows the PQF as it was used in science UREs in the final semester of implementation (and subsequently in those courses where use has continued). The TREASURE final report explains how the questions were adapted for different types of research experiences. We found that it was important to tailor the PQF for different course contexts by developing extra, specific questions in consultation with course convenors. However, the majority of these questions were included in all participating courses and are presented here as a guide for the kind of prompts that we found useful.

The PQF is structured to contain initial and final questions, as well as 'regular' questions which students answered regularly throughout their research experience. First post questions were designed to probe students' expectations of research in terms of learning and skills and their prior experience of research. Final questions mirrored these to some extent, asking about what had been learned and whether expectations had been met. Regular questions were designed in consultation with staff who had supervised URE students and reflected different aspects of both the learning about and experience of research, including what was done, why it was done, progress and problems, the research environment, metacognition, links to other learning and applications. Students could choose which questions to answer for each entry.

PQF for immersive, apprenticeship style UREs in science
First post questions: • Why have you chosen to do a research project and what are you expecting to get out of it? • Have you undertaken a research project previously? Describe it. • What are you expecting to be different in this research project experience from your normal coursework? • What skills do you think you need to be a good researcher?
Adaptation for second cycle of Learning Logbook implementation

• What did you do on your research project/activity since your last post?
• Have you made any progress since your last post?
• Did you encounter any problems or obstacles?
  ○ If so, what made them problems?
  ○ How did you go about solving them?
  ○ What would have helped you overcome them?
• What might you have done differently if you had known what you know now, a few weeks ago?
• Has the focus of your research project/activity changed? If so, how?
• How have your recent activities helped you address your research project/activity?
• Can you see any connections between your course/project activities and your other studies?
• Can you see ways in which you could apply what you have learned to date to other activities, in or out of university?
• Have your recent activities raised any questions you would like to discuss with your supervisor/course convenor? If so, list them.
• What have you learned about your research topic, science and research, or your own learning?
• How do you see the research environment you have been working in?

Adaptation for third cycle of Learning Logbook implementation
• How have your recent activities helped you address your research question? • Have you made progress in the last fortnight?

- If so, what allowed you to make progress?
- What kind of activities did you engage in that helped you make progress?

- Problems and obstacles are a normal part of research. Did you encounter any?
  - If so, what made them problems?
  - How did you go about solving them?
  - What would have helped you overcome them?
- What might you have done differently if you had known two weeks ago what you know now?
- Has your research question changed? If so, why, and what has it changed to?
- Have you found/learned anything unexpected? Explain.
- Has anything you've learned shifted the focus or aims of your project? How?
- How confident are you in drawing any conclusions from your observations or results? Why?
- How have you chosen the approach or methods that you are using for your project?
- What are the connections between your research activities and your other studies?
- Can you see ways in which you could apply what you have learned to other activities, in or out of university? How?
- What have you learned about your project topic, science or research more generally?
- What have you learned about yourself from doing this project?
- Has your view of what research is changed from your project experience? Explain how.
- Has this fortnight's activities raised any questions you would like to discuss with your supervisor? If so, list them.

Last post questions:

- Has your research project/unit met your expectations? Why/why not?
- What have you learned from undertaking this research project/unit?
- Would you do another research project/unit if you had the opportunity? Why/why not?
- What skills do you think you have developed or strengthened through your research project?

Nugget 8: Guide for Staff Implementing Learning Logbooks

In this guide, we draw on our experience with Learning Logbooks in a range of courses in three institutions to highlight issues we considered in the implementation of Learning Logbooks and in their subsequent analysis. The purpose of this guide is to identify the most important factors that contributed to the successful implementation of Learning Logbooks and to suggest alternatives that may suit different requirements. This guide is structured as a series of questions for potential implementers, with some thoughts on what we found relevant for each. Many of the issues raised here are addressed more fully in the accompanying report or in other sections of this document. Two reviews covering the use of reflective journals and their role in learning that may also be useful are Kember et al (1996) and O'Connell and Dyment, 2011).

What do you hope to achieve by using Learning Logbooks?
Learning Logbooks can potentially provide benefits to students, supervisors, course convenors and the institution. It is important to be clear on why you are implementing them so that they can be best structured to meet your goals. Potential benefits to different stakeholders are summarized briefly here.

Students – By prompting students to think about their project regularly, Learning Logbooks may promote deeper learning. Some students wrote that they found the Logbooks useful for this purpose. Many found that simply having to make regular posts forced them to think about what they had achieved, helping them keep on track. There is also some evidence that keeping Learning Logbooks or any reflective journal may help students develop metacognitive skills.

Supervisors – Learning Logbooks can provide a window into student thinking and thereby help a supervisor better understand their student's conceptions and misconceptions about research. This could lead to timely interventions for that student but may also feed into better project design in the future. Learning Logbooks can therefore act as a professional development mechanism for the supervisor by helping them reflect on their strengths and weaknesses in supervising undergraduate research students.

Course convenors – Learning Logbooks can allow convenors to identify common problems or misconceptions, allowing them to provide useful feedback. Occasionally individual students wrote about potentially serious problems in their logbooks, for example communication problems between a student and their supervisor. This may raise ethical issues with the use of Learning Logbooks so expectations and responsibilities need to be made clear to all students and staff involved in the course. Learning Logbooks can also provide feedback on whether the course is meeting its aims and where students need more help.

Institutions – Learning Logbooks can provide a mechanism by which development of generic skills and graduate attributes can be monitored. This could be used in a variety of contexts, for example, to demonstrate meeting AQF criteria or to justify the existence and structure of a particular course.

Which PQF questions are appropriate for your course?
Prompt questions need to be carefully tailored to unit contexts and desired learning outcomes – while they are effective in directing students' attention towards aspects of their experience, they can also direct attention *away* from other aspects. The questions sow the seeds of reflection, and since students only have limited time they are likely to reflect on what is being highlighted for them by the questions in front of them. Our PQF questions

were initially designed to prompt students to think about learning during a science research experience and were developed after workshops and interviews with supervisors about their learning outcomes for students involved in UREs. We later modified some questions to accommodate other disciplines and lecture courses that had embedded research experiences. If your course has different learning outcomes, you many need to add or change questions to better reflect them. For example, we added a question on collaboration in courses where the research project was done in groups.

While many questions in the PQF are quite general and we found they were appropriate to a wide range of research experiences, this may not always be the case. We also found that the questions are quite sensitive to wording and context. For example, in one course with an embedded research component, some students did not recognize that they were doing research and therefore found questions that mentioned 'research' difficult to answer. Providing students with questions that were clearly linked to the activities undertaken proved much more effective. Questions need to be clearly linked to course aims and learning outcomes as well as being introduced to the students with appropriate information.

How will the assessment structure support use of Learning Logbooks?
Learning Logbooks can be voluntary, a course requirement with no marks allocated, contribute to assessment either by awarding marks simply to using the logbooks or by assessing the quality of entries. Where possible, we chose a model where posts contributed a small amount to assessment (typically 1% per post just for doing each of the five posts). This avoided issues associated with assessing reflective writing and the problem of students writing what they think supervisors/course convenors want to hear, both of which can cause difficulties with reflective journals (O'Connell and Dyment, 2011). The marks provided enough of an incentive for most students to satisfactorily complete the required posts. While this was successful for a range of courses participating in the TREASURE project, other models might be valuable in courses with different structures or learning outcomes.

In two courses, a final reflection piece asking students to evaluate their learning during the semester was also included as part of the assessment. This appeared to be effective in prompting students to look back at their own development over the semester and therefore may be a useful addition to Learning Logbooks. Whether this is assessed as CRS, for a grade or not at all also needs to be considered.

When and how often should students make Learning Logbook entries?
Our preferred model (based on experiences throughout the project) is for students to do five posts at regular intervals during a semester-long project, answering about three questions in each post. Two of the posts are directed towards the initial and final questions, with the other three posts giving students a choice of questions from the PQF. This did not seem to onerous a workload (at least when some marks were allocated for each post) and was enough to be useful in tracking the thoughts and development of students' understanding of research over a semester.

The timing of each Learning Logbook entry also needs consideration. While regular posts work well for apprentice-style UREs, in courses with embedded research experiences it may be better for students to answer questions at specific times during the semester, to better link them to the teaching and learning activities undertaken at this time. In one course with an embedded research component, we found a significant improvement in the relevance of responses when the questions were directed at the activities undertaken with responses due shortly after completing each activity.

Will feedback on Learning Logbook entries be provided? If so, when and how?
There are a number of sources of feedback (supervisors, convenors or peers), feedback could be to individuals or to a class and feedback could be an essential part of the Learning Logbook or an optional activity. Good feedback is always valuable and Learning Logbooks are no exception. However, providing feedback can be costly in terms of staff time so the

benefits need to be weighed against the costs. We had initially hoped that supervisors would regularly read and respond to their student's Learning Logbooks. This happened only rarely, although it was more likely in supervisors who were using logbooks for the second time. Consequently, in our project feedback was infrequent and optional. Two suggestions for feedback on Learning Logbooks were raised throughout our project.

Firstly, the possibility of students having access to each other's Learning Logbook was repeatedly raised in workshops. This was thought to be particularly useful for apprentice-style UREs; as students usually do these individually, they lack a cohort so sharing logbooks could enhance the experience through shared learning. Additionally, as projects vary so much, learning could be extended through the realization that not all projects were alike. We raised this with students in a focus group and obtained a mixed response. Some students agreed that it would be beneficial to see what others were experiencing while others were concerned that this would impact on what was included, with students being less likely to admit to concerns or lack of confidence if the logbooks were not private.

Secondly, convenors (especially those of courses with embedded research components) found Learning Logbooks useful to identify common concerns or misunderstandings. They felt that intervention could usefully be done at the level of the whole class. Identifying the issues as coming from logbooks, but not identifying individual students, overcomes confidentiality issues while also making it clear that the response is to student-generated concerns. This approach would be more efficient than providing individual responses and could also promote class discussion.

What platform will be used to implement Learning Logbooks?
Although we set up Learning Logbooks as private blogs for each student using the *Edublogs* platform, this was in part driven by our need to implement Learning Logbooks across three institutions. This did have a number of other advantages, however. Online logbooks provide accessibility for staff and students and can easily be used to give feedback through the comment function. The blog structure allows students to easily personalize their Learning Logbook and to integrate pictures and diagrams. Other users can be added, for example if it was desirable for students to see each other's Learning Logbooks, this could be done. Students can also look back at earlier posts and see their own progress throughout the project as well as changes in their thinking. However, some administrative support was required to set up blog templates, add new students to the system each semester and provide assistance to the small number of students who had initial difficulties in using the blog.

Other models may also be suitable to meet particular needs. For example, in one course, students responded to questions similar to the PQF but emailed their answers directly to their supervisors (Campbell and Lom, 2006). Questions could also be added onto existing written assignments to become an extra component to be submitted or could take the form of a learning journal to be submitted at the end of semester.

What scaffolding will be used to support reflection/Learning Logbooks?
Students may need direction and support to become reflective practitioners (Kember et al, 1996). This is probably especially true in science where reflection is less common. We chose to provide only minimal guidance on reflection for students in the form of a brief introduction to reflection and its value in the Learning Logbook guide. This decision was made partly because of the nature of most of the courses involved (where students work with individual supervisors and only rarely come together as a cohort) and partly because we hoped that supervisors would provide feedback to students. As mentioned above, the latter occurred only rarely. We also hoped that using prompt questions, rather than unstructured reflection, would assist students to think about broader issues associated with the nature of research and their learning. While this worked well for some students, other logbooks entries were largely descriptive, with little evidence of reflection. These students avoided the more reflective questions, choosing to answer those that lent themselves to descriptive answers, eg by focusing on what they had done. Providing greater support to

develop reflective thinking and writing skills may have been beneficial to these students.

If supervisor responses are desired, it may also be useful to provide some scaffolding for supervisors, especially those who are unfamiliar with reflective journals. This could include information on reflective practice, highlighting common intervention triggers, suggestions on how to frame responses, case studies from Logbooks where students reported successful interactions with their supervisors, for example.

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Nugget 9: Intended Learning Outcomes for Science UREs

Throughout the TREASURE project, we considered intended learning outcomes for UREs and other research experiences. As described in the TREASURE final report, during the interviews with convenors and supervisors carried out in Phase 1 of the project, we asked these academics to describe the kinds of things they hoped students would gain by undertaking projects. We interviewed research-active science academics at both ANU and UWS, sampling fields from pure maths to applied psychology and career stages from first permanent position to close-to-retirement. Despite the diversity of interviewees, there was a great deal of commonality in terms of how potential benefits to students were described – and also a significant degree of consensus about what is, isn't and couldn't be measured or evaluated during the assessment processes.The table below represents outcomes from a thematic analysis of these interviews to show the intended learning outcomes that were put forward by most supervisors and convenors.

The table of learning outcomes was subsequently presented to a group of project supervisors and convenors at ANU for their consideration at a workshop aimed at designing an initial prompt question framework; these academics were satisfied that the thematic grouping provided a fair representation of their intended learning outcomes for their own students. Subsequent presentation of the ILOs at the ACSME conference and other workshops yielded similar levels of agreement.

Intended learning outcomes for student: initial analysis
Disciplinary/technical skills/knowledge Students should: • Acquire technical skills (equipment, computational etc) • Acquire methodological skills (data literacy, statistics, applying disciplinary approaches) • Apply theoretical/methodological knowledge/skills • Acquire/develop scientific/professional communication skills • Acquire project management skills (time management, organization, prioritization, self-discipline) • Develop mastery/complete learning (move towards disciplinary expert status)
Engaging in/understanding process of research Students should learn how to: • Analyse and interpret data • Come up with a question • Turn a question into a research question • Design an approach to answering a research question; make it feasible (conceptualisation to academically defensible method) • Attack a complex problem – experience the kind of strategies that aren't possible in simple, set-piece problems • Understand what constitutes relevant data/evidence • Understand how data are generated • Make inferences, drawing conclusions

• Understand how the whole process fits together
Ways of thinking Students should develop a variety of ways/habits of thinking: • Independent thinking • Creativity, originality • Awareness that creativity can be connected to a logical process • A conceptual (as opposed to procedural) approach – marriage of creativity and independence • Critical thinking, externally directed (data, the work of others) • Critical thinking, internally directed (tracking own thinking, reflection) • Deep thinking • A habit of looking for patterns – generalizing • The habit/desire/intention to integrate learning from multiple/disparate sources/courses • The attitude that a body of knowledge is something that can be built on/used to achieve something new, not just something that should be absorbed
Sense of self as scientist Students should: • Have a sense of ownership, control • Cope with being stuck, with things not working; persevere/persist • Become (temporarily) part of community • Experience what it is like to have expertise • Develop confidence in own capacity to do research • Develop informed enthusiasm for field/discipline

Later in the TREASURE project, we examined Learning Logbooks from science URE students with the aim of mapping what students wrote against these learning outcomes. Analysis of this mapping exercise led to the following table which links activities students might undertake as part of their URE to possible learning outcomes and ways of thinking. It provides a basis for linking what students write in their logbooks with the intended learning outcomes, which could be used in URE project design or to help students recognise their learning. This analysis is discussed more fully in nugget 10.

Activity for student to engage in	**Related ways of thinking and dispositions**
Developing disciplinary/technical skills/knowledge	
Acquire project management skills (time management, organization, prioritization, self-discipline)	Critical thinking about, e.g.: • data, methods, possible outcomes • own dispositions and habitual work patterns Creative thinking about, e.g.: • data management / organisation • Conceptual thinking to keep the bigger picture in mind Self-discipline and persistence

Develop mastery/complete learning (move towards disciplinary expert status)	Critical thinking about, e.g.: • The impact/consequences of following or not following procedures/protocols • The development of the disciplinary knowledge base Perseverance, persistence Curiosity (for motivation to persevere)
Engaging in/understanding process of research	
Understanding that research requires asking a question • Coming up with a question • Turning a question into a research question • Designing an approach to answering a question	Independent thinking Critical thinking about, e.g.: • evidence, methods, data interpretation and the interaction between them • previously published work Creative thinking, e.g.: • to identify new areas of focus • to design new methods or approaches Curiosity The habit/desire/intention to integrate learning Seeing knowledge as something to build on or used to achieve something new Desire to bring forward the disciplinary community's knowledge
Attack a complex problem – experience the kind of strategies that aren't possible in simple, set-piece problems	Critical thinking aimed at, e.g.: • trouble-shooting • own practice • Independent thinking Creative thinking (generating solutions) A habit of looking for patterns A sense of ownership, control Perseverance/persistence Desire to bring forward the community's knowledge Willingness to learn from others in the community Sense of expertise Confidence in own capacity
Understanding how the whole process fits together • Understanding what constitutes relevant data/evidence • Understanding how data are generated • Making inferences, drawing conclusions	Critical thinking aimed at, e.g.: • data and methods • inferences made by oneself and others • alternatives hypotheses • uncertainty and the status of assumed (disciplinary) knowledge A habit of looking for patterns The habit/desire/intention to integrate learning Willingness to learn from others in the

	community Sense of expertise Confidence in own capacity

Nugget 10: Revealing Evidence for Intended Learning Outcomes in Science UREs

The apprentice-style science research projects at ANU and UWS were assessed for grading, and "normal" coursework continued in parallel for the students. The project team therefore expected supervisors and unit convenors to have some intentions with regards to specific learning outcomes for the students. The intended learning outcomes and benefits to students that came out of these interviews are presented in Nugget 9.

The first thing to draw attention to about the intended learning outcomes and benefits to students described by our interviewees is their extensive, wide-ranging and in many cases aspirational nature. When faced with this summary, most supervisors/convenors felt they were a good reflection of what they hoped for, but simultaneously accepted that they were perhaps unrealistic for a single-semester, quarter-load project! When asked in the interviews or workshops to describe how they might know whether particular outcomes had been achieved (or how they might go about assessing them), many of the participating academics also admitted to a lack of evidence.

Those outcomes that were felt to be relatively easily observed and assessed are listed in bold face in the table. For the remaining intended outcomes, some were felt to be outcomes for which evidence could be relatively easily identified but which should not be assessed, while others were felt to be problematic to provide concrete evidence for (either falling into the "You can just tell" or "There's no way of knowing" categories of outcome). Indeed, most of the intended outcomes for/benefits to the students seemed, to our interviewees and workshop participants, to either be unsuitable for inclusion in the assessment process or, what is perhaps more worrying, impossible to even tell whether they had been partially or wholly achieved!

The Learning Logbooks, however, provide powerful evidence for much of the desired learning. They provide a good way of obtaining evidence for students' developing understanding of the nature or science; their practicing and/or developing ways of thinking such as creativity/criticality; and their changing sense of themselves as potential or even current practicing scientists.

The following analysis draws on ~60 blogs kept up by students undertaking at least one full-semester, stand-alone research project in the science faculty at ANU. The TREASURE team read through these blogs looking for evidence of the learning outcomes indicated in the Table 1.

We found that the blogs were extremely effective in providing evidence for some learning outcomes and occasionally or partially effective for most others. In addition, they helped clarify how some of the learning outcomes might be more clearly articulated; revealed others that had not been explicitly articulated by academics in the interviews carried out before the projects took place, but that nevertheless struck the TREASURE team as valuable and related to the outcomes that had been identified prior to the projects. Perhaps the most important of these were:

- Many students realised, perhaps for the first time, that research progresses through discussion and collaboration, and that it is in this mutually trusting exchange of ideas that problems can be solved and the seeds of future inspiration sewn
- The projects allowed some students to recognise the limits of what research can do/what questions can be answered
- For many students, professional habits and behaviours that had been enforced on them in other settings (such as keeping lab logbooks, being rigorous and careful, or using technical language) suddenly became meaningful, as their consequences

became clear. While the dawning of this understanding can be understood as part of what it means to "experience what it's like to have expertise", it was evident in such large numbers of the blogs that we feel it is worth drawing attention to

- In the process of deciding what data were relevant, or what procedures to employ, several students recognised the role of judgment, and some started to develop the capacity to decide whether an idea or detail was worth pursuing. This was clearly an important realisation for students – that, as practising scientists, they would have to determine their own boundaries for action and choose between competing goals.
- provided concrete illustrations of more and less sophisticated thinking by students immersed in research activities.

We soon found that it was easier to identify evidence for some learning outcomes being achieved than for others. We should stress that there are several possible explanations for this, including:

- These projects weren't providing a good way for students to achieve those learning outcomes.
- The blogs weren't providing a good mechanism for students to show evidence for them, either because we weren't asking the right prompt questions or because students are for some reason more reluctant to or less capable of articulating them. For example, the prompt questions did not explicitly ask the students what they felt they had personally contributed, or what ideas they had come up with of their own; it is likely that questions prompting the students along these lines might reveal more about their levels of creative/original thinking, and hence also their awareness of a need to connect such thinking to logic. Similarly, in the case of the goal of "developing informed enthusiasm for the field", in a few cases it was clear that students had become more enthusiastic about their field of study through their project, but in many more cases they were enthusiastic from the start, or the value of the field was not discussed at all. Since none of the prompt questions asked students to consider the value of what they were doing, it may well be that other questions would more easily reveal the development of informed enthusiasm.
- Some learning outcomes are essentially either components of or syntheses of others. For example, "deep thinking" is always directed at something, and so instances of deep thought were generally more helpfully categorised as critical thinking (directed externally or internally) and/or attempts to understand experimental processes, integrate, reflect on or build on existing knowledge, generalise and so on.

The grouping of learning outcomes provided in Table 1 was arrived at on the basis of analysis of interviews with frequent supervisors/convenors of project units, during which we discussed what these academics hoped for as a general rule. Since the categories and individual learning outcomes struck supervisors as valid representations and useful clarifications of their intentions, in the spirit of constructive alignment, we might try to construct marking rubrics or grading criteria based on these various outcomes. In so doing, we might come up with a somewhat more fine-grained version of the Research Skills Development Framework developed by John Willison at the University of Adelaide, or perhaps Domain A (cognitive and intellectual abilities) and parts of Domain B (personal effectiveness) of the Researcher Development Framework created for UK PhD students by Vitae. However, the blogs suggest that there may be alternative approaches that could provide more effective guidance for students in their own self-development as well as more illuminating tools for supervisors.

As well as providing evidence that students are, indeed, gaining some of the benefits that supervisors hoped for during their projects, the learning logbooks suggest ways in which

staff can identify different levels of sophistication in their students' thinking. At the simplest level, we can use the words of the students themselves to provide examples of what constitutes evidence of high quality, average and poor critical thinking, for example. This allows us to construct a rubric of the type presented in the table below, which illustrates how different levels of thinking can be differentiated between for the intended learning outcomes of project management, designing an approach to a question and externally-directed critical thinking.

Table 1: Identification of achievement of intended learning outcomes in Learning Logbooks (pseudonyms used to identify students)

ILO	Excerpts showing excellent understanding or performance	Excerpts showing good understanding or performance	Excerpts showing a need for improvement or intervention
Project management skills	"I have gained a much deeper appreciation for the amount of time and effort that goes into collecting and analysing data. I have learned the importance of setting deadlines for finishing tasks, such as data analysis, and sticking to these deadlines (or changing my expectations in order to be able to meet realistic targets)." (Jane) *This comment differs from those in the 'good' category in that J has recognised the need for flexible, responsive planning and expectations.* "It's like a puzzle, trying to work out the best way to organise files and data so that it's easier to see a result and to make connections from your data. Originally I thought that all the leg work is out in the field, but it's actually in all the prep. Once you have your field steps they don't change, but to get to that stage takes much consideration of how to test what you want to." (Amy) *In this excerpt, A's experience of data management leads her to insights about the nature of research.* "As the research I conducted was in the form of a meta-analysis, I have also honed skills associated with dealing with large quantities of data. This includes organising the data in a neat, logical and accessible manner, for	"Hard work and a lot of time spent searching. When searching for subjects is unsuccessful, I re-focus on the literature to establish the baseline of what is known about vocal mimicry and what functional explanations have been proposed to explain it. This helps me establish my introduction for my report and what questions might be answered by our study. And stops me from getting depressed that I cannot find enough birds … when one avenue fails, re-focus on something that I can get on with in the meantime" (Donald) "It is not just about having fun in the experiments but to do things in a disciplined way. I believe this is even more profound when you have a research grant. It is necessary to plan things out properly if you are spending a lot of your grant in that field project." (William) "I had prepared excel worksheets prior to results collection which gave me an outline of what I needed to do/collect. I think that had I not done that things would have been disorganised and the task would have taken longer." (Louise) "Not having scheduled hours for this course has meant that every week I have had to plan when to spend time on it. This	"I am not naturally good at doing small amounts of work regularly, over a sustained period of time. What I did with this analysis part of the project was essentially to wait until I was nervous that I was running out of time, and would be receiving an email from Andrew at any stage, and then spent 2 days and nights combing the data in depth." (Andrew) *While we know that students often work like this, explicit discussion and the development of intermediate goals and reporting could help this student manage his workload.* "… it is a very good idea, during the planning phase, to allow for experimental mishaps, or repeat experiments to confirm results, or simply for new experiments which become interesting over the course of the project, because they can serve to explain, or to investigate hypotheses that arise from experimental data. In future I will create a detailed experimental plan over the span of the whole research project (allowing for the fact that new experiments will appear of course)." (Edward) *The first half of this excerpt shows a promising*

	example grouping associated traits together, and copying relevant data onto new sheets when exploring particular traits." (Imogen) *In this excerpt, I relates her developing skills to the nature of her research activities.* "While I am enjoying the freedom and self-directed nature of work, I am also becoming acutely aware of the importance of effective time management, organization of materials, setting of deadlines and follow-up/reflection processes – all of which are critical in ensuring a steady transitionary flow from one phase of the research process to the next. I believe that as long as I keep all these in mind, I should be well prepared to tackle research at a higher level" (Matthew) *This excerpt shows a dual awareness of freedom and responsibility.* "… I spent far too much time reading and trying to understand thoroughly the resources I was using (for example, the approach used to calculate diffraction efficiencies). Although this will have some relevance to future courses, it was not an efficient use of my time, since these things were only peripheral to my project. I learned that in research it may be necessary to take certain results and techniques on faith since there can never be enough time to fully understand all of the results and techniques employed. Also, I realised that I far overcomplicated the selection of the output angle ... This emphasised to me that in experimental work there are some things that must be precise and some things that can just be "good enough", and it the two are confused time will be wasted trying to	has encouraged me to have a plan of when to do study for my other subjects, and my study schedule has become a lot less erratic than it used to be." (Kasey) "Planning ahead had allowed me to make a strategy for concentrating more that 15mL of solution in my concentrating tubes, but very good planning would have been to have ordered more 75mL tubes a few weeks prior to the beginning of the experiments." (Edward) "I need to pay more attention to detail when performing experiments, this mainly involves having to check off steps as they are completed and keep notes of the progress of the experiment. This is especially prevalent when only in the lab for 1 and a half days each week, where it can be easy to feel 'out of practice' with such long breaks between lab work. This also occurs due to preoccupations with other coursework." (Amber) *Each of these excerpts shows a focus on one aspect of project management – and, reflecting our data, that aspect tends to be the importance of planning. Whilst this is undoubtedly a good thing to learn, the sense that research can be a highly-regimented, controlled activity is probably a little misplaced.*	*recognition of the inevitability of the unexpected in research. However, E's response – to create ever more detailed plans – ix unlikely to be workable in the long run.* "… it is a severe drain on the amount of resources I can put into other subjects, and as someone who is looking to complete further study, this is a problem. My marks in other courses have most definitely suffered as a consequence of this research project" (James) *J clearly needs some advice on prioritisation – and perhaps his supervisor needs to become more aware of the impact the project is having on his other courses.* "I would have liked to have all my data by the end of last week but this was not possible as I was helping with processing of other plant samples … The problem of time was one that was frequently discussed with my supervisor and other members of the lab … It is all about making the most of the resources (in this case human hours) and prioritising the most urgent things" (Tom) *This rather sad case shows how T's participation in the communal activities of the lab is having a detrimental impact on his sense of progress. A restructuring of the project to embrace those activities, or a contract of reciprocal help, could be of benefit here.*

	perfect things that simply don't need to be perfected. If I had avoided these two mistakes … I would have achieved much more in my project." (David) *This excerpt shows D moving from his concrete experience to generalising about research, and then back to use this general insight to inform reflection on his own practice, before again generalising to research as a whole.*		
Designing an academically defensible approach	"Originally I thought that all the leg work is out in the field, but it's actually in all the prep. Once you have your field steps they don't change, but to get to that stage takes much consideration of how to test what you want to." (Amy) *This excerpt shows A drawing inferences from her own experience to research in general.* "This most recent, unexpected finding with the out-cross mice is an example of how complex and multifactorial the SNV calling process is. With this in mind and knowing what I know now, if I was doing this again my approach would be quite different: instead of starting with just one particular metric and looking for broad correlations across a large sample set, I would instead start with just a handful of samples and all of the data points, looking for relationships and correlations and then slowly growing the sample set." (Sam) *Not only does S propose a revised approach, he explains the type of evidence (relationships and correlations) he would look for.* "I have been curious about the light effect on the CEP peptide expression. Since we grow the Brachypodium under 20 hours daylight condition, I wonder if the daylight length might affect the actual CEP peptide	"We had a couple of meetings and have finally decided on our main aim and the experimental set up. Our aim was to investigate the behavioural displays of Jacky dragons in response to different sized intruders. 12 male Jacky dragons would be used as samples for this study. The enclosures that are holding the focal males would be our "stage". For the set up, we would be introducing an intruder of varying sizes in the enclosures. The focal male (also resident males) is exposed to "Same size" intruder and smaller intruder. Intruders are always kept in a separate tank (even when lowered in the enclosures) during the experiment to prevent physical contact between the lizards. We also made a blind in which we could observe behind during the experiment. The trials will be recorded with a video camera and observed at the same time." (William) *This articulate explanation of the adopted design does not consider any alternatives or potential problems.* "More generally I've learned that it may be worthwhile to experiment with existing protocols under some circumstances-for example when sectioning large 2-3 wk galls it may be useful to use slightly thicker agar (>3%) because these kind of galls are quite a bit thicker than	"is it possible to design novel experiments and projects that push the boundaries of what is already known and carry them out as an undergraduate, without instructions and with only some supervision? " (Harriet) *This excerpt shows a student who lacks the confidence to design her own approach.* "Since my supervisors had planned the majority of my project before I contacted them, I am still getting acquainted with all the background knowledge" (Hilary) *This excerpt suggests a lack of (perceived) opportunity to engage in or contribute to the design process.* "Problems included trying to determine wording and explanations for experiments which were designed. These did not follow any previously used protocol so diagrams and photographs are the best aid." (Laura) *Given the apparently novel experimental design adopted, this student could benefit by being asked to consider and evaluate possible alternatives.*

	expression. We won't compare the difference in this project because all the plants are treated under the same condition. It might be interesting to grow the brachypodium under different daylight length and compare the expression level of the CEP peptide. I have heard that the CEP peptide of the Meidcago truncatula can be affected by different daylight length by observing the roots development. It might be interesting to know if the daylight length also can effect the Brachypodium CEP peptide expression level." (Frances) *Here F is proposing an extension to the project based on a new question, explaining why the current project doesn't allow for that question to be answered but indicating an understanding of what **would** allow this.* "It is interesting that chiloglottone was found in high amounts in the sepals of C. seminuda; is it possible that if you remove the sepals, pollination will still occur? Or is it vital to the overall system? I think it would be interesting to remove certain parts of the floral tissues and see the 'success' of the remaining parts that produce chiloglottone, possibly to view the differences, or roles each part plays in attracting a pollinator, or if it is simply a system to which enough pheromone is produced (and concentrated in the appropriate place) such that the pollinator is attracted and pollen is transferred." (Ebony) *Here, E proposes a question, alternative hypotheses, and a direct test.*	uninfected roots and they often they just come out of the agar." (Louise) *While considering adapting existing protocols, this excerpt remains tightly focused on the task at hand.*	

Critical thinking (externally directed)	"Crystallization trials render one highly concerned with the most minute details of droplet composition. I wonder whether there are, or may be, significant effects on crystallisation behaviour arising from human-contributed vapours. We have a blanket ban on chlorine-based bleaches in our lab, due to the gradual perfusion of vapours into other experiments. How much might one's aftershave or the remnant fragrance of last night's garlic-heavy dinner contribute to the outcome of a crytallization trial? I'm aware that our noses can be quite sensitive, and that many smells are due to molecular concentrations in the few ppm range. Vapours in this concentration range, it would seem, would not be likely to have a significant effect, but perhaps there are human-borne vapours occurring in higher concentrations which might." (Charles) *Here, C uses his critical thinking about processes in the lab to generate new questions.* "I loved seeing the data take shape, becoming an answer to our hypothesis. And then thinking about why we got what we did, what does this mean? And then thinking off all the new questions this opens up. Sure we found that Brown thornbills appear to understand the calls they mimic, but why these calls? Is it because new holland alarms are more reliable? Do they only mimic alarm calls or do they mimic non-alarm calls too? And if so why? Are they useful for mixed species flocks during the winter? Or useful for interspecific territoriality? So many more questions!" (Amy) *Here, A uses her critical thinking about her results to*	"when you look at your results and consider what your next course of action will be, you are using your own critical analysis" (Hilary) *H recognises one form of critical thinking in science.* "I'm still not sure of what mistake I made, but it was a useful learning experience to have my error exposed by inconsistent data, which eventually lead me to recheck my calculations, and to find my mistake by glaring factual inconsistency" (Andrew) *Here, A has exercised some critical thinking in recognising his data were inconsistent.* "why we are using macrophage cell lines as opposed to another type, and if another cell type could be used? Especially since a during our second round of samples, some of the cells weren't looking too good, even though they hadn't been passaged many times. I wonder if a different type of cell may be more suitable?" (Hilary) *Here, H is starting to question the experimental design, but does not suggest any concrete alternatives.* "the bird strains incubated at 42C had significantly higher absorbencies after the 6 hours than the water isolates did. This finding was unexpected, and could be due to a number of possibilities. It could be that the bird strains are better able to utilise the substrates in the Luria Broth at the higher temperature, compared to the water strains, and thus are able grow more efficiently. It could also be that the water strains are forming biofilms on the sides of the well, reducing the number of cells suspended in the broth, consequently causing a lower absorbance" (Kasey) *Here, K explores various possible causes for an unexpected*	"Similarly another experiment was conducted where cyclohexamide (acts at protein levels) was added to the toxo parasites to inhibit the expression of ALAS and Ferrochelatase. Just as in the previous experiment same time points were used to add the drug to the parasites before harvesting. On doing a western blot it was seen that the ferrochelatase wasn't effected at all and ALAS gave some really unexpected results." (Norah) *This excerpt represents the end of a section in N's blog – showing that although she has encountered an unexpected result, she is not putting forward any possible explanations or thinking through the implications.* "I got the surprising result that cavitation threshold was around – 2.3 MPa. In saline conditions, other papers have shown that plants tend to increase the cavitation resistance, not decrease it. I have a long way to go." (Mark) *This excerpt shows M looking to published work as definitive/authoritative, rather than considering whether any differences in experiment or procedure could allow her results to be valid, even if different.*

	generate new questions. "From my experiences so far my previous views of research have changed to an extent. I always knew that conducting research is met with setbacks but you don't experience it really with other courses. In other courses the experiments you do are set, they have a known outcome, and there can be 80 odd people all doing the same thing, so you have more help along the way. But with this project I think that I have a better idea of how often things just don't go according to plan. You're always told that experiments don't necessarily work but when it comes to courses you only learn about what did work, not about what the scientist had to do until they found the right way to test something. It's often portrayed as 'this particular scientist went out and did a fantastic study straight off the bat' but what if it took them a few tries to find out what worked? While I always knew that there was plenty of trial and error I always had the impression that in most cases things just worked. So after the few setbacks of this project so far, this misconception is being rectified, I'm now seeing that shit happens and it's what you learn from it that matters." (Amy) *Here, A thinks critically about her experiences of research and makes inferences to research in general.* "Important take-home lesson for the week about science and research: be discerning about published results and compare different studies where possible! Two studies examining the same species of coral reef fish from the same location had notably different metabolic rate results. This came to our	*finding, but neither moves to evaluate their relative likelihood nor suggests ways of controlling for them.* "I spent almost all of second term attempting to digest, extract, ligate, precipitate this one construct, and the constant failure was I will admit disheartening. I learned how to think critically about the problems encountered and what possible methods could be used to resolve them" (Liz) *Here, although valuable lessons about critical thinking have evidently been learned, the experience has not been as positive as it could be.*	

	attention as the study with higher metabolic rates than expected contributed many data points in the graph exploring trends in metabolic rates in a range of temperatures. Ruling out differences in environmental conditions and population differences, we examined the methodologies of the studies – it appeared that one study rested the fish for far less time than the other. Measuring metabolic rates in fish involves transferring fish into an air tight chamber in order to account for the decreasing oxygen levels in the chamber (used as a proxy for oxygen consumption by fish and hence its metabolic rate). This process is stressful for the fish, and the fish needs to be rested in the chamber until it reaches a stable resting metabolic rate. When the fish is not given enough time to rest in the chamber, it is still stressed and the 'resting metabolic rate' taken will be a lot higher than its actual resting rate. The fish's maximum metabolic rate may also be affected consequently. As the methods section of a paper may be often overlooked, this experience has definitely made me more aware of the impact methodologies can have on the results obtained." (Imogen) *In this excerpt, I combines a rational, critical analysis of specific published research with a realisation that science and scientists are not infallible.* "I'm much more able to tell a good piece of literature from a 'bad' piece of literature. This may be for several reasons including that I have a much stronger understanding of the research areas and the writing structure and conclusion they make from the evidence they have. This is by no means		

	restricted to scientific research or university. Being able to identify a good piece of work from a bad one is crucial in understanding the validity of the arguments presented. These skills are beneficial now and will continue to benefit me later in life. " (Michael) *Here, M moves from his own experience to the idea that critical ability is a generally useful skill.* "At times this was challenging; to be able to distinguish between functional code and remnants, and to recognise code relevant for my purposes. It was difficult to understand both another person's methodology and terminology, especially combined with a limited knowledge of FORTRAN. To overcome this difficulty, I found the writing and testing of small, simple sections of code to be the most effective method, as they allowed the isolation of each problem. As a result, code could be broken down and understood in sections, rather than being overwhelming as a whole, an approach broadly applicable to any task." (Nadine) *Here we see N developing a general procedure for critical analysis.*		

Nugget 11: Successful URE Supervision from the Student Perspective

URE supervision is often a highly individual process, but is usually based on an apprenticeship model. Supervisors of URE students are generally trusted with the responsibility of designing a project, supervising its execution, providing advice on assessment and in some cases, specifying assessment. This contrasts with the processes of design of lecture courses where there are usually guidelines for the development and reporting of curriculum and assessment. A successful URE usually results from a fine balance between an authentic research experience and consideration of learning outcomes, especially when the URE provides credit towards a student's degree. The role of the supervisor is also critical in contributing to a positive experience for the student. The following supervisor checklist may be helpful in designing a project:

- What specific elements of research will the student engage in through their URE?
- What do I intend the student to learn from this URE?
- What activities/strategies can I put in place to assist the student to learn these things?
- How will I know they have learned these things?

Although different disciplines and different supervisory approaches result in enormous variability in UREs, the Learning Logbooks show some common themes in what students expect and value in their project and supervision. The logbooks have been used to develop some advice for supervisors, using student comments to illustrate the kinds of things that students want or appreciate.

1. **Design a project with clear goals and foster student ownership**

A good project is one with a clear and achievable goal. Students value feeling that it is their project or that they are trusted to make a contribution to the supervisor's research. If there are opportunities for your student to have input into the project design, make this clear and help your student to contribute. Where projects are highly technical and/or the student is contributing a small part to a larger project, ownership is not always evident. Different areas of research may allow different degrees of independence for students but in all cases, it is important to explain to your student their role and what you hope the project will achieve.

'I have learnt how to approach science in a more creative and open frame of mind. Considering portions of my project were based on my own curiosity and discussions with my supervisor, it has been nice to be able to act upon such initiatives and find success in the consequential results.'

'I also enjoyed being able to express and develop my thoughts about the topic with my supervisor, as I have never really been the type who participated much in class. I liked having ownership over a project and really have a sense of self accomplishment after completing it.'

2. **Encourage questioning and listen to your student**

Students may not have the background knowledge to understand the scope or detail of a research project. Expect your student to have lots of questions and be available to answer them. Ask them about what relevant courses they have taken and don't make assumptions about your student's knowledge. Encourage your student to question their own knowledge and assumptions. Students need to feel that it is OK to admit to ignorance and ask 'silly' questions. The project should be a positive learning experience for the student, in addition to a contribution towards your research.

' I also found that it was really important to ask my supervisor a lot of questions, both about things I knew I didn't understand and the things that I thought I did understand (often I didn't!) because it is very easy to make assumptions that seem to be perfectly reasonable, but turn to just be wrong. Having a number of relatively long one on one discussions seemed to be more productive in a lot of instances than just reading, a lesson which can be applied to learning in general and not just this research project.'

'As far as research goes, the meetings seem to be a good way for individuals to both share their work and get input from other members of the lab. My supervisor seems to be very good at asking just the right questions to help you figure out a problem yourself rather than just giving you an answer.'

'This situation also illustrated issues about assumed knowledge. Our supervisor thought we knew all there was to know about locating our subject, but we did not (although I thought we did!!!), and this would have made the experience less stressful had this conversation been conducted right from the start. This was simply a matter of each party thinking they know what was going on and not communicating effectively.

3. Be aware of your student's time commitments

Students commonly report that their project takes more time than any of their other courses, sometimes a lot more. Most are willing to commit more time because they value the opportunity to do a research project and most also develop a feeling of responsibility towards the supervisor and project. However, supervisors should be aware that students are usually doing other courses at the same time and do not have unlimited time to devote to the project (even if they would like to). Many students report that their time management skills improve as a result of juggling their project and other courses; supervisors can support the development of improved time management while not putting students under pressure to spend more time than that allocated to the project.

'This course has been a lot more work than I expected. Collecting the data always takes longer than anticipated. I think, given the nature of the course, it is always going to be more work than regular undergraduate courses. However, I knew it was going to be more work than other courses, and I knew it would be more intellectually stimulating.'

'The main obstacle I encountered was the amount of time it took to complete my experiments, and the amount of repetative work involved. At times this was very exhausting, and difficult to fit in around my other subjects. The only way to overcome this was to keep ontop of all my work, and to keep on going! Asking questions about the fastest and most efficient way to get things done was also very helpful.'

'The most difficult part of writing the report is the fact that I have to focus on other classes for such long periods of time. I want to be able to focus only on the report, but life is inconvenient.'

4. Be aware of when your student needs help

Supervisors need to remember that students are novices and may require help at many points throughout the project. Some key points where students appreciate assistance are:

- early in the project where they may feel overwhelmed by the need to master new approaches or techniques

'Since I will be doing things I have never done before, I'm expecting a very steep learning curve. I hope I don't annoy my supervisor too much with my lack of experience!'

'But is it possible to design novel experiments and projects that push the boundaries of what

is already known and carry them out as an undergraduate, without instructions and with only some supervision? Perhaps I'm merely overwhelmed by the technical and detailed knowledge required to carry out a single experiment and figure out what was wrong, how to interpret unexpected results, and how to work around any technical difficulties.'

- when data is first obtained. The steps required for presentation and interpretation of data may not be obvious to your student. Students often have the misconception that data should provide an immediate and clear answer to a question or may be unsure of what analysis is appropriate.

'However, I do now have (hopefully) both sets of data finalised! I'd really like to get the analysis done as soon as possible so I can get my results and start writing, but I haven't heard back from my supervisor yet. I'm so curious about what I've found! I'm also really anxious, though – what if there are more problems with the data?'

'Right now I have a lot of data, a lot of questions and a lot of possible approaches to test so I feel a bit overwhelmed. I also need to work on presenting the data in the best way to make sense of it. With this in mind, my next move will be to spend some time working out a strategy and checking it with my supervisor.'

'I have collected a lot of data – many, many numbers, and did not know how to compile these into a format that i could use for analysis. I spent a lot of time thinking about the best way to go about organising the data but was unable to come up with a solution.'

- when the project does not proceed according to plan. If the project does not proceed smoothly (which is, of course, very common), this needs to be normalized for the student so that they understand that it is not a personal failure but a normal part of research. Students value a supportive supervisor who helps them develop alternative approaches without putting them under pressure to achieve positive results. Supervisors also need to recognize that the project may not be completed because of the student's assessment deadlines.

'The extent to which lab members would discuss and even sometimes criticize each others' work made me realize what a supportive community I would be getting into. I have made some mistakes but have never gotten discouraged because my supervisor made it really seem part and parcel of the learning process. In fact, when my first experimental failure and bout of discouragement came about, his e-mail suggesting various potential BIOLOGICAL issues that might be at play really did inspire me to engage in troubleshooting, and do more background research.'

'So I have learned about the frustration of failure in research, and about how rather than struggle to explain these failures that could have occurred for any number of reasons, we just attempt it again. A significant number of consecutive failures can lead to results just as well as a significant number of successes, because there has to be a reason for something to fail, and sometimes these reasons are worth investigating.'

- during preparation of assessment items. The project contributes to the student's degree and many students want to do as well as possible. They therefore value assistance with producing the final report, seminar or other assessment items. Supervisors who read drafts and provide constructive advice for improvement are seen as the most helpful. Many students report realising the need for a better understanding/mastery of various generic skills such as time management, writing or statistics. Supervisors who support the development of these skills are appreciated.

'Last week I submitted my 1000 word skeletal report to my supervisor. I got some feedback on this report and made note of the key points made. The feedback that I recieved from my supervisor will definitely make my final product better. I will now start to work on my poster for the unit and will be sure to include the feedback that was given to me.'

'In general, my main questions can be summarised as – 'does this graph look right to you/does this sentence make sense?', but I want to get to a position where I have completed more of the report before I start asking such specific questions; I still have a lot of other areas I can focus on. I am particularly concerned about the phrasing in my report, as I want to make sure I am clearly conveying my meaning, but do not always know the correct words to do so.'

'I would like to feel more confident performing tasks associated with research such as literature searches, running statistics and writing a scientific report…..'

'I also didn't expect to have such useful feedback from [my supervisor], I've probably only had feedback on drafts etc. in half of my research project ASCs. …… I was really quite happy with my ASC report in the end and I'm sure it had a lot to do with being given lots of writing support and ample time to do it in.'

5. **Help your student understand the excitement of authentic research and to feel part of the team**

Students value supervisors who take the time to explain the overall goals of the research and the part that the student's project plays. The opportunity to do 'real' research as opposed to the somewhat artificial situation of undergraduate laboratory exercises is seen as inspiring by most students. They enjoy feeling that they are discovering something completely new, or at least contributing to a discovery. Although many projects require substantial time devoted to necessarily repetitious activities, you can help your student see how this contributes to the direction of your research. Students also enjoy feeling that they are part of a team working towards a common goal but may need guidance to understand their role. They value the experience of a collaborative environment, which may be an unexpected outcome of the project for them.

'Their [the supervisors'] willingness and apparent enjoyment in interacting with us and passing on their experience and knowledge is motivating, and makes the work so much more enjoyable because you feel that you are contributing to their work; building on their research at the same time as learning, rather than coming in as some inexperienced student and distracting them from important work.'

'Discussing the steps to do next with my supervisor was one of the important activities that helped me make progress. Doing so allowed me to have a clear idea of where the project is heading and I had less doubts during the steps in the protocol. Any questions I had were answered and my supervisor also gets to know which step I am on and whether I need any help.'

'I really didn't expect to feel so included in the group, and so supported by all of my supervisors. I also feel especially lucky hearing that this wasn't a universal experience from other students, although this actually just made me feel even more indebted to the people in my lab.'

6. **Make links to theory/methods discussed in courses your student is doing and show how your research applies them**

Students often enjoy using techniques and approaches they have heard about in other courses and appreciate the opportunity to develop a greater understanding of where information heard about in lectures actually comes from. Some report that they learn better with hands on experience rather than simply hearing the theory in lectures and others report they value the generic skills fostered by their research experience. While many students make these links themselves, supervisors could also discuss with students how the project or the methods chosen relate to their other courses.

'To be honest, this project has exposed me to many first hands-on experiences, one example is with bioinformatics, which I haven't been able to work on in 'classroom bioinformatics' courses. Previously, we could only see lecturers putting up slides with gene annotations, contigs and scaffolds, but this time I actually get to 'be' the person annotating genes and knowing how it actually works!'

'This is linking back very nicely with the Infection and Immunity course I am currently doing as some of the topics we have covered in class are crucial to my research project. It is also very interesting to see some real world applications to the techniques being discussed in class along with being able to apply the general laboratory techniques learned in lab classes to something other than set up practicals.'

Nugget 12: Value of Learning Logbooks to Supervisors and Convenors

Learning Logbooks will only be more widely adopted if supervisors and course convenors perceive them as valuable for themselves and/or their students. An important component of the TREASURE project was interviewing supervisors and convenors after the experience to gain their perspectives.

One way in which Learning Logbooks might enhance learning is through timely supervisor or convenor feedback that results from reading the logbook. We saw different responses to the Learning Logbooks from URE supervisors and convenors of courses with embedded research components. As noted in the main report, very few URE supervisors accessed their student's logbook during the semester. However, many students did express considerable uncertainty, for example, about the direction of the project, the appropriate methods of analysis or the meaning of unexpected results. While many also record discussing such issues with their supervisor already, this was not always the case. Several supervisors (including those who felt they communicated well with their students) noted surprise at the logbooks as it gave them a different perspective on their student's thinking or made them more aware of differences between their expectations and those of their student. The quotes below are from interviews with supervisors whose students used Learning Logbooks.

'It was actually helpful in a couple of cases where they wrote things in here that I wasn't aware of as to what types of things they were finding difficult and what types of things they were just really happy with.'

'I think with the frustration I would have picked that up …….. I would have brought something, just an anecdote of - just to highlight how often that happens and that this is not necessarily a reflection of that project or a reflection of the student's failure, that's just the nature of the beast.'

'I guess what it made me realise was that she was actually enjoying doing the project, which she didn't verbalise to me. What she says was more like, I'm freaking out about having to do this experiment but then on the blog there was a different kind of reflection. I don't know if that was put on or what, which was the genuine bit. So, I think it did shed light on things that weren't necessarily obvious from having spoken to her.'

These responses suggest that many URE supervisors could benefit from seeing their student's less formal thoughts recorded in the logbooks. A second way in which Learning Logbooks might enhance learning is by allowing supervisors recognize issues that are difficult for students and change the design of future projects to provide better scaffolding for the desired learning. The two supervisors quoted below reflect on how they might alter their supervisory practice as a result of reading logbooks.

'I felt in hindsight that maybe I didn't do such a good job of just letting him know my expectations and what you get out of these undergraduate projects ….. the useful thing is for them to write it for themselves because it makes them reflect on what they've learnt. For me it's useful reading it after the fact because I can think a bit more carefully about how I might modify the course in the future.'

'You know if I have another student doing this again, I don't know, I might approach it differently. You know if the first instalment had come in, I might read it and have a chat with him about it which perhaps would enhance the reflective value of the exercise.'

However, other supervisors were much less open to the idea of using input from students in

the design of the project or in their interactions with them as shown with this quote.

'I think that's [the logbook] more or less what you would expect from what I saw in her. So it was okay, I don't care much about that. Because we do what we do, no matter what she says and what she thinks, we're not going to change our attitude, we have our objectives, we're doing fine, and students generally are quite happy. So if there are students who are not, that's that student's problem, not ours, we don't have this sort of an issue.'

Continued use of Learning Logbooks is likely to increase supervisor familiarity with the potential benefits. In the TREASURE project, most supervisors experienced the logbook only once. If the logbooks became a routine assessment component, supervisors may be more likely to access them. As an alternative approach, we have produced a guide for URE supervisors (Nugget 11), based on students' reports of difficulties they experienced, indicating likely points during the project where intervention by the supervisor can be especially beneficial.

Convenors of courses with embedded research components showed better engagement with Learning Logbooks during the semester. In two courses, especially, convenors reported that the logbooks were a valuable way for them to keep in touch with the progress of students as they did their projects in addition to helping the students themselves. Both courses participated for the first time in the final semester of the project and both convenors felt that they could have used Learning Logbooks to respond to issues raised by students more effectively, as shown by these quotes.

'Anyway, the logbooks let me understand their thinking process more. In many ways it might have been more useful to me than it was to them. Having said that, I think I could have integrated the logbooks more into our learning throughout the semester. So I kind of just ignored it for long periods of time and then - just purely time. When I did look at them I thought, oh, bloody hell, I wish I'd looked at this two weeks earlier so I could have responded to that more effectively.'

'I mean part of the reason I'm thinking about this is because a few weeks in, one person said, look I'm struggling with the readings, could we have a discussion about them in class every week. Great idea, let's do that. …….. because it doesn't take long to have a quick eyeball of them [the Learning Logbooks]. Write a few notes on some of the kind of key themes that have come up. Then take that to class - 15 minutes to just like oh I noted it was really interesting, someone mentioned this and someone mentioned that and what do you think?'

These quotes show that both convenors found the logbooks useful as a way of monitoring progress of the class and identifying potential problems. However, one class had 80 students, making regular reading of logbook entries a significant time commitment for the convenor. Both convenors also felt that the logbooks helped their students, for example,

'I think logbooks are useful as a sort of stepping stone through making sense of that first assessment task coming back in and thinking about what they had learnt. So it did help them in that sort of processing of feedback.'

The context of a course with a single convenor managing the research experiences for many students is quite different from an apprentice-style URE. In this environment, it may be useful to better integrate logbooks into the course through provision of class-level feedback as suggested by both convenors. An alternative approach could be to use shared, rather than private, logbooks which would allow students to recognize shared issues and problems. Use of similar learning logbooks in a manner that mediated a shared dialogue between the teacher and the students was found to support learning and the development of a community of learners in an advanced physics class (Audet et al, 1996). However, if Learning Logbooks were not private, students may be less open about difficulties they are experiencing. Decisions about access and the nature of the questions included in the PQF will need to take into account the various factors relating to provision of feedback, privacy

and assessment to best support desired learning outcomes.

One lesson emerging from these interviews is that use of Learning Logbooks was a learning experience for supervisors and convenors. Most who were interviewed did agree that they had learned something about their student and/or their supervisory practice by reading their student's logbook, even if this occurred only at the end of semester. URE supervisors who participated in a second round of Learning Logbooks were more likely to access them the second time. These considerations suggest that lack of familiarity with Learning Logbooks is a factor inhibiting their more widespread adoption. This is potentially difficult to address as it can lead to a Catch 22 situation; staff won't adopt something new because they don't see it has value but they only recognize the value as a result of experiencing it. Without the project team to identify and support champions who were prepared to trial Learning Logbooks, more widespread adoption could be difficult.

References

Audet, R., Hickman, P., and Dobrynina, G. (1996). "Learning logs: A classroom practice for enhancing scientific sense making." *Journal of Research in Science Teaching*, 33, 205-222.

Nugget 13: Case Study of the Implementation of the Prompt Question Framework in a Biology Course

A research projects course in biology is presented as a case study. This course used Learning Logbooks as part of the assessment for three consecutive semesters during the project and a number of supervisors involved have been interviewed. Feedback from this course was instrumental in changes to the PQF and in understanding the factors involved in introducing and supporting the use of Learning Logbooks.

Context
BIOL3208 was a new course, replacing two separate research project courses existing in biology at this institution. As a result of this merger, the new course had a new convenor and a review of the assessment was undertaken. The course operates on a typical URE model, with students enrolling in the course after negotiating a semester-long project with a supervisor. The course is equivalent to a normal lecture course and provides common assessment although the students work independently of each other. In both courses contributing to the merger, a major component of the assessment was a report modeled on a scientific paper. However, there was diversity in other assessment components, for example oral presentations, literature reviews and lab or field notebooks.

During the review of assessment, the introduction of Learning Logbooks was discussed with the convenor and head of Biology Teaching and Learning and it was agreed that they would be trialled for one semester, with an option to continue if they were found to be useful. It was also agreed that a short reflective piece in which students reflected on their learning during their project would be introduced as a component of the assessment in this course. This was to be submitted with the final report. Completion of the Learning Logbook contributed 5% to the overall assessment (1% simply for doing each post, provided that questions were answered). The final reflective piece was not marked separately but completing it to an adequate standard was a course requirement.

As a result of the initial trial, Learning Logbooks and the final reflective piece have been permanently integrated into the assessment for BIOL3208.

Guidelines for students taken from the BIOL3208 course outline
Guidelines on blog entries
You will be given 3-4 prompt questions every 2 weeks for the first 10 weeks of semester. You should respond to these using the blog set up on the BIOL3208 wattle site. How much you write is up to you; we just want to encourage you to keep track of the bigger picture as a contrast to the fairly specific focus of your research project. The aim of this exercise is to help you understand the structure of your project and what you are learning from the experience. It may be helpful to review your earlier entries before responding each fortnight.

Sample blog questions
What did you do on your project during the last fortnight? Have you made progress?
How have the activities that you undertook this week helped you address your research question?

The reflection section of the project report (500-700 words)
The purpose of this section of the report is for you to identify what you have learned about doing research. You should not simply describe what you have done but critically assess how undertaking this project has contributed to your ideas about what biological research is and how it is done. This section is about your opinions so there is no right or wrong answer and you do not need to write in formal scientific language. You do, however, need to provide evidence for the opinions that you express. For example, if your views of research have

changed over the semester: why, and what experiences led to the change? How was your experience of research different from lab or field work in other courses, and what specifically helped you see the differences? What did you learn about the limitations of research in your area and what does this mean for science as a whole? Your blog entries should be helpful as a starting point for this part of the report.

This section of the report will be assessed on how clearly you explain your opinions and the reasons you hold them. We would like to see you using your experiences this semester to make some more general statements about how you see scientific progress occurring.

Evolution of the PQF

The initial prompt questions were developed in conjunction with supervisors at a workshop at this institution. Attendees came from across the sciences, including some from biology. Following finalization of the PQF, the questions were introduced into BIOL3208 (and three other courses) as the first trial of Learning Logbooks. Our initial philosophy was to introduce a range of questions prompting different degrees of reflectivity in the answers. Some questions were more factual as it was hoped the range of questions would eventually lead to increasing levels of reflection as students became familiar with the idea of writing about their projects. For example, the initial PQF included these questions:

- What did you do on your research project since your last post?
- Have you made progress on your research project since your last post?
- If so, what allowed you to make progress?
- What kind of activities did you engage in that helped you make progress?
- How have your recent activities contributed to your research project?

These questions, in various ways, all address the same issue – what has been done – but are framed in different ways to prompt different degrees of reflection or a different focus. However, after two semesters the first question was dropped as responses to this question were, in general, not reflective at all and students were willing to answer all three questions. It was observed in the BIOL3208 responses that students who were less reflective regularly answered the first question, often with extended answers detailing specific procedures they were using. These blogs tended to remain unreflective and we felt that the tone of the first question may have discouraged a reflective approach. However, removing the first question from the PQF from the final semester of the trial had little effect on the overall level of reflection in the Learning Logbooks. Using the same questions in different courses (both using Learning Logbooks for the first time) resulted in sophisticated reflection in one course and a lower level of reflection in the other. Although the number of participants is small, this suggests that the tone of the questions is not the major factor in determining the level of reflection.

One factor that is worth investigating further is the influence of the type of project on the level of reflection. As an initial generalization, we observed that projects where students are required to use their own judgment early (eg some field projects in BIOL3208 and social science projects in other courses) led to more reflective blogs whereas those that are highly technical (eg molecular biology) and require students to master complex techniques led to a greater procedural focus. The procedural focus tended to be incompatible with higher level reflection as blogs were largely descriptive and concentrated on achieving technical proficiency, obtaining results and troubleshooting. More technical projects may require different questions, more explicit expectations for reflection or more information for supervisors to generate more reflective responses.

Another change to the PQF was made following experiences with the final post questions in the first semester of the trial. Initially we asked,

- What have you learned from undertaking this research project?

This elicited a range of responses but some were simply lists of techniques or methods of analysis mastered. This may have been a result of students interpreting the question as

referring directly to this type of learning. Indeed, one student wrote, '*I'm not sure whether this refers to specific learning relating to my project or more general learning from doing the research project course…*' and then answered the question on specific learning only. In addition, the question of learning was discussed at a supervisor workshop, with the general feeling that the PQF should also include a question on skills developed. We did not want to prompt students by identifying generic skills as we wanted to determine how they saw that they had developed. As a result, in the second semester Learning Logbooks were used, we added the following question to prompt students to tell us about a range of different types of learning.

- What skills do you think you have developed or strengthened through your research project/course?

The two questions were not seen as clearly distinct, with different students interpreting 'learning' and 'skills' differently. In spite of this, having both questions did appear to result in a greater range of generic skills being reported in final posts. It was common for students to answer both questions with a mix of specific and generic learning. It is possible that having both questions with their different wording prompted students to think more broadly about their learning even if they didn't separate their answers into distinct categories.

Further questions were added or changed in response to subsequent supervisor workshops (which included some supervisors who had participated in the BIOL3208 Learning Logbook trials). These addressed new issues that workshop participants felt were important such as confidence in results and the nature of collaboration. All questions were answered at least once although the frequency that different questions were answered varied. This suggests that the PQF in its current form covers a range of issues that are relevant to students doing research projects.

Student learning

The three semesters of BIOL3208 provides a cohort of 42 Learning Logbooks for analysis of what students write and the different types of learning that is visible in their logbooks. The Learning Logbooks provide evidence that most students demonstrate higher order thinking skills during their project. These might include critical analysis of some aspect of their project, an understanding of the nature of scientific research, discussion of uncertainty, creativity in their approach, for example. However, about one third of the participating students completed their logbook unreflectively, providing descriptions of what they had done during their project in response to a range of different questions. Despite this, most included (often only in the final post) evidence of some development in understanding the research process, in particular, how it differed from their experience of laboratory classes in normal courses. In response to last post questions about what they had learned during their project, 20% responded by listing techniques and experimental approaches without including any higher order skills. The remaining 80% identified a range of generic skills and/or demonstrated understanding of the nature of scientific research, often in addition to technical achievements.

The Learning Logbooks also demonstrated some success in prompting (or at least making visible) metacognition, with around one third of students reflecting on their own learning, particularly their weaknesses or strengths. A major issue was time management, with many reflecting on the need to improve their time management or the importance of being organized to both manage a research project and to combine a research project with other courses. The small number of students who provided feedback on using Learning Logbooks noted that keeping the logbook was helpful in understanding either their project or their own learning.

Supervisor responses

Introduction of Learning Logbooks by a convenor in a course of this type, which involves multiple supervisors proved an effective mechanism to provide experience in using Learning Logbooks. Initially, not all supervisors were supportive, some perhaps seeing the logbooks

as taking time away from the project while others felt that they communicated well with their student and did not need the logbook. However, by the end of semester, some initially reluctant supervisors had seen value in the Learning Logbooks and were more supportive. While supervisors had access to their student's logbook, most first time users did not use this access. At the end of semester, supervisors were sent their student's posts by email. Most read the posts and in interviews, were quite positive about the experience, finding that they appreciated their student's learning better. Several felt they would be better able to support future students as a result of having this window into their student's thinking. In subsequent semesters, supervisors who had had experience of Learning Logbooks were more likely to check their student's posts during the semester, seeing it as an additional and effective mechanism of communication with their student.

The experience with this course suggests that it is worthwhile introducing Learning Logbooks, even if not all supervisors are supportive, as the experience of using them generally overcomes negative first impressions.

In the broader context, Learning Logbooks can also be used to provide evidence of particular types of learning, for example, generic skills. Many students mentioned development in communication skills, problem solving, time management, quantitative analysis, literature reading and analysis (or at least recognition that these were important).

Factors contributing to the success of Learning Logbooks in BIOL3208

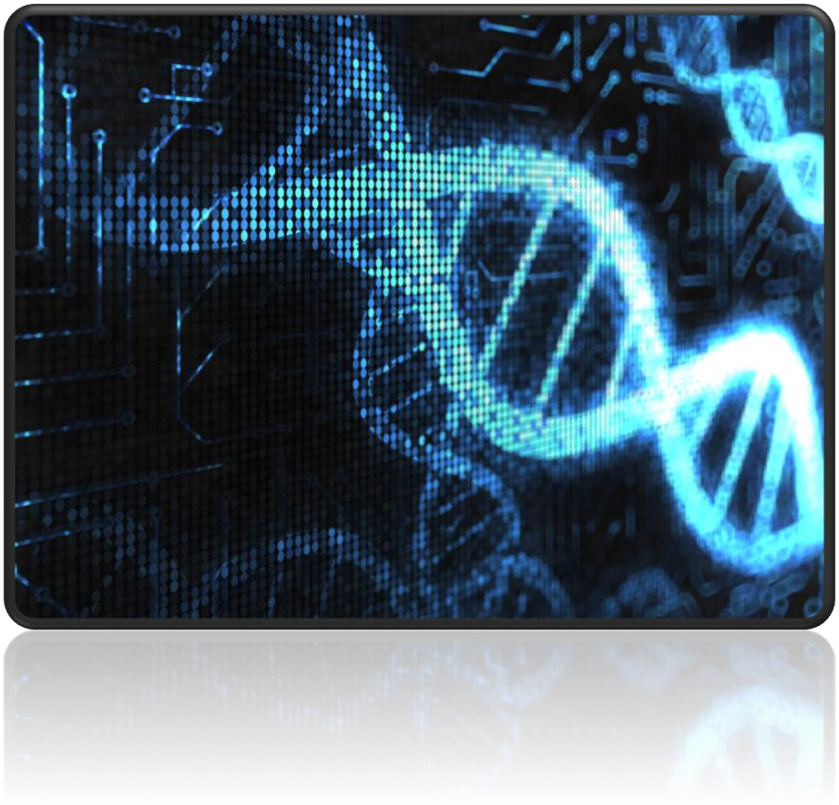
Familiarity. One of the project leaders was in the same department as the BIOL3208 convenor and was also known to most of the students through having taught them in earlier year courses. She introduced the project at the beginning of the first semester of the trial, ensuring that the convenor and students were familiar with the aims and approaches being used.

Support of the convenor. Following the first semester trial, the convenor was highly supportive of retaining Learning Logbooks in the course. She (like the project leaders) hoped that students would learn more than just content in their research area and was keen to support mechanisms to ensure this. She found that the logbook entries were useful in extending the learning of students undertaking projects and therefore became an advocate for the Learning Logbooks after the first semester.

Assessment of logbooks. In comparison with another course in the first semester trial in which Learning Logbooks were optional, there was a much higher completion rate in BIOL3208 with more than 90% of the students completing all five posts. In contrast, in courses where logbooks were not assessed, only 30% of students voluntarily undertook to use a logbook and of these only 31% managed to complete five posts, with many of the students not directly addressing prompt questions.

Student support. Feedback from students was generally positive. While there were initially some complaints about having one extra piece of assessment, an unanticipated benefit of the logbook was that students found it an effective mechanism for monitoring their own thinking and progress. Having to answer questions regularly helped ensure that they did not neglect the project because of assessment in other courses. Some students also found it helpful to reflect on their own learning.

Nugget 14: Sample Learning Logbook Guide for Students



A TREASURE (Teaching research — evaluation & assessment strategies for undergraduate research experiences) Project Resource Booklet

Course X: Learning Logbook Guide

TREASURE Project Resource Booklet

Produced: 2014

Learning Logbooks are part of a cross-institutional education project between the University of Western Sydney, the Australian National University, and the University of Canberra. The project has an acronym—TREASURE (Teaching Research: Evaluation and Assessment Strategies for Undergraduate Research Experiences) and aims to improve learning in undergraduate research projects. It is funded by the Office of Learning and Teaching. You can contact Susan Howitt about the project or about information in this booklet on: susan.howitt@anu.edu.au or on 02 6125 4356.

Content

Introduction

This is a resource booklet to help you hit the ground running using a Learning Logbook in your research project this semester.

You will be reflecting on the progress of your research and the logbook is the place to record and reflect on your experiences.

Your Learning Logbook is hosted by TREASURE (Teaching research - evaluation & assessment strategies for undergraduate research experiences), an educational research project involving three universities the Australian National University, the University of Western Sydney and the University of Canberra. It is funded by the Office of Learning and Teaching and runs between 2012 – 2014.

The logbooks are powered by the *WordPress* system and hosted by *edublogs Campus*.

What is a logbook?

The Learning Logbook is an online tool to assist you to think and practise as a researcher. Being an online resource you able to access your logbook from wherever you like, at any time that suits you. During your research project or course this semester you are to write posts at regular intervals about how your project or course is progressing and what you are understanding about research in your discipline. The purpose of the logbook and the prompt questions is to guide a deeper engagement with research thinking and processes.

Learning Logbooks can help you:

- identify problems you weren't aware of;
- see patterns that you hadn't noticed before;
- avoid repeating mistakes; and
- make sense of the research task and culture you are part of.

Logbooks & learning

For many of you, this will be the first time you have kept a logbook that asks you to write about your own learning activities. The core benefits of them for your practice are in areas of observation, reflection, understanding, conceptual development and critical thinking. All of these are important skills for researchers in any discipline to develop.

Observation and awareness

The practice of keeping a logbook can help you to identify and focus on the significant aspects of your research project. Regular logbook entries assist in surfacing beliefs, thoughts, feelings and processes, (of which you might otherwise be unaware) and to evaluate what you have been doing, why you did it, and what effect it had in terms of your project.

Clarification and understanding

Having to articulate your ideas and opinions can help clarify what they are. By writing your thoughts down in your logbook, you are also formalizing them, and consolidating the different experiences that have shaped those ideas.

Review and reflection

As a record of your research activities and observations a logbook helps you to review and evaluate your experiences over a timespan. It means that you can give deeper consideration to things you would otherwise let pass and think about what you could do differently or change.

Critical thinking

The logbook is a space to question and challenge accepted practice—particularly if you are recording your reactions to research findings, experimental design, research techniques and methods or data collection and analysis. The logbook provides an opportunity to think critically about:

- your project progress (what is going to plan, what isn't); and
- what you are learning from this experience.

Making connections

The logbook is also an opportunity to make connections between theory and practice. You can record in it any connections you see between and across disciplines, and between your project and other coursework.

Challenges in keeping a logbook

Students report that a common difficulty with keeping logbooks is **time** – simply finding the time to write regular, meaningful entries when you are busy with study, work, and life or because you just feel that you want to get on with the project itself!

Writing an entry at the end of a long day can be unappealing and there is always the temptation to put it off until you're feeling up to it. However, postponing writing means you are likely to forget important aspects of the experience you were going to record. One way to deal with this is to set yourself a specific time —like every Monday at 8am – and try to stick to it, or do it around a specific activity like your meeting with your supervisor. Writing a logbook entry can be pretty quick—it will vary depending on the issue you are writing about.

Another common issue is finding the motivation and self-discipline to keep the logbook going. That's why there are set deadlines for submitting the required posts—just to keep you on track with making regular entries. If you find yourself lacking in motivation, try discussing your posts with other students, your supervisor, or with your course convenor.

Logbooks & writing

Writing

Logbook keeping is very much a matter of personal style and it is a more informal writing style than a report or a journal article. As a guided reflection on your literature review it requires you to consider what it means to think and act like a researcher. You are encouraged to go beyond a description of 'what I did' in the postings—to explore what you know or are learning about doing research, It may be helpful to review your earlier entries before responding to each subsequent post. We are looking for evidence in your posts of how you:

- interrogate your own research experience;
- understand the motivations for performing research;
- connect your research experiences to future situations; and
- link your research experiences to personal strengths or weaknesses.

We do know that it can be hard to begin being writing when facing a blank screen. However the prompt questions are there to guide each of the posts you are required to make throughout the semester. You can of course go beyond the supplied prompt questions both in terms of answering additional questions if you wish and generating more of your own.

Viewing

You are the administrator of your site so you can decide if you want to allow any other people to read or comment on your entries. The default for all logbooks is that no one but you, the course convenor, your supervisor and a Treasure educational support person (in case you need assistance) have access.

Your supervisor, as a subscriber to your logbook, can, if they choose to, see your postings and make comments. It may be that some supervisors are too busy to do this, or are not familiar with online logbooks. In the past some students have printed out copies of their posts to take along to meetings with their supervisors, as a useful base to start discussing issues in their project.

Questions

Here are each of the question sets that you have been asked to use for the five postings in your logbooks.

First Post Questions
In your first post please respond to all four of these questions:

1. Why have you chosen to do a research project and what are you expecting to get out of it?
2. Have you undertaken a research project previously? If so, describe it.
3. What are you expecting to be different in this project experience from your normal course work?
4. What skills do you think you need to be a good researcher?

The Question Bank
In framing your second, third and fourth logbook posts here are the questions that we would like you to select from:

- How have your recent activities helped you address your research question?
- Have you made progress in the last fortnight?
  - If so, what allowed you to make progress?
  - What kind of activities did you engage in that helped you make progress?
- Problems and obstacles are a normal part of research. Did you encounter any?
  - If so, what made them problems?
  - How did you go about solving them?
  - What would have helped you overcome them?
- What might you have done differently if you had known two weeks ago what you know now?
- Has your research question changed? If so, why, and what has it changed to?
- Have you found/learned anything unexpected? Explain.
- Has anything you've learned shifted the focus or aims of your project? How?
- How confident are you in drawing any conclusions from your observations or results? Why?
- How have you chosen the approach or methods that you are using for your project?
- What are the connections between your research activities and your other studies?
- Can you see ways in which you could apply what you have learned to other activities, in or out of university? How?
- What have you learned about your project topic, science or research more generally?
- What have you learned about yourself from doing this project?
- Has your view of what research is changed from your project experience? Explain how.

Last Post Questions

In your last post please respond to all four of these questions:

1. Has your research project/course met your expectations? Why/why not?
2. What have you learned from undertaking this research project?
3. Would you do another research project if you had the opportunity? Why/why not?
4. What skills do you think you developed or strengthened through your research project?

Logbooks & assessment

As part of this course you will be required to regularly reflect on your experiences of research through online postings in your learning logbook. Here is an outline of the task:

Your task involves answering questions that will help you articulate your understanding of research and how disciplinary knowledge progresses. You will be required to make 5 posts, answering 3+ questions for each post. Questions for the first and last post will relate to your expectations for this course and your overall experiences, while those for the three middle posts will be about your research project/activity. For middle posts, you may choose any 3 questions from the Question Bank and they do not have to be the same ones for each post.

In summary the reflection task is worth 5% for this course.

Task	Task requirement	Due date	% of mark
Post 1	Respond to 1st Post Questions	? by 12 midnight	1%
Post 2	Respond 3 questions from Question Bank	? by 12 midnight	1%
Post 3	Respond 3 questions from Question Bank	? by 12 midnight	1%
Post 4	Respond 3 questions from Question Bank	? by 12 midnight	1%
Post 5	Respond to Last Post Questions	? by 12 midnight	1%

Note: No word limit for regular logbook postings but do expect at least a paragraph per post.

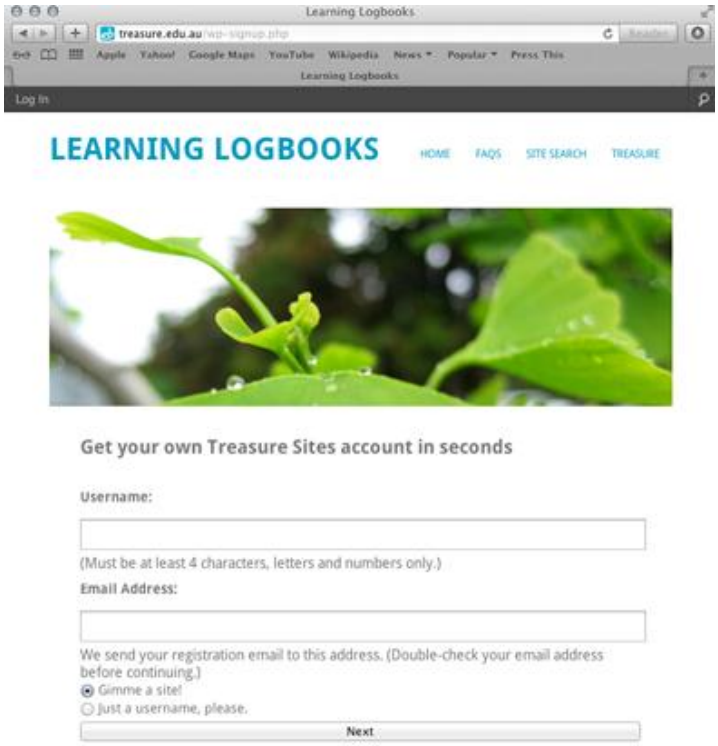
Your Learning Logbook will be marked by the Course Convenor.

How to 'drive' your logbook

Logging on to your logbook

To get into your logbook, you need first to have one, so if you haven't done so already please go to the sign-up page to create your own Learning Logbook, which is here: http://treasure.edu.au/wp-signup.php

This is what the sign-up page that you land on looks like:



Page 1: On this page you need to do two things:

1. Create your own user name
2. Enter your university email address (it needs to be your university account, because that is the domain that is recognised by our educational host, for security reasons)

Make sure the *Gimme a site radio* button is selected.
Then click on the **Next** button.

Page 2: You will be taken to a second page and will need to:

1. Fill in a site name for your Learning Logbook that becomes your own URL: http://treasure.edu.au/[your name for site]
2. Add a title for your logbook (this will appear in the header banner for your logbook).
3. After that choose the correct template for your Learning Logbook, based on your course code, SCOM3003 (you can't change this, so be careful).
4. Choose a blog category for your logbook again yours will be: anuscom3003
5. Then submit.

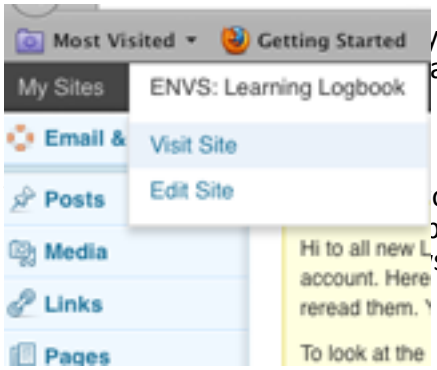
Shortly after this via your email you will receive your login instructions for your site…(its pretty quick). You will be required to click the link in this email to confirm your email in the blog system.

If you are experiencing any difficulties in getting into a logbook please check that you are using the correct username and password, if that fails contact email: treasure@anu.edu.au

The Dashboard

This is the working section of your Learning Logbook, it's where you post (write entries into your logbook). You can also add Pages, which will appear across the top of your logbook, or make Comments on Posts you have already made. Here too you can change the theme (that is the look of logbook), to something you prefer! The left hand navigation bar has the tools you need to make content and control how it appears!

The middle section of your Dashboard shows, when first open, a summary of your logbook



you use any of the available tools it will switch to whatever
a comment, or theme options.

ou logbook, on your Dashboard go to the horizontal bar
oard, hover over the name of your Learning Logbook and
s you can see your postings and all the information pages

Posts, pages & comments

The Learning Logbooks are composed of two main structures: Posts and Pages. Newbies to logbooks often struggle with the difference between posts and pages. Here's the lowdown:

Posts
These are the dynamic content of your logbook and usually contain the regular thought stream content of your logbook, In this course the posts will correspond with the tasks that have been set for each post.

Posts are commonly displayed in reverse chronological order with the most recent post at the top of the page. Usually most of the content published on a logbook/blog is normally written as Posts as this is the core, evolving information you want to share or reflect on. Your post 'trail' is a record of your shifts in thinking and learning over the unit. The logbook displays your most recent post, front and centre on the homepage of your logbook.

Pages
In contrast pages in learning logbooks are used for information that is more static, and in the case of the logbooks there are a number pages that we have created to provide you with information about logging. You can add your own pages, if there is information that your want to refer to on an ongoing basis. Pages are the tabbed content you see across the top or down the side of your published logbook (they might change position if you choose a different theme).

Comments
Now comments are there for you make comment on any page or post you have made, and to allow any invited users to comment on your postings if you so desire.

If you want to refer to a summary of the key differences between pages and posts then go to this URL here. http://help.edublogs.org/2009/08/01/the-differences-between-posts-and-pages/

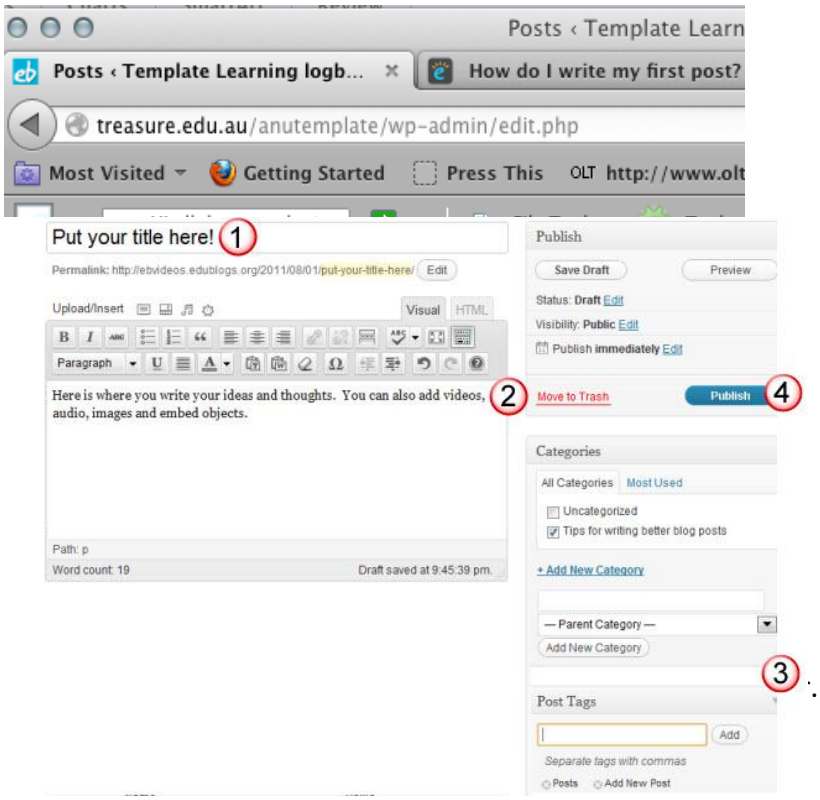
If you want more information on comments go here:
http://help.edublogs.org/2009/07/31/engaging-with-readers-through-comments/

Making a post

Publishing a new post is as simple as:

1. Go to your **Dashboard** and click on the **Posts** link in the left hand menu.

2. Go to **Posts > Add New.**



4. When finished writing click **Publish.**
You can preview your post before publishing by following these instructions.

*5. Be warned that previewing doesn't mean that you have saved that post, you must click **Save as a draft** or **Publish** for your post to save.*

Personal settings

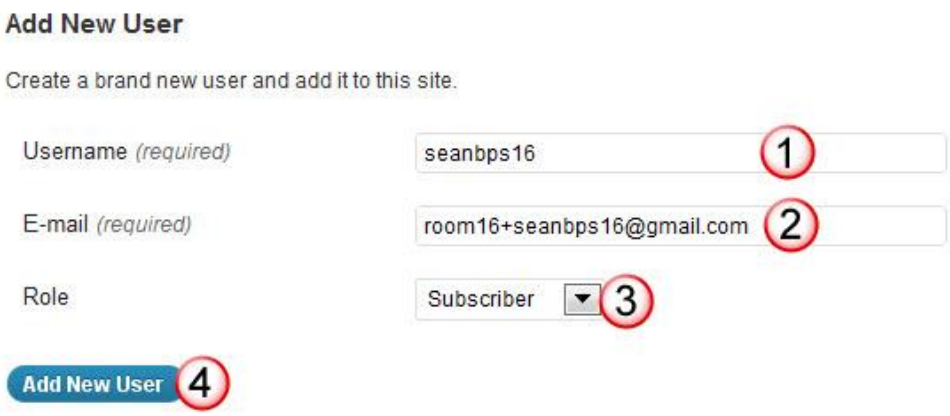
Personal settings offers a way of customising your logbook information to suit your needs and preferences. You reach your user profile through the logbook Dashboard via the **Users > Your Profile or Profile > Your Profile** menu option. This is the area in which you can change or update your display name, password, and display of some tools you use such as Visual Editor.

Remember to click **Update Profile** after making any changes on Your Profile screen. Go here for more info: http://help.edublogs.org/2009/08/25/changing-your-
-profile/

have a research supervisor they will need to have access to your
der to read any postings, if they so desire. So one of you first tasks
as a New User into your Learning Logbook.

and click on the **Users** link in the left hand menu.

2. Click on **Add New in the dropdown menu**



3. Add a suitable **username:**
   a. Use only lowercase letters and numbers, with no spaces, in the username
   b. The username is what your supervisor will use to sign into the blog dashboard and is displayed on posts and comments they write. You can't change a username, however you can change what name is displayed.
   c. If you are creating a new username and see 'Sorry, that username already exists!' it means you need to use a more unique username. A simple solution for supervisor username is their first name, followed by surname initial (e.g. John Pratt: username: johnp).
4. Add their **university email address:**
   a. You can't create several usernames with the same email address because the system resets password based on email address.

5. Assign their role: subscriber (learn more about user role's here)

6. Click **Add User (if a message comes up saying that user already exists, scroll to top of the screen and you will see option to Add Existing User).**

7. Your supervisor will receive an email and they just need to click on the confirmation email to be added to the learning logbook.

Your logbook & privacy

We understand that for many users privacy is a critical issue in making the best use of their logbook. Your learning logbooks are automatically set to be 'private' which means that they are not in the public domain, and only users that have been added to your site can access it. As the administrator of your own learning logbook, you can also choose to add other users to your site as you wish.

The logbook sites are hosted on *edublogs campus* and their servers are located in the United States.

Other useful things

There are a couple of cool tools on your Dashboard in the left hand navigation. You can use the **Links** tool, to build a list of links that relate to your project.

You can use the Webclipper tool "**Press This**", under **Tools>Available Tools**, to harvest material from the internet. You just need to drag this to your Bookmarks bar in your browser to get clipping. Select the relevant text, or other material and click on **Press This** in

your bookmarks bar, and it inserts your chosen material into a new Post which you can save as a draft or publish.

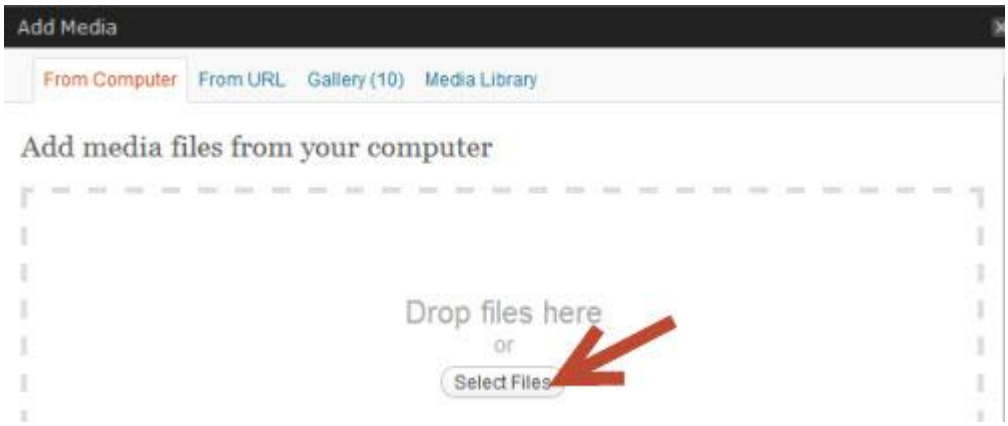
You can also use the **Media Tool** to build a library of media files—video, audio, images etc that are also of interest to you and that you might want to use in writing up or thinking about your project.

To insert media into a post or page simply:

1. Go to **Posts > Add New** or **Pages > Add New** or open an existing post or page in editing mode.

2. Place your cursor where you want the image to appear and then click on the **Add Media** icon above your post/page editor.

3. In the **Add Media** window click on the **Select Files** button.



4. Locate the file on your hard drive

5. Click **Open** to start uploading the file.

6. While your file is uploading you will see a progress bar.

7. In the media option screen insert a suitable title for the file.

a. When your file is added to your post this title is the link your readers see so is best to use a title they can identify with.

8. Click **Insert into Post**.

HELP

If you would like some assistance to get started using the logbook email: treasure@anu.edu.au or Susan Howitt email: susan.howitt@anu.edu.au

You can also access the *edublogs* user guide here: http://help.edublogs.org/user-guide/