Title:

A rapid prototyping approach for intensive field courses to build scientific and professional skills

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Abstract

This paper reports on the design and evaluation of Field Studies in Functional Ecology (FSFE), a two-week intensive residential field course that engages students to master core content in functional ecology alongside skills that facilitate their transition from ‘student’ to ‘scientist’. This paper provides an overview of the course structure, showing how the constituent elements have been designed and refined over successive iterations of the course. We detail how FSFE students are guided first to develop their own research questions (Field Problems), and then through a structured reflective approach of rapid prototyping and iterative refinement of each stage of the research process. Using

extensive evaluation data, we show how, coached by experts within a cognitive apprenticeship framework, FSFE students develop a coherent and nuanced understanding of how to approach and execute ecological studies. The sophisticated knowledge and skills as ecology researchers that they develop during the course is highlighted through high quality presentations and peer-reviewed publications in a student-led journal. We illustrate how field course elements can be used to provide cognitive, affective and reflective tools that allow students to gain maximum value from their educational journey, and the confidence to consider research in their future careers.

Introduction

Intensive and experiential contexts for learning can effectively enable students to engage with fundamental concepts and knowledge while also modelling the trials and tribulations of collaboration and 'real' science enabling them to learn by driving their own investigative processes (e.g. Estavillo et al, 2015; Pedaste et al, 2015). Effectively structured hands-on learning can provide outstanding opportunities for students to experience the excitement of hypothesis-driven research (Beckmann et al, 2015), to explore professional identity (Abrams et al, 2018), and to build skillsets that add value to a student's educational progression and prepare them for diverse careers (Jackson, 2016).

Field courses are an immersive example of research-led enquiry-based learning that can provide students with their first exposure to independent research (Geange et al, 2021). Field courses also provide particular opportunities for undergraduates to experience, recognise and experience integrative learning i.e., learning that connects disparate concepts or disciplines, as opposed to fragmented or compartmentalised learning (Durrant and Hartmann, 2014). However, field intensives also bring logistical challenges and are very demanding of resources. To maximise the value and return on investment, a field course needs to convey not only basic field specific content (e.g. ecological theory) but also to instil students with a broader professional skillset that adds significant value to their educational progression and beyond.

Here we outline the elements of Field Studies in Functional Ecology (FSFE), a two-week intensive field course, and present guidelines for how, and why, to design a course that empowers students to master core content in functional ecology alongside skills that facilitate their transition from 'student' to 'scientist'. This paper presents qualitative and quantitative evaluation of six years of staff, student and performance perspectives of FSFE in Australian and international settings. We use the FSFE example to demonstrate an effective pathway for building students' professional identity, as scientist not just student, early in the undergraduate degree, while giving them cognitive tools to gain maximum value from their educational journey, and the confidence to consider future options in research as part thereof. While few of our students will become researchers, by immersing them in the life of the scientist we help them build the confidence to engage in critical dialogue with experts, creating safe and rewarding collegial relationships driven by shared curiosity in the world. By facilitating this early shift in perception of their own identity, our students are enabled to approach their future studies with a much greater sense of agency, regardless of their ultimate career trajectory.

During two weeks in the field, coached but not directed by experts and by their peers, students iteratively design and implement their own research projects—the 'Field Problems'—in a structured reflective process that allows rapid prototyping with iterative refinement at each stage of the research process. With appropriate scaffolding via skills workshops, students work in small groups

(Intermediate) or individually (Advanced) to identify their own research questions. Exploring the fundamental principles of functional ecology in plants and animals simultaneously allows students to develop a coherent and nuanced understanding of the differences and commonalities among organisms, and how organisms have evolved to function and persist in their environment. The curriculum design of FSFE aligns with a cognitive apprenticeship model (Brown, Collins & Duguid, 1989), where students work closely with researchers in original research projects.

The FSFE model, described below, is ideally suited to adoption across a range of ecological and environmental biology disciplines because of its inherent flexibility. The course is loosely based on the model of the Organisation for Field Studies (OTS) field courses which expose their students to a broad range of tropical systems over several weeks (https://tropicalstudies.org/). Our course framework is easily modified and has been adopted (and adapted) for use at other universities. In each iteration the course covers the same theoretical principles and scientific concepts but can be tailored to location specific contexts in terms of ecological drivers and locally relevant aspects of protected area management, conservation, and climate change. We have varied course location and represented a broad spectrum of specialities of contributing experts in Australian alpine (2015, 2016, 2018) and tropical ecosystems (2017), as well as in Singapore and Malaysia (2018, 2019). Our students can choose to participate in the course in its Intermediate and Advanced forms in different locations, and in the process challenge themselves with exposure to different systems and thereby gain depth and breadth with complementary sets of ecological knowledge.

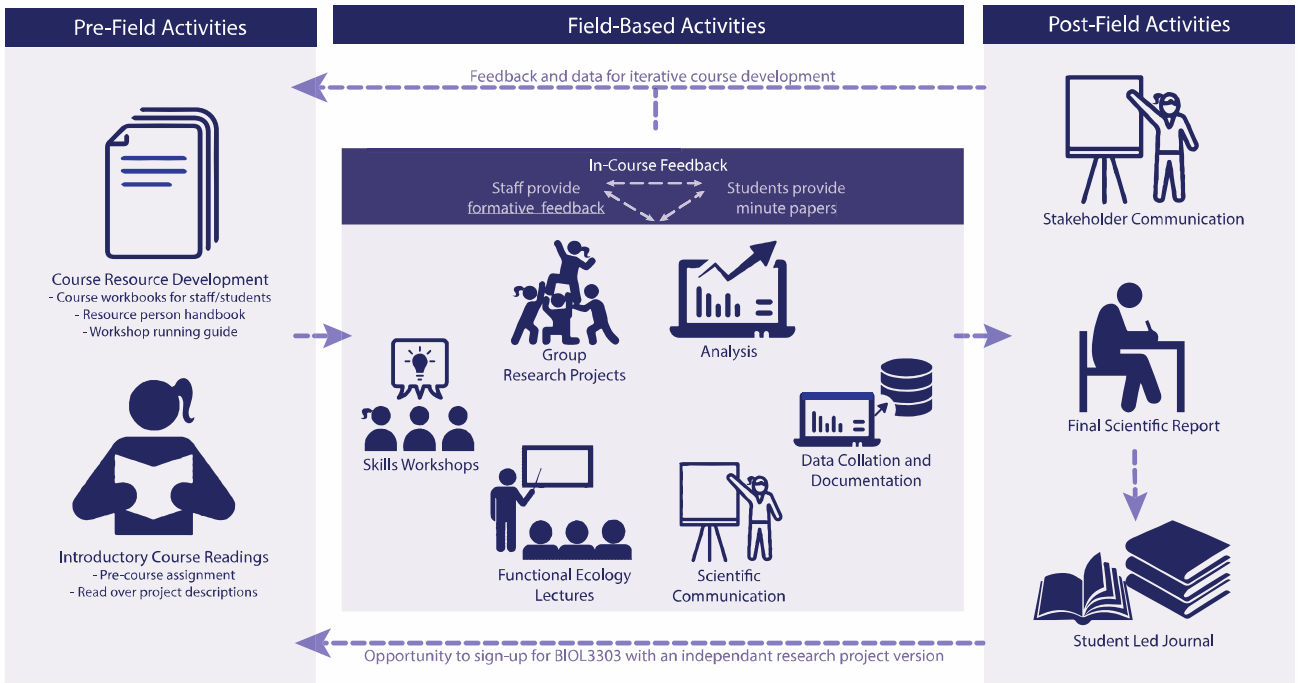
A central tenet of FSFE's original curriculum design is that students learn most effectively when they engage in real, collaborative science (Beckmann et al, 2017; Bruffee, 1993) and that they can do this especially well in a field setting (Behrendt and Franklin 2014). Sophisticated content provides the scaffold for learning rather than the focus—we emphasise internalising the concepts rather than memorising specific content. By supporting reflective learning, a field course provides a perfect opportunity for students to embrace a new identity as a scientist fully engaged in the investigative process.

How the course structure achieves the course aims

The curriculum design of FSFE shares many elements of a cognitive apprenticeship model, an effective teaching process in which students are 'apprenticed' into authentic practices by researchers who explicitly model their expert knowledge and skills in the context of specific learning activities and social interaction (Brown et al, 1989). There are six teaching strategies—modelling, coaching, scaffolding, articulation, reflection and exploration—that stepwise build a cognitive apprenticeship approach (Collins, Brown & Newman 1987; Enkenberg 2001; Dennen 2004). These six teaching strategies consciously and unconsciously underpin the structure of the FSFE curriculum, facilitating students in acquiring both cognitive and metacognitive strategies for content learning.

For some students, the geographical, cognitive, psychological novelty of being in the field—especially in remote ecosystems—may prove a constraint to learning (Cotton & Cotton 2009). However, like Goodenough et al (2015), we have found that this excitement and novelty can improve learning outcomes so long as students are adequately supported. Further, ensuring that students are guided to reflect on what they are learning helps to maximise long-term impact (Moon, 1999). Over the six years that FSFE has been offered, we have refined effective workflows to weave diverse curriculum components together in a way that is highly supportive of learning while also dynamic and responsive to context, circumstance, and student needs: logistically challenging at times but always manageable.

a) Overall Course Schematic



b) 'Rapid Prototyping' Field Research Projects

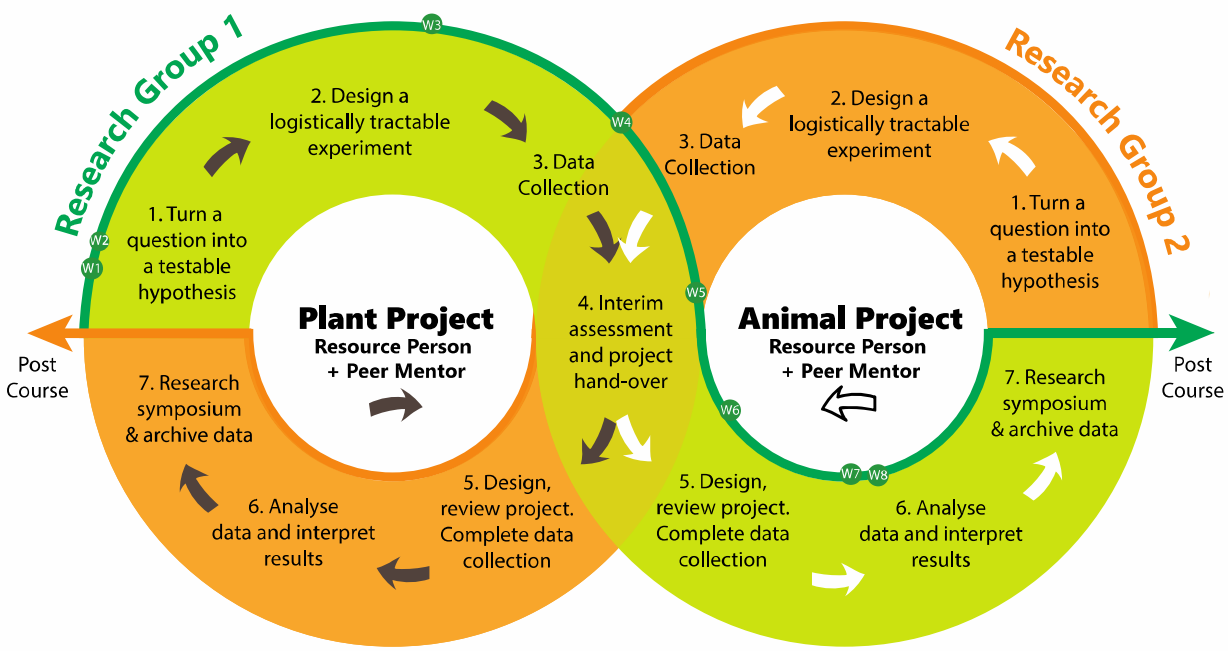


Figure 1 A schematic of a) the overall course structure pre, during and post-intensive and b) the rapid prototyping approach of the field problems.

Each FSFE course has three distinct phases: before, during and after the field trip (Figure 1a). Before the field trip, students prepare to participate by answering study questions on a set of pre-course readings. These questions are designed to focus students' attention on key principles and course specific content knowledge, and the answers provide a resource for the students during the course; students' submission of the written responses is thus a prerequisite for course attendance. The pre-course activities and a pre-course meeting helps to offset any cognitive or affective tensions borne from the novelty factor.

During the field trip, we provide a small number (~4) of intensive lectures to reinforce relevant theory and conduct workshops on key skills or concepts (Figure 1a). The workshops are scheduled to occur when students are asking relevant questions and wanting those specific skills. The FSFE curriculum explicitly recognizes the importance of a broad set of 'soft skills' that although considered beneficial, are not traditionally taught as part of a university science education. We believe that these skills—including effective teamwork and collaboration, reflective practice towards continuous improvement, and a deep understanding of research integrity—are core to a successful undergraduate education and underpin a successful transition to postgraduate study or employment. In designing the course, we recognised that interpersonal, communication, emotional intelligence, reasoning and problem-solving skills are among the top criteria employers seek when recruiting graduates (Graduate Careers Australia, 2016). We therefore explicitly focus on developing these skills in our students through the FSFE curriculum (Figure 1).

After the field trip, the students each finalise one project as a written report, taking time to delve deeper into the literature and cement their learning. Because we endeavour to make each project novel and scientifically rigorous, we have been able to establish and publish regular open-access volumes in a peer-reviewed, student-edited journal series 'Field Studies in Ecology' (Zurcher et al, 2017; Hazell-Pickering, Slatyer and Nicotra, 2019; Harris et al, 2021). The journal format reinforces learning by demonstrating that the students' original discoveries make genuine contributions to the field; it also becomes a resource for stakeholders and inspiration for others (Box 1).
Finally, students and staff are invited to reflect on the course retrospectively. For students, this is done through the university teaching and learning evaluation system and retrospective surveys. For staff, the field course design and implementation exemplify an experiential learning cycle (Kolb 1984) as we reflect on our own experiences and students' feedback collected on-site and subsequent evaluations. Thus, a notable feature of FSFE is that it continues to evolve with each iteration as the course developers reflect on the perspectives of the participants and the success of specific educational approaches and make changes accordingly.

The Field Problems: Bringing rapid prototyping into the research cycle

In design thinking, rapid prototyping involves using scaled-down working models to allow faster design, development, evaluation and improvement cycles (Dow & Klemmer, 2011; Garrard et al, 2017). In FSFE, we have applied rapid prototyping to the scientific method itself. Students refine a problem in animal and plant functional ecology that can be addressed using available equipment within a tightly defined time frame, and we enable them to engage in iterative research design, development, execution, evaluation and improvement cycles over periods of 2 to 4 days while maintaining academic rigour and quality (Figure 1b).

The core of the course is a series of mini research projects or 'Field Problems'. These are supported by specialist researchers in diverse ecological fields from our Research School, or elsewhere if appropriate. These experts are called 'resource people', because they are 'resources' for our students.

In the spirit of cognitive apprenticeship they assist, coach, model, and advise but do not determine the direction of the research. Although we ensure that some of the resource people have intimate knowledge of the local ecosystems (important when we run the course in different locations and contexts) because our focus is on fundamentals, not all our resource people need to be specialists in that system. The success of the conceptual underpinnings of FSFE — cognitive apprenticeship and rapid prototyping — depends crucially on the committed participation of our resource people.

Before the course, each resource person prepares a Field Problem and provides relevant background readings. The problem must address an unanswered, genuine question in the field. The guidance and mentoring by the resource people and the rest of the teaching team help the students to progress through the steps of the rapid prototyping cycle and to generate new knowledge about the system under investigation. The teaching and resource teams support the students to develop their skills in collaborative research, including project design and execution, data analysis and interpretation, and oral and written presentation of results to both scientist and stakeholder audiences. Notably, each resource person brings to the course their individual perspectives, scientific knowledge and valuable life experience as a scientist. Our intention has always been that by engaging with these experts, students gain insight not only into the science but also into the scientists themselves, contributing to the development of the identity concept of 'scientist' and the diversity of science career paths. Through their readings, lectures and subsequent application of the theory with their team and Resource Person in their field research, students come to understand the ideas of ecological trade-offs and the ways in which plants and animals show some similar, and other quite distinct, solutions to shared problems such as limitations of water or light, or thermoregulation.

In most iterations of the course to date, each student has completed two projects focused on animals and two focused on plants; each student is assigned to a different small group for each field problem (Figure 1b). Before allocating students to a project, we do a preliminary survey exercise in which students identify their relative interest in plants versus animals, in molecular perspectives versus landscape perspectives, and relative confidence with statistics. This gives us the necessary information to create small student groups that maximise diversity: by ensuring that each group includes students with different interests and skills, we are grounding students' understanding of multi-disciplinarity and complementary teamwork. Then, in the first stage of prototyping (Research Project 1, Figure 1b), students work intensively with their small group and Resource Person to shape a question and hypothesis related to the Field Problem, and to design an experiment to test that hypothesis (Figure 1b, Research Project 1 Steps 1 to 3). The group then initiates the project and conducts 1.5 days of research before handing the project to a new group (Figure 1b, Research Project 1, Step 4).

To make the handover effective, each student group must articulate the aims and objectives of their work, describe the rationale behind their experimental design, and show how it tests their hypothesis. Students prepare a detailed methods document and, engaging with research practices that are collaborative, reproducible and FAIR (Wilkinson et al, 2016), share a clearly organised dataset together with a dot-point summary of the results to date. They also provide the new group with any other resources – references or analytical tools – that they have compiled. This hand-over requires all students to reflect and take stock of what they have done and accomplished; it also tests the data-handling and communication skills of both 'senders' and 'receivers. In the process they develop communication, collaboration, and data management skills that are useful in a broad range of careers: public service, industry, and academia.

After hand-over, each receiving group chooses what to do with the project it has received: either continue it unchanged, take an entirely different tack, or adopt some intermediate approach. As all the

students bring the prior experience from their first group, in their second groups they tend to be increasingly effective in their rapid prototyping. After another 1.5-2 days of research, analysis and some very intensive interpretation (Figure 1b, Research Project 1, steps 5 and 6), the second group makes a short presentation on the entire project in the format of a scientific conference talk (Figure 1b, Research Project 1, step 7). This cycle is repeated in the second week of the course (Figure 1b, Research Project 2, steps 1 to 7). By the end of the course, each student has participated in four different projects, developing their research process skills iteratively and rapidly, and can choose any one of these four projects to write up as the final scientific report for assessment. Before the final day, each project group is required to upload their methods, data and all presentation materials to an open access archive for post-course use. This not only gives the students maximum flexibility in writing up their final paper after the course, but it also models a key element of modern science (Gallagher et al, 2020; Parker et al, 2016). While these final reports are written individually, in the style of a research paper, the design and conduct of the experiment as well as analysis, interpretation and presentation are recognised as collaborative products.

This model may at first appear complex, but in practice it flows remarkably smoothly, as an elegant example of the cognitive apprenticeship strategies in practice. The short-term and iterative nature of the rapid prototyping approach encourages quick design, development, and execution. This not only maintains a high level of engagement and novelty, but also alleviates the pressure on students to obtain conclusive results, since we recognise that perfection cannot be achieved in a four-day research project, and also explicitly invokes reflective evaluation, consolidation and improvement cycles (Finlay, 2008; Hubbs & Brand, 2005; Kember et al, 2008; Kolb, 1984; Temponi 2005), supported by workshops on reflective practice and reflective journals as assessed tasks. As the students grapple with a variety of questions and study species, catering to students' individual interests and providing a broad view of the ecosystem under study, they iteratively strengthen their research skills.

Workshops: Explicit focus on skills development

The course has a clear set of achievable learning outcomes which are constructively aligned with the assessment tasks to increase teaching efficacy (Biggs and Tang, 2011). These outcomes and the task alignment (Figure 2) are made very clear to students as well. Often science educators assume that the ancillary skills of research and collaboration are implicit and will develop as a by-product of good teaching and research practice. In contrast, we place these skills 'front of house' so that the students can reflect on their skill development and progress throughout the course. Our premise is that creating an environment that encourages explicit awareness of both 'hard' and 'soft' research skills (Laker and Powell, 2011) while fostering a culture of reflection and constant development is more likely to increase the efficacy of learning and provide the students with lifelong skills. These skills are presented in a series of intensive workshops 'bootcamps', that are aligned with course learning objectives and assessment, and are timed to occur exactly when the students need them during the course (Figures 1a and 2).

Each Workshop is structured to give the students agency in their own learning. A student handout clearly states the Workshop's objective and an outline of the content. Each Workshop ends with a 'minute paper' evaluation (Stead 2005) in which the students pause to reflect in writing on what they have learned during that Workshop. These reflections are valuable for both students and staff and have yielded highly valuable feedback for ongoing refinement of Workshop approach, content and delivery. (See Figure 2 for typical quotes drawn from these Minute Paper evaluations to demonstrate what the students learn from each.) The Workshop Facilitator has access to a Facilitator's Handbook, additional handouts, slide presentations, and any required equipment (Figure 1a). The Handbook approach

Learning Objectives

1. Understanding of the commonalities and differences in the way animals and plants cope with environmental conditions and acquire the resources needed for growth and reproduction
2. Identify and critically evaluate the current state of knowledge about a specific research question in functional ecology
3. Formulate a testable hypotheses and design experiments to effectively test them, based on an understanding of the research literature
4. Conduct functional ecological research and apply a range of current techniques
5. Interpret data against original hypotheses and knowledge of the literature, and suggest avenues for future research
6. Collaborate as a group to reach research goals
7. Communicate scientific findings in written and oral forms to diverse audiences

Assessment Tasks

Field notebook: students will keep a field notebook containing notes from lectures and directed field problems, data, and records of results and conclusions. Students will also be expected to answer reflective questions on their learning throughout the course. Notebook will be assessed twice during the course (25) [LO 1,2,3,4,5,6,7]

Final report: each student will select one directed field problem to write up in the form of a scientific paper. This will be due one week after course completion. (30) [LO 1,2,3,4,5,6,7]

Presentations: Students will present results of directed field problems as a group with each presentation worth ~4% (25) [LO 5,6,7]

Mid and end of course quizzes: Two one hour quizzes of lecture material 10% each (20) [LO 1,3,5,7]

Posing Questions *LO: 1,2,3* 1

Students explore the local plant and animal communities and **pose questions** about what they see. With a peer mentor, small groups transform the questions into **testable hypotheses** and **effective experimental designs.**

"Reminded me of the importance of beign curious and questioning everything. I know that these skills are useful in almost every aspect of life."

"I started seeing research as question-oriented: hypotheses come from questions and methods/results work to answer those questions

Reflection and Self-identity *LO: 1,2,3* 2

We explore **professional identity** as a student and scientist and in the process develop an understanding of the value of **components of reflection** and **reflective process in science and learning**

"I feel [reflective writing] is a skill that can be used in a multitude of other activities"

"It's okay not to know who you are!" "Reflective practise was introduced to me during this course and is something that I definitely incorporated into my studies (and life) after the course. I still use it!

Experimental Design and Data Handling *LO: 1,2,3* 3

We learn about **principles of experimental design** and **data handling** by **designing a hypothetical experiment** (e.g. to test the effects of sleep and caffeine on student performance).

"Making experimental designs [in a group] really brought home how important collaboration is, by allowing our peers to highlight our biases. People have different views/opinions which can help them 'tweak' experimental design."

"I am more aware of having a clear and well developed set of aims and a hypothesis before undertaking any work."

Statistical Analysis Bootcamp *LO: 1,2,3* 4

Students learn to **select appropriate analytical methods** and work as small groups to **interpret results** of their own **works in progress.**

"I had a greater appreciation for metadata, and keeping good notes and records. I also understood more about methodology and statistics than I otherwise would have at that point in my degree... I am confident in my ability to interpret and appreciate research as well as communicate it effectively."

Collaboration and Group Identity *LO: 1,2,3* 5

We explore **why collaboration and group work are important in research**, gain an understanding of how **group identities are formed** and have an opportunity to reflect on previous group work experiences in order to **improve collaboration skills** for the field course and beyond.

"I liked the thought experiment regarding how a new group member might integrate and what that depends on"

"Reminded me to be more self aware of the role I play in groups."

Giving Good Presentations *LO: 1,2,3* 6

We explore the elements of **giving good presentations** and do a **pressure test group presentation** on a light-hearted topic to **break down apprehension and build up confidence in public speaking.**

"The lighthearted example of doing a five minute presentation took away some of the "talking in front of people" anxiety. [There were] good, helpful tips, especially about stalling for time and presentation tricks."

Legacy of Reflective Writing in Ecology *LO: 1,2,3* 7

To further develop skills in applying reflective writing in a professional setting we **analyse famous examples of field biologists** who use their field notebooks for creative inspiration and to explore their scientific skills in-situ.

"I liked reading the journals of the heavy lifters; it reminded me they are just people, methodical and hardworking; maybe there's hope for the rest of us"

"Reading the notes from other ecologists helps to determine how to format my own reflections."

What is Research Integrity *LO: 1,2,3* 8

We have a frank discussion around **responsible conduct in research**, some **ethical delimmas**, and **how these issues affect science students** as well as career researchers.

"I really enjoyed doing this as I have felt that we haven't learnt enough about ethics since we came to uni"

"Interesting hearing about authorship and publication process."

Scientific Storytelling *LO: 1,2,3* 9

Our writing workshops **unpack the classic paper structure** and use **engaging writing excercises to build on experience** from prior science courses and **develop skills in effective science writing.**

"Science is not a straight line..... Useful. I wasn't sure how to set out my report but now I feel much more confident"

"I learnt ways to phrase results that go against my own expectations and past studies"

"Made me think to put my current work into perspective."

Peer Mentoring *LO: 1,2,3* 10

Our peer mentors **contribute to delivery of the field course** while engaging in their own course at a more advanced level. For them, we provide **training in peer mentoring** so that they can **support their more junior colleagues** and also learn by teaching

"[I learnt] to step back"

"It is more about encouraging students with strategies on how to approach a problem, rather than telling them the answer"

"[These skills] might actually help me when I'm struggling too."

Figure 2: Students are presented with the Learning Outcomes of our course from the outset and Assessment Tasks are aligned to enforce these outcomes. A series of workshops, timed to provide skills at key points in their research process, supports the learning objectives. Quotes drawn from Minute Paper evaluations conducted at the end of the workshops demonstrate what the students learn from each.

ensures that Workshop delivery is easily accomplished by different teaching teams: indeed, the Handbooks have become a living resource as each successive cohort of facilitators has added individual flavour and customisations to accommodate their student cohort and context. Thus, although carefully designed from the beginning (see Beckmann et al, 2017), the Workshops evolve as they are fine-tuned over the years by a collaborative team representing a wide range of research career stages, in keeping with our reflective and continuous improvement stance. Within the set of Workshops are two sub-sets: one unpacks the scientific process, while the other examines the concepts of collaboration and researcher/scientist identity.

Unpacking the scientific process: Each course begins with a 'Posing Questions' workshop (Figure 2, W1**)** in which students are supported to simultaneously familiarise themselves with the local flora and fauna and develop skills in converting observations and curiosities into focused questions and testable hypotheses. When each student group has a question framed as a hypothesis, they are ready to delve into aspects of experimental design and consider how best to handle the data they will produce (W3). As they near the end of their first Field Problem, we provide intensive consideration of applied statistics (W4). At the end of each Field Problem cycle and at the end of the course students present their results in research and stakeholder symposium sessions (Figure 1b, steps 7). To make this potentially daunting task manageable, we present a light-hearted evening workshop beforehand, pairing public speaking with improvisation activities (W6). Towards the end of the course, an exploration of science writing from the perspective of designing a narrative prepares the students to write up their chosen project (W9). Finally, we spend an evening considering research integrity, where students learn about authorship, ethical considerations and the codes of practice that inform professional research (W8). For most students this is their first exposure to ethical practice beyond the issue of plagiarism, and it has proved a revelation to most of them.

Collaboration, researcher identity and reflective practice: Three overarching goals of the course are to allow students to develop skills and experience in collaboration through their participation in the Research Problems, to foster student interest in research by exposing them to experts in different fields of ecology and related disciplines, and to encourage students in a lifelong reflective practice in the context of being a 'researcher' – whatever their career aspirations. All three goals relate to the cognitive apprenticeship model; recognise that affective learning is as strong a component of field courses as cognitive learning (Boyle et al, 2007); and are linked to the body of theory underlying the 'social identity approach' (Haslam, 2004). The latter is an influential framework that helps explain how expression of individual social psychology can mould behaviour within and between groups and was central to our design of FSFE (Beckmann et al, 2017). The concepts of individual and group identity are explored in our Reflection and Self-identity workshop at the very start of the course (W2). They are then extended in a further session on collaboration and group identity (W5) that occurs when the students have conducted their first small group research project and are realising the distinct differences among individuals. By explicitly teaching the social identity approach, we offer students a lens for reflection on their experience in collaboration and working in groups.

In addition, as we explore how research scientists, students, and ecologists build self-identity, we encourage the students to reflect on their own self-identity in the context of scientific research and university study. Students often initially think of reflective practice as requiring extended, public diarising. We counter this by showing how reflective practice has a long history in field research, which we illustrate by exploring field journals of notable naturalists and ecologists (W7), and link these to the field notebook assessment task (Figure 2). We explore how field observations and good descriptive notes, paired with subsequent reflection on mechanism and process, have been instrumental to development of fundamental theories in ecology and evolution. When social identity and reflective

learning are presented in the context of the field course, and students are asked to set aside 'journal time' each day, we have found students enthusiastically dissect their recent first-hand experiences and reflect deeply on how they will approach the next iteration of each rapid-prototyping exercise.

It becomes clear when the teaching team reviews and gives feedback on the reflective journals each year just how powerful and deep is the learning being gained. It is often possible to see in a single page of reflections a whole sequence of a student's affective experiences and emotions with learning the science, including frustration (at the complexity of a scientific concept or the vagaries of scientific equipment), confusion, persistence, experimentation, excitement, discovery and satisfaction—all experiences common to any researcher. By contrast, in another journal one might find a sequence that relates very much to identity aspects—recognising fears, understanding peers, reflecting on new skills, being open to peer feedback, setting new goals, planning to learn, and planning to improve.

In terms of collaborative skills, as the students move from their first to their third or fourth groups, we have observed tangible improvements in teamwork. Individuals are quicker to recognise the range of diverse skills and capabilities within the student cohort and broader group of resource people, and learn to share responsibilities and outcomes more effectively, discovering together and supporting one another. An interesting side-effect of instilling a reflective culture is that students have permission to be self-aware and to remove themselves from the action when they need a break from the intensity of the course. In addition, they show greater awareness and tolerance when they need to accommodate their peers' limitations.

The Teaching Team is a crucial element

The field-based intensive teaching model presented by FSFE presents an effective professional development opportunity for staff as well. In the six FSFE iterations to date, a total of 41 staff (teaching academics, technical staff and resource people) have participated, with 15% of these contributing to three or more iterations.

Clearly our resource people are crucial to the success of the FSFE model. We actively recruit these specialists from diverse backgrounds, always looking to balance the relative expertise in animals and plants. Our staff are primarily recruited from the Australian National University Research School of Biology (RSB), but with some FSFE locations (e.g. Cape York, Singapore, Malaysia) it has been a privilege to augment our core teaching team by welcoming local specialists onto the teaching/resource team. To avoid the risk that varying membership of the staff compromises the safe space of the field course community, we ensure that the core teaching team remains constants and are the sole staff for the first few days. Once that sense of belonging is established the students are able to welcome the influx of each group of resource people for the duration of each of the Field Problem cycles.

In keeping with the cognitive apprenticeship and development theme of the course, the course also aims to provide opportunities for researchers, especially those early in their careers, to experience and grow from field-based teaching (Geange et al, 2021). This has required a conscious professional development focus, and application of the apprenticeship model, to bring early career researchers into the teaching team, and to embrace high turnover in the broader staff group. Before, during and after the course, staff receive constructive support and feedback from one another and from students (e.g. via minute papers) regarding their teaching style, course goals, student supervision and execution of research projects, and general approaches to support. Since the first course, new recruits to the teaching team have been able to refer to compilations of course resources, such as course workbooks for staff

and students, the Resource Person Handbook, facilitators' notes (Figure 1a), and the student-led journal *Field Studies in Ecology* (Box 1). This support, coupled with the iterative nature of the field course, provides an opportunity for FSFE staff to enhance their personal academic and professional skills. In addition, the senior staff regularly mentor the junior staff and encourage them to pursue external development opportunities and recognition.

Logistical and resource constraints are part of real science

Over the years, we have learned how to frame research questions that cover fundamental concepts in functional ecology, generate data that can be analysed at an appropriate statistical level and be effectively executed in the field, whatever our location. Students answer their research questions with methods that span from simple counts of chosen species through measurements of morphological and physical properties to more advanced physiological assays, such as estimating metabolic rates or biochemical constituents.

The selection of methodological approach and equipment also compels students to consider the trade-offs researchers must make. For example, more sophisticated equipment—such as leaf gas exchange systems and metabolic heat systems—are appealing because they generate data at a finer scale. However, such equipment is generally difficult to transport, organize and operate in field settings; is more likely to break down; and often requires a power source. The trade-off is thus often a much smaller sample size and data set than is obtainable using simple and highly reliable equipment, such as rulers, binoculars and weighing scales. Students thus learn to balance the returns and risks of simple versus complex equipment in a field context. Choosing an appropriate methodology after considering these trade-offs allows the students to experience the realities of research, with its inherent constraints on funding and access to equipment. When planning each course iteration, the teaching team works closely with invited Resource People to ensure students will have access to the range of equipment that will be most useful and effective in addressing their Field Problems. This means we need to provide multiple sets of common equipment and schedule Field Problems carefully to manage the availability of the more complex and less available equipment. Students are also directed by the Resource Person to methods resources (e.g. PrometheusWiki.org) to ensure they have access to community best practice approaches.

We also carefully consider the study organisms in advance, and focus on those which we can reliably, legally and ethically investigate in high enough numbers to yield effective sample sizes (given seasonal and weather constraints). Target organisms to date have included insects, reptiles, and birds as well as plants. Mammals and rare species, although enticing to researchers, have not been the subject of direct study due to pragmatic constraints on time and measurement capacity, as well as the need for more complex licensing and ethics approvals. In each study location we highlight the unique flora and fauna in their ecological contexts. As rarer organisms are important to understand in ecological monitoring or as sentinel species, but are often 'risky' study subjects in terms of availability and accessibility, during the course we supplement the research projects with other activities that inspire and educate students about the local ecosystems. For example, we have included spotlighting for arboreal mammals at night, talks from local land managers, and informal hikes and field excursions through different landscapes.

Core to our model is a commitment to constant development and improvement. Working with different teams of Resource People each year means that we commit to pre-course training for this broader teaching team. We also take full advantage of the valuable opportunities to learn from the experiences of these successive cohorts of experts, and we take heed of any suggestions they may have for any

aspect of the course. We are also very flexible in delivery style, cognisant of the constraints of different locations: the approaches that are most effective when living closely with our students in an isolated field station in the Australian high country, for example, differ substantively from what is functional when living on a university campus in an urban setting in Singapore.

Extension opportunities are built-in

Two key extension opportunities in the course design recognise the potential for students to engage at both levels intermediate and advanced undergraduate levels and to extend their experience to include involvement in dissemination of results as peer reviewed publications.

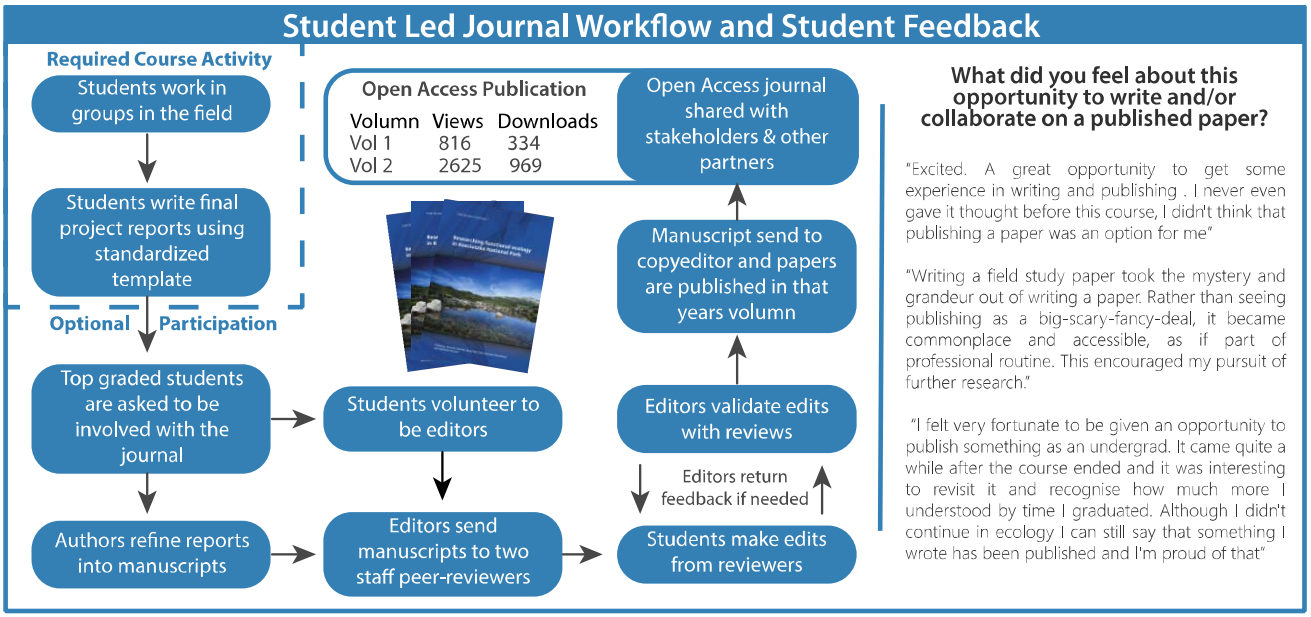
Advanced course, with Advanced students acting as peer mentors: FSFE is delivered simultaneously at Intermediate and Advanced undergraduate levels (course codes BIOL2203 and BIOL3303, 2nd and 3rd year respectively). Advanced level students carry out independent research projects developed in consultation with a specific Resource Person. To acknowledge the skills these students already have, and their need for more progressive, often individualised skill development, a parallel stream of Workshops are provided for Advanced students to ensure extension development. The Advanced students also receive training as peer mentors (Figure 2, W10) so that they can develop another important skill (Dolan & Johnson, 2009) and contribute to the teaching of the Intermediate level students. Each peer mentor accompanies a Field Problem group and provides personalised learning support related to experimental design, analysis, interpretation and presentation, which enhances the learning of the Intermediate students while also enriching the Advanced experience.

Student-led journal: FSFE provides an effective and directly introduction to the publication culture of research; in science, perhaps even more so than in other areas, research that is not published in some form often has no impact beyond the development of the researcher (US National Research Council, 2003). Thus, our students incorporate substantive background and comparative data from primary sources, and have a final assessment in the format of a journal paper formatted to external specifications. We also emphasise the responsibility that researchers have to communicate their findings with stakeholders and the general public. The course ends with a research symposium that includes invited local and specialist stakeholders as well as the whole student cohort and teaching/resource team. This provides an opportunity for the students to present their findings to, and engage in discussion with, professionals who work in conservation, management and industry. Recognising the quality of these presentations and the associated written work, we have launched a student-led peer-reviewed journal to publish a selection of outstanding examples of student work (Box 1).

Box 1: From Student Assignment to Peer-Reviewed Publication: *Field Studies in Ecology*

Our students have the opportunity to publish the research conducted during the FSFE courses in the peer-reviewed, open access journal '*Field Studies in Ecology*'. The first two volumes cover the 2015 and 2016 courses respectively at Kosciuszko National Park (Zurcher et al, 2017; Hazell-Pickering et al, 2019) while the third volume also includes research at the Daintree Rainforest Observatory at Cape Tribulation, Queensland, in 2017 and at the Bukit Timah Nature Reserve in Singapore in 2018 (Harris et al, 2021). Volume 4 is in preparation. This body of published work reflects the values of student-led learning and is driven by students as both the primary researchers and journal editors. This continuous engagement—from initiating the project idea in the field through to publication—develops in students' first-hand engagement with the peer-review process, an aspect of scientific communication rarely

available to undergraduates or even very early career researchers (Guilford, 2001; Uigín, Higgins & McHale, 2015).



Submissions: Course assessment requires students to submit a final report based on one of their field projects. To nurture and reward enthusiasm, effort and quality, students who do this to a good standard (usually graded at 70% or more) are offered the option of submitting their manuscript for traditional peer-review, rewriting to an even higher standard, and consideration for publication in the journal. We only accept one paper per Field Problem, so if more than one student wants to submit for the same small-group project, we support them to collaborate in joint authorship.

Student editors: Applicants for the journal editor roles come from the FSFE cohorts, and are subjected to a rigorous selection process. Mentored by academics and professional editors as they develop their skills, the student editors are given a high level of responsibility in handling the whole peer review and publication process. This includes managing all the student authors and the very large number of peer-reviewers involved, including many senior academic researchers. The leadership skills that the editors develop are proving an exceptional asset to their career paths, whether they continue in academia or move into other professional areas.

Undergraduate authors: To achieve publication, the student authors must demonstrate a high level of mastery of relevant discipline knowledge and research capabilities. The peer review feedback naturally strengthens these aspects, as well as bolstering the student authors' skills in written communication, critical thinking, data analysis and synthesis, all key employability skills. The process also facilitates career thinking about the realities of academia.

Research dissemination: In addition to its role as an educational tool, the journal aspires to contribute more widely by making available data and thinking on the ecologies of some vulnerable ecosystems—addressing a specific gap in the publication space. The journal is not only open-access but is actively shared with many stakeholders, including other scientists, government agencies, land managers and industry professionals. Data analytics show that the journal is viewed and downloaded regularly.

Student feedback: Students' reflections on their experience with the journal have been collected from the course-required reflective journals and the recent participant survey. These data show that the opportunity to publish research as undergraduates was not only unexpected but quite transformative. Students overwhelmingly underestimated their capacity to contribute, and then demonstrated a more than sufficient understanding of requirements to produce work of high quality. In the process students gained a sense of achievement and satisfaction from working as a group and being able to publish a body of work from their cohort. Even when asked some years later, students reported that the exercise developed their identity as legitimate researchers, illustrated the benefits of teamwork, and gave them an inordinate sense of pride.

Assessing the effectiveness of the FSFE model

As already noted, we have maintained a consultative continuous improvement cycle (Temponi, 2005) across all facets of the course since the first iteration. This has included impacts noted in students' reflective journals and minute papers during each iteration giving insight into in-course outcomes (with a typical selection exemplified in Figure 2), as well as proximate post-course evaluations giving more holistic views. In addition, after several iterations we assessed the effectiveness of the FSFE approach more objectively via a retrospective survey. Quantitatively, we have compared academic results and outcomes across Science of FSFE participants compared with non-participants. We also quantitatively analysed students' capacity for reflective practice using surrogate indicators. Qualitatively, in 2020 (when the course was cancelled because of COVID-19 circumstances) we surveyed all former students, teaching team and resource people who had participated in FSFE since its inauguration. This allowed us to consider especially the longer-term impact of FSFE on students' career trajectories, which is of special interest given the course's focus on both the scientific method and student identity as scientists.

Quantitative assessment of student outcomes

Even though at our university FSFE could account for usually only one, and at most two, of the required 24 courses for graduation with a Bachelor of Science, we conducted a quantitative analysis to see whether participation in FSFE had any measurable effect on academic outcomes.

As our sample of FSFE students was not random, we compared academic outcomes of the FSFE cohorts relative to their peers using a dataset of paired student contrasts. Here, we paired each FSFE student with another student who had not taken the course, but who had achieved the same grade in the same first year prerequisite course and was enrolled in the same degree. Using Generalized Linear Mixed Models (GLMM) implemented in R statistics package "lme4" (R Core Team, 2021; Bates et al, 2015), and the paired student design based on anonymised academic transcripts, we assessed graduates' final overall Grade Point Average (GPA) in relation to whether FSFE alumni were more or less likely to complete their degree or continue onto Honours (an undergraduate research year in Australia) or postgraduate study. In each case, we specified a binomial GLMM with logit link, with 'completed degree' or 'postgraduate study' as response variables. Fixed effects were log GPA (centred and scaled) and a categorical factor for whether or not the student had participated in FSFE, and we included a random effect for the student pair.

We found that completion of FSFE was not clearly associated with higher degree completion rates, although the small overall number of non-completions make the uncertainty around this result very high. We did find a weak positive association between completion of either the Intermediate or

Advanced FSFE course and going on to further postgraduate or Honours study, although again with the small sample size this effect did not achieve statistical significance.

To assess whether GPA was influenced by participation in an FSFE course, we specified a model with standardised GPA as the response variable, and FSFE student status and first year biology grade (log, centred, and scaled) specified as fixed effects. This analysis recovered the expected strong positive effect of higher first year grades being associated with higher overall GPA but revealed no significant effect of FSFE course participation on GPA. Overall, participation in FSFE did not have any strong direct effects on the overall trajectory of students' degrees or on academic performance as measured by GPA. These findings were in keeping with our neutral expectations, the small sample size and the difficulty of modelling complex multivariate social phenomena. Nevertheless, we did note a slight trend for FSFE students to continue into research pathways.

Objective analysis of reflective practice

Enabling our students to become more active reflective learners was a key goal of FSFE. As already noted, students were trained in reflective practice and writing during the course (Figure 2, W2 and W7), and their reflections were assessed at the course mid-point and at the end of the course. We therefore analysed whether students improved in their capacity for reflective practice during the course. Firstly, anecdotally, those of us reviewing and assessing students' field notebooks across the two weeks of each course observed clear shifts in the quality and depth of students' reflections, moving towards the higher-level attributes that Moon (1999) associates with effective reflective writing. Moreover, from our conversations on site to the survey responses one to five years after participation, we observed students (especially in those who returned for the advanced course) clearly shift from 'reflection on action' to 'reflection in action' which Schon (1983) considered the core of 'professional artistry', and Findlay (2008) described as indicative of the expert who acts "both intuitively and creatively [as they] revise, modify and refine their expertise".

Then in 2020, we collated a random sample of 85 mid/end reflective journal entries from across all course iterations (in 2017 a reflective question on the mid and end of course quiz was assessed instead of the journal) and both Intermediate and Advanced students. Four experienced members of the teaching team then scored the students' reflective writing across four attributes—descriptive detail, emotive engagement, critical reflection, and meta-reflection (after Moon, 1999; Kember et al, 2008)—with a grade from 0 (none shown) to 4 (excellent evidence). We analysed the mid/end score pairs with ordinal logistic regression in R-package 'MASS' (Venables and Ripley 2002). As we provided both the cohort training and written mid-course feedback on each students' individual reflections, our hypothesis was that students' reflective proficiency and competencies should show signs of improvement over the course. From the outset of the course students scored consistently high on descriptive detail, which is appropriate as this is the most basic attribute of reflective writing (Moon, 1999). In contrast, students showed statistically significant increases in scores for emotive engagement ($P=0.01$), critical reflection ($P<0.001$), and meta-reflection ($P<0.001$) between the mid- and end-of-course assessments, indicative of increasingly sophisticated and more-effective reflective practice.

Qualitative assessment of student outcomes

In their recent large-scale study at University of California Santa Cruz, Beltran et al (2020) found that field courses were associated with higher self-efficacy gains (more so than lecture-based courses), higher college graduation rates, higher retention in the ecology and evolutionary biology major, and higher Grade Point Averages at graduation. While our much smaller-scale quantitative analyses did not

find such clear-cut metrics, we certainly anecdotally recognised self-efficacy gains in our FSFE students, and decided that qualitative evaluation would provide a more detailed understanding of the impact of the FSFE experience on students' learning outcomes.

Student survey

In late 2020 we contacted all students who had participated in at least one of the six FSFE iterations using university email addresses. Noting that these might no longer be accessed by graduates, reducing potential response rates and sample size, we also relied on word of mouth and course-specific Facebook groups. We invited the students to respond to an online survey in which we asked open-ended questions on their perceptions of the impact of FSFE, and Likert-scale questions on whether FSFE had stimulated increases in specific areas of interest, knowledge or skills.

The sample of 43 respondents was spread evenly across course iterations (each represented by responses from 8-13 former students) and course level (86% had participated at Intermediate level and 45% at Advanced level, with 30% having taken both). All respondents were enrolled in a Science degree, with 24% also enrolled in a non-Science degree (double degree). When they first attended FSFE, 60% were in the first year of their Science degree, 20% in their second year, 17% in their third year and 2% in their fourth or later year. About 60% of survey respondents had graduated since taking FSFE. Of these, the majority (72%) had continued into research or further study (50% enrolled or planning to enrol in Honours or Masters programs, 20% enrolled or planning to enrol in a Doctor of Philosophy program and 12% enrolled in Doctor of Medicine degrees). Of the other graduates, 24% were working in science communication or government science policy, while 12% were employed in non-university ecology research.

Respondents reported substantial impacts of their FSFE experience on their subsequent studies and interests (**Figure 3**). The novel settings, the student-led approach, and the opportunities for high quality interactions with staff stood out for many as specific features of the course itself. Many reported that FSFE provided their first experience of 'real science' and that they were sure the improved confidence and skills they gained during the course positively impacted their subsequent academic performance.

One specific set of survey questions asked how much FSFE had stimulated increases in various aspects of relevant interest, knowledge or skills, with potential responses presented on a Likert scale ranging from 1 (not at all) to 5 (very much). Mean ratings above 3 were considered to indicate an increase in the relevant sphere (Figure 3). Almost all respondents reported notable increases not only in their *knowledge* of ecology and the ecosystems they visited but also their *interest* in ecology and ecosystems, and in research overall. Some two thirds reported notable increases in their skills in formulating research questions and planning research methodology post-FSFE, and a similar proportion noted that their technical confidence in using lab and field equipment had increased.

> *… discussing our [possible research] questions was extremely rewarding and engaging as I was both learning and collaborating with others …. I felt different after the group discussion knowing it was one of my questions that we are going to test tomorrow.* (Extract from reflective journal, 2018)

In addition, most respondents reported that FSFE had increased their capacity to work effectively in groups (83%, mean 4.0/5) and gave them confidence to identify themselves as scientists (76%, mean 4.0/5). Responses to the open-ended questions clearly showed that these FSFE participants felt being supported through the scientific process had enabled them to think more critically, assimilate new

information with greater ease, and develop specific scientific/academic skills that benefited their future study.

Most respondents (83%, mean 4.4/5) also reported a notable growth in their networks of peers and staff as a result of their participation in FSFE.

> *It was revolutionary to … find myself in a group full of people just like me, who'd stay up … going through the literature and fixing the presentation … who didn't mind that I'd done the reading, who'd done the reading themselves, who would actually discuss what we'd read.* (participant in 2015 & 2016, BA/BSc, now working in government policy development)

> *I learnt to accommodate more work styles in order to achieve a shared goal* (2015 & 2016, 2nd year student, graduated BSc, now technical officer in research agency)

> *I was better able to organise myself to work with … group members after the field trip … useful on some of the larger projects I had later in my degree, through finding out the best division of labour to each task.* (2017, 1st year student, graduated BSc, planning Masters of Ecology)

> *I found it easier to work in groups after learning more strategies of ways in which groupwork could be assigned and completed. I learnt that everyone has something unique to offer during groupwork, and that even if you do not have a perfectly cohesive group, that group is not forever.* (2019, 2nd year student, enrolled BSc)

The responses from the survey demonstrated very clearly that these former students—some of whom had taken the course five years earlier—felt that they had approached learning and community-building quite differently after FSFE. Most respondents (76%) reported that post-FSFE they experienced a greater capacity to reflect on their own learning in their subsequent university courses. Specifically, they described how being supported through the scientific process enabled them to think more critically, assimilate information with greater ease, and develop specific scientific/academic skills that benefited their future study. Some reported specifically that taking FSFE had motivated a shift in their study trajectory toward taking more biology and ecology courses, and many reported that FSFE had increased their motivation to pursue further research, which was evidenced in their post-FSFE study/career paths. In open-ended responses, many described the lasting impact of the course: they felt participating in FSFE had affected them in ways that still permeated both their personal and academic lives, stimulating memories and reflections even years later.

Qualitative assessment of staff perspectives

To establish what impact involvement in FSFE has had on staff, we also asked contributing staff to respond to an online survey with Likert-scale and open-ended questions that, where appropriate, paralleled those asked in the student survey (Figure 3). About half of the 21 staff who responded were in early- to mid-career stages, and a few had themselves initially been students in FSFE.

When asked to reflect on what they considered the value of the course for students, staff respondents were unanimous in their view that FSFE students benefited from the course's applied, immersive nature. There was a particular recognition that the practice-based need for students to be realistic in their approach to data collection and project design/management while on site had given the students a 'real' experience of practicing science.

	Student Perspectives		Staff Perspectives	
Interest & Knowledge	**Interest in research**	4.2/5 "It was nice to realise that being a scientist doesn't require oneself to sit in a lab, rather it can be out in nature for data collection. It's also given me an appreciation of the type of research in ecology ..."		3.0/5 "Connections and conversations with academics sparked new ideas that have contributed to grant proposals"
	Interest in ecology and ecosystems	4.2/5 "I studied plant science with a different outlook i.e. taking ecosystems into consideration rather than simply individual species."		
	Knowledge of ecology	4.3/5 "I knew almost nothing technical/scientific about ecology before [FSFE] ... I still have light bulb moments where I'm in class and I'm learning about something and I go "Wow, that makes sense because I remember this and that from the FSFE course".		3.7/5 "As such, participating in this course, gave me the opportunity to develop a much more holistic understanding of the functional ecology of the plant and animal communities found there."
	Knowledge of the ecosystem(s) they visited	4.6/5 No relevant quote		3.8/5 "I benefitted from the opportunity to learn more about alpine ecosystems and by teaching others to use the experimental systems that I had been using on my own."
Skill Development	**Skills in formulating research questions**	4.3/5 "I was more able to think critically like a scientist and had the confidence to formulate my own research questions and experiments to explore these"		
	Skills in planning research methodology (Students)/ Teaching (Staff)	4.0/5 "I am more aware of having a clear and well developed set of aims and a hypothesis before undertaking any work." "The field trip really helped me analyse the potential problems in methodology, since we encountered many in the field."		3.5/5 "It consolidated, some areas of my understanding and enabled me to reflect on my career in a new light." "The first time I have seen... pedagogically up-to-date [teaching] in a university course context"
	Technical confidence in using lab and field equipment	3.9/5 "I am more aware of having a clear and well developed set of aims and a hypothesis before undertaking any work." "The field trip really helped me analyse the potential problems in methodology, since we encountered many in the field."		2.6/5 "In conjuction with the project management, and collaroration elements, the wide range technical skills found across the researach projects during the courses have also been invaluable."
Individual & Group Dynamics	**Capacity to work effectively in groups**	3.9/5 "Knowing that the other people in your group will welcome you as you are enables you to not only perform but to truly participate." "I realised that everyone finds their own way to contribute, even if people are at different places in their career/studies. It definitely improved my perception of group work, since everyone participated enthusiastically." "... I left the course better able to work in groups, because I gained some practical insight into what works and what doesn't. Going into the course, I [had] very little experience working with others, and had a habit of taking control of groups and/or taking on too much of the workload."		3.2/5 "Helped the students... to build strong collaborative relationships and work out for themselves what skills and compromises work best in research relationships." "My knowledge and understanding of group work and theories of leadership definitely did improve from the background research and training I undertook to create the materials"
	Concept of themselves as scientists	4.0/5 "I was more confident in 'being a scientist', and comfortable with the idea of starting and finishing a project." "[FSFE] was my first exposure to 'cutting edge research'. Going forward, it made me aware that knowledge in the field of biology is changing and growing all the time, so I studied with a more critical lens."		3.1/5 No relevant quote
	Capacity to reflect on learning during later courses	4.2/5 No relevant quote		3.5/5 "This course allowed me to... iteratively develop my approach."
	Networks of students/staff at the Research School of Biology	4.4/5 "The close interactions between staff and students on the field courses broke the traditional lecturer-student barrier such that I was more able to interact with lecturers as people rather than being nervous to reveal my boundless ignorance."		4.0/5 "These relationships have continued to serve me after the field course, both in terms of sense of community and knowing who to reach out to for advice or assistance."

Figure 3: Responses of students (left column) and staff (right) to a retrospective survey of perceptions of the impact of FSFE. The survey questions used a Likert-scale ranging from 1 (not at all) to 5 (very much). Mean ratings above 3/5 were considered to indicate an increase in the relevant sphere. Open ended comments from the survey are included to illustrate impacts. Blank spaces on the staff side indicate that a question was not asked of the staff.

All 21 staff respondents reported having some kind of university teaching experience before participating in FSFE, with most (85%) having tutoring/demonstrating experience in on-campus courses and 30% having been course convenors. These respondents' professional interest in teaching was evident: almost half (45%) had been involved in peer discussions about teaching, some had completed teaching development programs (35%), and some (25%) had received professional recognition in teaching, such as national or institutional teaching awards and/or fellowships of the Higher Education Academy (25%).

However, just 15% reported having already been highly experienced in supporting residential field courses—which we defined as having taught in four or more field courses before FSFE. Notably, 60% reported having had no experience in teaching or supporting students at residential field courses before their participation in FSFE. While these findings are unsurprising given the ongoing global cost-cutting shift away from field-based teaching that started in the 1990s (Boyle et al, 2007; Cotgreave, 1996), it shows the value of the professional development focus of FSFE for staff.

What was most striking about the staff responses in this context was that—irrespective of prior teaching experience—all staff respondents reported that their professional participation in FSFE had improved their teaching skills. The great majority (90%) felt FSFE had specifically improved their capacity for reflection on their own teaching practice, and most felt this experience had improved their overall teaching, substantially in some cases. Many staff reported that, after participating in FSFE, they had been encouraged to do more teaching and seek out further professional development around their teaching.

Staff also commonly reported that FSFE benefited their research, by inspiring future research endeavours, and/or their career pathway, by providing development of both practical and 'soft' skills. Almost two thirds of teaching staff specifically reported an increase in their own technical confidence and their knowledge of ecology, with half of these reporting a significant increase (Figure 3).

About two thirds of staff respondents also reported that participating in FSFE had resulted in a notable or significant increase in their professional networks. Staff identified a range of the longer-term benefits that had come from these broadened professional relationships, including unique opportunities to gain mentorship, initiate collaborations, and strengthen previously limited links with specific researchers.

Concluding remarks: elements of a successful field course

Our five-year evaluation of FSFE has shown a great array of positive outcomes which we believe demonstrates increased self-efficacy, learning gains, confidence, collaboration skills, research interest and more among our students. The field course model provides an outstanding vehicle for research-led education, to recognise and nurture talent, and to foster collaboration skills that will prepare students to address the pressing challenges the world is facing. It also can create a genuine and active community of scholars, recognising that the ability to conduct sound research requires much more than understanding of basic science alone. In his seminal work on scholarship, Boyer (1990) explored the notion that knowledge is acquired through research, synthesis, practice, and teaching, which are all foundational principles in our FSFE design. Moreover, the FSFE field course not only provides all these activities *to* the students, but over time has engaged ever more fully with the principles of peer learning (O'Donnell & King 1999) and 'students as [research and teaching] partners' (Cook-Sather, Bovill & Felten, 2014).

In summary, for those considering designing or revising a field course, there are a few elements we particularly encourage you to consider.

The **rapid prototyping** of small-group or independent research projects conducted as apprenticeships mentored by experts is highly effective, particularly when offered alongside carefully timed injections of content and skills development workshops. In part by natural evolution and in part by design, the model onboards many contemporary conceptualisations of pedagogy—research-led teaching, constructive alignment, cognitive apprenticeship, collaboration, authentic learning, social identity, transformative learning, reflective practice, to name a few. Incorporating these effectively relies on careful curriculum planning but becomes second nature with practice.

We strongly recommend **explicitly weaving concepts such as social identity and reflective practice** into the course fabric from the outset as this yields solid early outcomes that allow the continuous improvement approach: build on strengths rather than trying to address weaknesses. We took the intentional stance (Dennett, 1989) that we are all lifelong learners and that even our first-year students are 'apprentice ecology researchers' rather than 'students'. If this perspective imbues the whole teaching team, including resource people, the course can facilitate this identity transition in the students. It is quite rewarding to observe this gentle shift in viewpoint and behaviour from 'we are a group of students and academics' to 'we are all scientists creating knowledge together'.

A **commitment to teaching complex 'soft' skills** like collaboration, teamwork and reflective writing can have surprising and clear payoffs. The shift we noted from reflection 'on action' to reflection 'in action' meant that individuals became more capable of recognising the range of diverse skills and capabilities within both the student cohort and the broader group of resource people This enabled all to share responsibilities and outcomes more effectively, discovering together and supporting one another. Supporting students through the complexities of first-hand experiential learning about the scientific process requires more commitment than simply providing pre-digested information, but is much more effective in developing the knowledge handling and critical thinking skills that will benefit lifelong learners.

Indeed, students consistently report that **content taught 'just in time' or discovered 'on the go'** and under some pressure was assimilated more quickly and deeply than the equivalent knowledge taught in packaged lectures over a semester in a campus-based course. Our students learned that they could assimilate a much greater amount of complex content than they initially believe they can, especially if they are genuinely curious and/or 'need to know', and they also learned that content alone does not equal learning. The structured reflective, apprenticeship approach and rapid prototyping and refinement of each stage of the research process, enable students to quickly develop an enhanced scientific understanding of diverse local ecologies and quite sophisticated knowledge and skills as ecology researchers. These cognitive gains and efficiencies led directly to the very high-level symposia presentations at the end of each course with which invited guest scientists were so impressed, and to the recognition that we had quality material that with respectful but rigorous peer review could provide an entire student-led journal.

The field course also provides an ideal vehicle for **modelling elements of real contemporary science.** We have high expectations of our students to work hard and to challenge themselves, but because we **don't ask them to do anything that we wouldn't** (or don't) do ourselves, they rise to the occasion. Within reason, a modern field course can incorporate remarkably high-tech equipment and teach cutting edge technique. Equally importantly it is a vehicle to introduce students to the principles of

open access publishing and **data sharing.** Our Field Studies in Ecology Journal has been an extension of these principles and introduces our students to academic publishing culture. Finally, we also suggest that actively **engaging the relevant local stakeholders** has far reaching rewards.

After a successful field course **many members of the student cohort remain in 'scientist' and 'team' mode** and are eager to stay connected with the teaching team and topics, and so we have found a range of avenues for them to maintain those networks. Becoming authors and editors in the student-led journal (and also in this paper) is one opportunity. We also provide a pathway for some students to return as Advanced students or to seek roles as FSFE tutors or eventually Resource People. The field course can also be a pathway to broader leadership roles (e.g. in the university's Biology Society). A satisfying outcome of a course like this is students report that they leave the course with increased confidence and a comfort in identifying themselves as practicing scientists. They are on the road to satisfying and varied careers, using their newly acquired capabilities and skills as team-based researchers, analysts and creative, critical thinkers.

An ancillary benefit of our model has been that our **staff often report significant spin-off benefits of being involved in the course.** This is expressed not only in research outcomes, collaborations, and students interested in further study with them (e.g. in Honours, Master and PhD projects), but also in their own development as research-led educators. We have shown the FSFE staffing model is ideally suited to supporting research-intensive early career scientists who would like teaching experience but are not in positions that reward or enable extensive periods of ongoing teaching.

We hope that our exploration of how the FSFE course functions as a living and evolving form, constantly changing to suit the context in which it is taught, and the expertise and interests of the teaching team provides fodder for development of other field courses. Through field courses our students experience real science with real researchers and develop skills to prepare them for a diverse array of successful careers.

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A range of supporting materials for this course (including Field Problem Abstract Books and workshop materials) are available on request.

Author Contributions

All authors made substantial contributions to conception and design, acquisition of data or analyses. All authors contributed to writing the paper and approved final submission.

Competing interests statement:

None to declare.

Data accessibility statement:

Data will be made publicly available on FigShare as allowable under human ethics constraints.

Figure Legends

Figure 1. A schematic of a) the overall course structure pre, during and post-intensive and b) the rapid prototyping approach of the field problems.

Figure 2. Students are presented with the Learning Outcomes of our course from the outset and Assessment Tasks are aligned to enforce these outcomes. A series of workshops, timed to provide skills at key points in their research process, supports the learning objectives. Quotes drawn from Minute Paper evaluations conducted at the end of the workshops demonstrate what the students learn from each.

Figure 3: Responses of students (left column) and staff (right) to a retrospective survey of perceptions of the impact of FSFE. The survey questions used a Likert-scale ranging from 1 (not at all) to 5 (very much). Mean ratings above 3/5 were considered to indicate an increase in the relevant sphere. Open ended comments from the survey are included to illustrate impacts. Blank spaces on the staff side indicate that a question was not asked of the staff.

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