A guide to pedagogical research for scientists from a biological sciences background

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A guide to pedagogical research for scientists from a biological sciences background

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Abstract

How we teach science and engage with the public, particularly in fast moving subjects such as microbiology, are constantly being reflected upon, improved and innovated. This has led to a significant increase of pedagogy publications by microbiology educators in higher education that have had a positive impact on teaching quality, student retention, progression and course satisfaction as well as how science is communicated with the public. In this paper we describe the different types of pedagogical manuscripts that biological scientists could write and the benefits that derive from doing so. We provide a glossary of terms often seen in educational literature. Project design and qualitative and quantitative research methodologies are discussed, highlighting ethical and General Data Protection Regulation (GDPR) considerations. Suggestions are made regarding how to network with colleagues who are also keen on writing pedagogical papers as well as examples of good practice. Lastly, a handy how-to-start guide aims to help with first steps. We hope that this paper will be a useful survival manual for colleagues who wish to engage in exciting pedagogical research in the field of microbiology and the broader biological sciences.

INTRODUCTION

Pedagogy is the study of teaching and learning in an educational setting and spans early years, through schools and colleges into higher education and out into the general public. At its heart, pedagogy research aims to improve the experience and outcomes of learners utilizing evidence-based approaches, often framed around the actions of the educator. Within a higher education setting, academics are primarily concerned with the university student experience and the retention, progression and attainment of students. In addition, interests may lie in the transition for students from post-16 education into higher education, aspiration of school students to study in higher education as well as the public's understanding of scientific research. This has led to the development of various creative interactive approaches for improving student participation and experience in the lecture theatre, classroom and laboratory as well as initiatives focusing on increasing student attainment and narrowing the awarding gap of marginalized student groups [1–5]. As a result, the volume of pedagogical papers published by teaching-oriented natural scientists has increased significantly during the last 5 years [6].

Microbiology, as well as a stand-alone degree subject, is a key component of Biosciences courses due to the role of microbes in human, animal and plant diseases as well as being invaluable to the field of biotechnology. Microbiology teaching faces similar challenges to those across the sciences, with microbiology students traditionally being required to memorize the names of microbial species, link them with specific diseases and then remember numerous virulence factors and disease symptoms, elements that many students find challenging and often frustrating [7–9].

Public engagement or outreach is often seen as distinct from higher education pedagogy but shares many similarities as it predominantly aims to understand the impact of work and participants' understanding of, or relationship with, science. Pedagogy research undertaken in schools and colleges is critical as it inspires the next generation of scientists. Although outreach events are often targeted to the public instead of university students, the latter can be often involved in such activities, participating in the noble cause of science communication. Citizen science projects link school and college outreach with science communication to

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Abbreviations: ANOVA, analysis of variance; BERA, British Educational Research Association; GDPR, general data protection regulation; NSS, National Student Survey.

the general public, which can be invaluable in raising public awareness about major microbiological issues such as COVID-19 and antimicrobial resistance [10]. Finally, papers describing outreach activities are also extremely useful in evaluating and sharing best practice and innovation [10–12].

Motivations for undertaking research in pedagogy

Pedagogy research is rooted in driving evidence-based improvements to students' education. In addition to the clear benefits of pedagogy research for the improvement and support of learning and educational experiences, undertaking and disseminating pedagogy research has several significant benefits for the individual academic, their department and institution, as well as the wider scientific community.

For the individual academic researcher, when improving their own teaching and making the associated modules/courses better and more sustainable, undertaking research to quantify the impact on students gives evidence of good and excellent practice. Creating traditional outputs (conference talks, manuscripts) from this research gives scholarly impact to support career development, such as appraisals, Higher Education Academy fellowships, promotion applications as well as funding bids. These are particularly helpful for academics in teaching-focused roles such as teaching fellows, colleagues who want a career change from research to teaching and PhD students who are interested in a career in university teaching [13].

Departments and institutions benefit from improving teaching, learning and assessment and student performance and satisfaction, as these can directly help improve NSS (National Student Survey (UK)) scores and university league table rankings for an academic institution [14].

For the wider scientific community, undertaking and disseminating pedagogy research allows the sharing of new ideas and tools for improving teaching and can lead to the formation of a valuable body of pedagogical literature for the community. Practices for pedagogical research, such as statistics, ethics and elements of study design, can be standardized and built upon, leading to comparable and transferable results of higher quality and stronger impact, driving better quality teaching and outreach. Finally, outreach papers show us new ways for attracting the public's attention about key microbiology issues that directly affect our lives and communities [15, 16].

Aim and objectives

The aim of this paper is to motivate and facilitate microbiology, and more widely biological sciences, educators in higher education to carry out and publish innovative pedagogical and science communication research. This will be achieved by highlighting the benefits of doing so, how to navigate challenges that might be encountered and finally suggesting solutions for making things easier through this journey, especially for individuals starting out in the world of pedagogy writing. To achieve our aim we will provide useful information about pedagogical terminology, project design challenges, research methodologies, and networking with research partners and mentors.

PEDAGOGY LITERATURE AND THE LANGUAGE IT USES

Microbiology, and more widely biosciences, pedagogy research can be found in a range of outputs that mirror traditional scientific research, and include blogs, conferences posters and presentations, book chapters and journal articles. Pedagogy and public engagement journals range from social sciences-based journals (e.g. *Public Understanding of Science*, *International Journal of Science Education*) through to subject based educational journals (e.g. *FEBS Open Bio*, *Access Microbiology*), with subject-based educational journals being more accessible to researchers new to the field.

As with any field, pedagogy has its own style and language (Box 1), with biosciences education journals having a style which can be seen as a mixture of a science-subject journal and sociology journal. Microbiology-based journal research articles, such as in *Journal of Applied Microbiology*, are written in short concise text, with multiple tables, graphs and figures with clearly defined introduction, methods, results and discussion sections. Sociology-based journals such as *Public Understanding of Science* and *Journal of Research in Science Teaching*, may have more descriptive language and a different layout, with an extended introduction leading to a theoretical framework, methods section, analysis and conclusion. As a newcomer to the field, it is often easier to access and develop knowledge and confidence in biosciences education journals before migrating to sociology-based journals.

HOW TO UNDERTAKE PEDAGOGY RESEARCH: A START TO FINISH GUIDE

Stage 1: Project design

Pedagogy research ideally starts with an idea and research question. The project is then planned and undertaken in much the same way as biological research; it is initiative-taking in its design, is hypothesis driven and can lead to high-quality research. To consider in this stage: What is the research question? Is it relevant? How does the research design answer this question? To be able to fully plan a research project all elements must be considered, from ethics, to methodologies and data analysis (see stages below).

Box 1 : Top 10 new words

A new research area means new words. In this box there are a variety of different approaches, theoretical bases, data collection and analysis methods that will be explained in more detail in the rest of the paper. Here is a summary of what each of our top 10 new words means as a source of reference.

Iterative approach – where the research method, data and research outcomes are revisited as each piece of research is analysed to best answer the research question.

Focus group – a group of participants brought together to discuss a predetermined set of research questions. Focus groups are typically recorded and transcripts made for further analysis [52].

Mixed methods – where both qualitative and quantitative data are collected and analysed by researchers to answer the research question.

Coding – coding underpins both **thematic analysis** and **grounded theory** and is the process of labelling sections of text. Different types of coding range from the initial process of describing qualitative data to scanning data for predefined codes [53].

Thematic analysis – a method of qualitative analysis which identifies common elements known as **themes**. Thematic analysis is flexible and relatively straightforward compared to a full **grounded theory** approach [26].

Themes – developed during **thematic analysis** themes are key and recurring phenomena, ideas or patterns that are relevant to the research question. Themes are identified by **coding**.

Grounded theory – a common method of qualitative analysis. The analysis is grounded in the data and takes an iterative approach to **coding, constructs** and theories [27].

Categories – within **grounded theory, coding** is first used to identify concepts (analogous to **themes** in **thematic analysis**) and these concepts are further described and identify real-world phenomena.

Theoretical framework – an existing theory, such as **science capital**, that research study is based around. This gives a specific lens, or viewpoint, from which the research question answered.

Science capital –a common **theoretical framework** which is based on social and cultural capital. It is how much science, and affinity to science, someone has accumulated in their lifetime, and includes scientific knowledge, attitudes and values towards science, interaction with science media and family science-based skills, qualifications and employment [18, 54].

In some instances, a project or event has already been planned or even undertaken, and the author(s) would like to write it up, most often as a case study. This observation-driven approach may lead to difficulties if ethics and General Data Protection Regulation (GDPR) considerations are not in place before data collection.

An additional form of project design, more frequently seen in social sciences, is when research can start with collecting data and then develop a narrative or hypothesis from that, hence grounded theory, where the act of interaction with the project leads to the hypothesis [17].

Theoretical frameworks are most often found in social science journals as opposed to biological sciences-based journals. A theoretical framework is an educational theory upon which the research question and method is built or hung. They can be viewed as different approaches to view the same question, whereas in microbiology researchers may take a metagenomic or culture-based approach to learn more about a particular disease state, and theoretical frameworks can give different lenses to look at the same question. Theoretical frameworks are a very different way of thinking and organizing research than biologists are used to, so if starting to framing research around one, it would be advisable to collaborate with an educationalist or sociologist in the first instance [18] (Box 2).

Stage 2: Ethics and GPDR

Depending on the type of biosciences research undertaken, researchers may have very little to vast amounts of experience in ethics. For those with little experience, ethics for the entry-level researcher is discussed. Ethics is a major consideration of pedagogy research, and most journals will not allow publication without it in place; however, many higher education institutes do not permit retrospective ethics, so data collected specifically for a research project without ethics in place may be unpublishable and may even need to be destroyed.

Ethics applications can be time consuming, but as part of the project design process they provide an important opportunity to think about what the purpose of the research is, consider what the best research questions are in the context of existing literature and ensure the most appropriate methodologies are used. Starting ethics applications for the first time often feels overwhelming, and resources such as those by BERA [19] can be of use as well as institution-level ethics training in addition to a mentor. Key ethical considerations are around protecting those involved in the study, the researcher conducting the study and the research institute. Asking questions in the design of the experiment will aid the ethics process.

Box 2: Learning theory

Most pedagogy research will, perhaps unknowingly, draw on or be based around an learning/educational theory. These theories are often described as a lens to look at a research question or data set, or a window to look into a room with the research question or data inside, with different windows, or learning theory, giving a different perspective on the data. It is tempting to speculate that an easier analogue for bioscientists is a different methodology, which when applied to the same bacterial strain, will give different data sets that allow the research to investigate different elements of the strain. Widely used and study learning theories are:

- Behaviourism – think Pavlov's dog; education is about the learner being influenced by both positive and negative environmental stimuli. The learner is seen as passive.
- Humanism – education is all about the learner; focusing on creating an environment to meet the learner's education needs with the teacher assisting the learner in this journey.
- Cognitive – think the brain as a computer; learning is influenced by internal and external factors. Learning is built on prior knowledge.
- Constructivism – building blocks; the learner builds upon previous experience and interactions to build (construct) new understanding.
- Connectivism – think the internet; learners draw on a large pool of knowledge and make connections within the information to undergo learning [55].

For example: Do I really need to collect these data? Are all the elements of your questionnaire or focus group questionnaires needed? If you do not need the answer to the question to answer your research question, then why are you asking it?

Will any student group be advantaged or disadvantaged through my action? If you have two groups, one being given better teaching than the other, then this is unethical as it is disadvantageous to one group over the other. To ensure this does not happen, the alternative teaching method can be offered to the other group after the intervention evaluation.

Could what you are about to study put you, or your institute, on the front page of the local or national newspaper for the wrong reasons? If what you are going to research is possibly contentious, think about how you are going to manage the research so it does not bring you, or your institute, into disrepute.

Within the UK and EU, data protection (GPDR) compliance is critical for researchers and is often embedded within the university's ethics procedures as there are several core overlapping elements. For example: where will the project data be stored and who will have access, why do they need access? Data should be as secure as possible and only those in the research team should have access.

Are the data only being used for what the participants consented to? Are the data as anonymous as they can be whilst being stored? Data do not have to be fully anonymous, but storing information that is not needed, such as names and email addresses, increases the severity of a data breach.

Finally, many universities now require completion of a Data Management Plan before starting any work.

Stage 3: Research methodologies

Pedagogy methodologies are diverse and span complex numerical data sets that life scientists feel familiar with to qualitative data that is the analysis of words, ranging from short open text responses within questionnaires to semi-structured interviews and written text. Choosing the correct methodology for a study, one that will allow the research questions to be answered, will vary depending on the project, budget and the confidence of the researchers in utilizing these methodologies.

Broadly speaking, pedagogical research is split into quantitative and qualitative research methods, with research that combines them referred to as mixed methods. Some data may be pre-existing or already collected within the usual business of an institute, such as assessment marks, module and course reviews, and student demographics, whereas other data will be collected within the study. Quantitative data are typically collected through questionnaires/surveys and qualitative data can be collected through questionnaires in the form of short and longer free text responses, focus groups and interviews as well as through participants' written reflections [20].

Mixed methodology is a combination of qualitative and quantitative methodologies brought together to answer the research question. This mixed methodology could be within the sample data collection, for example the combination of Likert scales and short answer questions within a questionnaire, or within a study, for example with a questionnaire and its analysis providing a basic understanding of the research question and then focus groups, informed by the previous data analysis, being used for in-depth analysis of more interesting or complex issues [21].

Stage 4: Data collection

Questionnaires are ideal to collect the views of a large group and are ideally quick and easy for participants to fill in. Key elements of questionnaire design are being research question-focused and ensuring the questionnaire is accessible and straightforward to answer [21]. It is also important to identify how biases are going to enter the data set. Think about how the questionnaire is presented to participants; are only engaged students at the session? If the questionnaire is to the public at an outreach event, are attendees opting-in to fill in the questionnaire or are researchers undertaking exit questionnaires to gain a representative sample [22]?

Focus Groups are a good way to gain more detailed and nuanced research from a group of participants and allow the participants to discuss and explore ideas or questions together. Focus groups are structured by pre-determined questions and the design of these questions is key to answering the research question [23].

Structured Interviews also utilize pre-determined questions but are conducted in a one-to-one setting. They are more time consuming than focus groups to reach the same number of participants but can give a more detailed data set. Structured interviews are ideal when discussing personal experiences but particular care is needed of the power dynamic between the interviewer and interviewee. The biases within focus groups and semi-structured interviews come primarily from asking leading or unsuitable questions and who the participants are, and if they are representative of the communities the research wishes to engage with, as well as participants not feeling comfortable in the setting and answering the questions how they think the interviewer wants them to be answered [24].

Stage 5a: Data analysis – quantitative data

Quantitative methodologies are often where life scientists start in terms of pedagogy study design, as this is the data that biological scientists are most familiar with. If Excel, R or Prism (other software is available) can be used then researchers feel more comfortable in their abilities to analyse them and draw relevant conclusions.

Some quantitative data feel very familiar; **interval/ratio data** such as student marks and participants' ages can be analysed in a similar way to data frequently analysed as biological scientists, with corresponding statistical analysis, such as *t*-tests and ANOVAs, and their nonparametric equivalents being utilized.

Ordinal data are those which can be ranked, often in the form of Likert scales, where participants identified their experiences on a scale, e.g. 1 – strongly disagree to 5 – strongly agree. These data can be analysed as numeral values but as they are ranks, rather than values, care should be taken in the analysis of such data and most often medians are reported rather than means and statistical methods such as Krusall–Wallis and Mann–Whitney's utilized.

Finally **nominal** data, such as gender, course and ethnicity, are often key in answering research questions and can be used within bivariate analysis to determine differences between groups of students in terms of their attainment or student experience and also analysed within their own right with frequency tables and statistical analysis such as Chi-squared tests [20, 25].

Stage 5b: Data analysis – qualitative data

Qualitative methodologies and data are often new and unfamiliar to microbiologists and biologists but offer a richness of data that cannot be achieved by quantitative methods. In the simplest sense qualitative data analysis is the analysis of words, either the written word or transcripts of spoken words. They can range from the analysis of short responses within questionnaires through to analysis of multiple, hour-long interviews. Unlike quantitative analysis, qualitative analysis has a more iterative approach, with analysis being undertaken, and further literature reviewing followed by further analysis. Similarly, data can be re-analysed after further work as well as within a mixed methodology, with short answer questionnaire responses informing questions for focus groups and interviews. Software such as NVivo is widely used for analysis of large pieces of data such as transcripts of interviews and focus groups.

Thematic analysis is the qualitative method of choice for most subject-focused educational research, as it allows an accessible approach to analysing open text and focus/group interview data without having to undertake the more complex task of working within analysis frameworks such as grounded theory. Briefly, thematic analysis is where researchers identify themes within data, such as motivations or experiences, and the data are then coded with these themes. Themes can be predetermined based on the research question (close-coding) or be based on the data (open-coding). Reflection on the literature and an iterative approach can evolve themes determined by open coding in axial coding. If these themes are part of a mixed data set, such as a questionnaire, themes can become part of the data set, and act as quantitative, nominal data. This is a conforming way for many life scientists to start qualitative research, because although the data and analysis were qualitative, the merging of the data with quantitative data returns the researcher to the safe space of spreadsheets and numbers, tables and graphs. For larger pieces of data, such as reflective essays, focus groups and interviews, thematic analysis provides a framework to pull out key themes within a dataset, with examples of text being given to support these themes upon dissemination [20, 26].

Grounded theory is a more involved approach, with themes being replaced with concepts and categories and an extensive iterative approach taken. Briefly, grounded theory is more often used where qualitative data are collected over a period of time, with each round of data collection and analysis impacting the research questions and future methodological design. Grounded theory is often used to make new theories and frameworks; these are more often seen in pedagogy journals at the social sciences end of the spectrum, rather than subject area-specific journals [20, 27–29].

EXAMPLES OF GOOD PRACTICE

Pedagogy encompasses a wide range of topics, which are often interlinked and build upon one another. Some of these papers start with a certain research question, while others involve an evaluation study following the introduction of an educational activity.

Innovative teaching methods: Creative flipped classroom approaches where learning changes from teacher-centred to learner-centred have become excellent alternatives to the traditional methods of delivery [30–32]. They usually involve problem-solving exercises, teamwork, journal clubs and debates. In these cases, the instructor initiates and moderates the activity, but most of the work, subsequent discussion and often peer reviewing is undertaken by the student groups [30, 31]. Case studies of innovative teaching can often describe beneficial activities such as field trips, summer placements, events and laboratory experiments [3, 11, 33, 34]. In addition, innovative teaching methods and resources can also be used with outreach with schools and colleges as well as the general public [11, 12, 35]. For instance, Duckett *et al.* [36] ran a *Night at the Museum* activity, where visitors attended a Halloween-inspired microbiology-themed series of interactive exhibitions hosted within a national museum.

Games: Gamification of teaching in higher education is another very successful trend. Introduction of creative games can improve engagement, as students learn in a recreational and enjoyable way, and it boosts enthusiasm about the field of study. These methods can also be used to engage the public and school children. Types of such activities include card, computer, board and role-playing games [37–41]; this approach can also be used for research project design [17]. For example, Efthimiou and Tucker (2021) [39] applied a microbiology card game that combined the use of microbe trump cards and Cards Against Humanity questions, managing to boost student performance and enthusiasm [39].

Use of social media: The use of Twitter, Facebook and other social media in microbiology teaching has been found to be very effective. For instance, Racaniello [42] showed that utilization of science blogs and podcasts via social media allows microbiologists to easily teach about complex science [42]. Piantola *et al.* [43] launched an 'Adopt a Bacterium' project via Facebook, an activity that was very positively evaluated by the students, helped them to change their attitude on how to process information and facilitated knowledge retention [43]. Furthermore, Twitter was employed for delivery of #EURO-microMOOC, the first free worldwide Microbiology Massive Open Online Course content analytics indicated that more than 3 million users saw their posts [44]. Finally, WhatsApp was used effectively for teaching microbiology, although several students were concerned about the time adjustments required before this approach is routinely used in their curriculum [45].

Increasing equality for marginalized groups: Using student data (ethnicity, gender, educational history, socioeconomic background, etc.), researchers can increase the accessibility and equity of teaching by ascertaining the impact of an intervention on different marginalized student groups compared to their peers [46–48]. The same approach can be taken when determining if the participants of outreach events are representative of the wider community or if some groups are underrepresented [36, 49]. For instance, Hubbard [48] followed a series of data-driven approaches to address systematic awarding gaps, aiming to improve equity and diversity for success in higher education.

Student experience: How students interact with their curricula and their experiences in higher education can be investigated and how these experiences are affected by students' self-esteem, stress or confidence can also be examined, often in collaboration with an educational psychologist. Such studies can lead to improvements of performance and retention by taking a student-focused approach in curriculum and pastoral support design. For example, Okpala *et al.* [50] highlighted the effects of parental involvement, instructional expenditures and family socioeconomic attributes on student achievement.

Reviews: Collection, description, critical analysis and synthesis of recent publications on a specific pedagogical topic, as well as meta-analysis of their data, can be very useful for colleagues who want to familiarize themselves with an area and its controversiality [50, 51]. For instance, Oliveira *et al.* [6] wrote a very useful literature review about emerging technologies as pedagogical tools for teaching and learning science.

HOW TO FIND YOUR PEOPLE

Scientific research is enhanced by collaborations and mentoring, and pedagogy research is no different. Depending on your institute, you may already be in a department with active pedagogy researchers, there may be a group of like-minded colleagues wishing to start publishing research or you might find that you are the first person in your department to start

pedagogical research. The lack of research partners, mentors and critical friends when starting a new research area can make it difficult to start, so how do you find your people?

Most institutes that undertake teaching will have learning, teaching and assessment or student voice working groups at college/faculty and university level if they are not present within departments (the name of these groups will probably vary from institute to institute). Look for people doing interesting things and groups already in place; start from the local level of your teaching teams to your department, then wider to your college/faculty and research institute and then finally across your whole institute. You may find a research partner within your teaching team and a critical friend outside your department.

Finally, look for your national and international networks. The biosciences pedagogy community is incredibly welcoming and supportive and runs workshops, mentoring networks and conferences where you can meet new friends, research partners and mentors. For example, The Microbiology Society has the Microbiology Educators Network and the Royal Society of Biology the Biosciences' Mentoring Network. The Microbiology Society and the Royal Society of Biology have pedagogy and outreach workshops and conferences that run throughout the year.

HOW TO GET STARTED

Beginning a new field of research can be daunting and it can be difficult to know where to start. In addition, funding for pedagogy research is limited and so academics often do the lion's share of the project, which can be difficult in an often already time-pressured environment. There are some similar steps to make starting your research easier.

Step 1: Don't go it alone – finding your people is important but finding a research partner is invaluable. Having someone as invested as you in your project to discuss the research, share concerns and help drive the project will make starting research in a new field much less daunting and keep the project moving.

Step 2: Put the learners first – pedagogy research is all about having an evidence-based approach to teaching, learning and assessment, so put improving learners' experiences at the heart of projects.

Step 3: Bat smarter not harder – embed your pedagogy research in current practice or a current role. Complement what you are already doing.

Step 4: Use the resources you already have – the chances are that you will not get lots of time or money to do your pedagogy research, so be canny with the resources you have. Final year capstone project students can undertake pedagogy research, and coursework from higher education training courses can be adapted to form an introduction to a paper.

Step 5: Start with what you know – if you are apprehensive about mixed methods and qualitative research, that is OK; start with what you know. Quantitative data that already exist, or are easy to collect, can form interesting data sets and are within the comfort zone of most biological scientists.

Step 6: Have an achievable aim – knowing what you want out of your research is really important. You might want your first small piece of research to be written up into a blog for your institute or be presented at a conference and then the next project be a journal article. If you are not sure where you can publish your work, get familiar with journals and the type of papers they publish. Do not be afraid to email journal editors and ask if they would potentially be interested in your work; knowing where you are aiming a paper early on makes it much easier to write.

Step 7: Remember: if you are not having fun, you are not doing it right! – pedagogy research shows what you are doing has a real impact that affects students and the wider public lives and thus it is really rewarding. The biosciences and microbiology pedagogy research community is very friendly and supportive, so research here is hard work, but really, really good fun.

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