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Participatory science and course-based undergraduate research experience to improve research-informed teaching of evolution and palaeontology

Stephan Lautenschlager[1,2*]

Abstract
This study introduces a participatory science-inspired approach to teaching and curriculum design, involving undergraduate students directly in active research. Using a case study on dinosaur eye size, integrated into a first-year undergraduate course in Geology and Palaeontology at a UK university, this study presents the advantages and disadvantages of this approach for both teachers and learners. As part of the study, 22 undergraduate students were involved in data collection, analysis, and the subsequent publication processes, emphasizing active student participation in research. A subsequent survey demonstrated high student engagement and perceived relevance of this participatory science-style teaching approach. Results indicate that students found the approach appealing, engaging, and beneficial for understanding scientific concepts and methods. The case study shows that a participatory science approach through a course-based research experience can enhance student engagement and learning by providing meaningful, hands-on research experiences. This approach allowed students to apply theoretical knowledge in a realistic context, fostering their understanding of evolutionary theory through active data collection and analysis. However, care should be taken concerning data accuracy and ethical aspects, such as exploitation of labour and the recognition of knowledge creators and participants. Despite these challenges, the benefits of integrating such approaches into higher education curricula can be substantial, offering a valuable model for teaching evolutionary theory and related topics.

Keywords Palaeontology, Earth science education, Participatory science, Student engagement, Research-led teaching, Research-informed teaching

*Correspondence:
Stephan Lautenschlager
s.lautenschlager@bham.ac.uk
[1]School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, UK
[2]Lapworth Museum of Geology, Birmingham, UK

Introduction

Over the last 60 years, there has been a significant evolution in the role of research and its intersection with teaching in higher education (Committee on Higher Education 1963; Elton 1992). In particular, in the UK and other English-speaking countries, the paradigm of *research-led teaching* has emerged as the benchmark for bringing research into university lecture rooms (DfES 2003; Schapper & Mayson 2009), championed by research-intensive institutions aimed at securing a competitive edge in student recruitment (Healey et al. 2003). However, a clear definition of what constitutes research-led teaching remains more elusive, with various synonymous terminologies being used. In fact, numerous studies have been dedicated to expanding on the original concept and on the different forms of integrating research into teaching curricula (Healey et al. 2003; Griffiths 2004): (I) *Research-led teaching involves* specialist educators (i.e. researchers) introducing research findings in taught modules, often selected from their area of expertise. (II) *Research-oriented teaching* places greater emphasis on the processes of how research knowledge is acquired and produced, often highlighting inquiry-based skills, and drawing from the experience of researchers or conventions and standards in the discipline. (III) *Research-based teaching* is centred around inquiry-based activities to achieve learning objectives. (IV) *Research-informed teaching* brings all of these elements together with teachers and students actively engaging in inquiry-based activities underpinned by the teacher's research background.

The first two definitions and approaches predominantly position students as passive audiences, receiving information they may find useful but cannot necessarily connect with. In fact, students may perceive research-led teaching as a disadvantage if they feel sidelined by the prioritisation of educator's research activities over their own learning (Neumann 1994; Jenkins et al. 1998; Zamorski 2002; Healey et al. 2003). In contrast, research-based and research-informed teaching includes students as active participants in both their learning as well as research activities. A number of studies and papers have been dedicated to engaging students in learning and research going beyond the classic transmission model of just including and presenting research in the curriculum. For example, Brew (2002) makes a distinction between teacher-focused and student-focused learning, similarly arguing that the latter is beneficial with students being able to take ownership of their own learning. However, the question remains how students can be confronted with research content effectively and be motivated to engage with it. The approach presented in this work takes inspiration from different examples where researchers and learners (in the widest sense) engage and interact on a mutually beneficial basis: participatory science (also known as citizen or community science) and course-based undergraduate research experiences (Auchincloss et al. 2014).

Broadly defined as involving the public in large-scale data collection efforts for specific research projects in collaboration with researchers (Vohland et al. 2021), participatory science has gained traction in recent decades. This is not a new concept, and although the original term citizen science was coined about 30 years ago, some initiatives to have the public participate in scientific data collection date back to the 19th century; for example, the National Audubon Society's Christmas Bird Count project has benefitted from thousands of volunteers collecting data on bird sightings for more than a century (Bonney et al. 2009). However, it is only in the last decades that participatory science has become a widespread tool, underpinned by rigorous scientific protocols and data collection metrics (Cohn 2008). Employed commonly (but not exclusively) within natural and life science disciplines, numerous examples have now solidified participatory science as an important research tool to integrate the public and to maximise data collection.

Many research questions in the context of evolutionary theory and deciphering evolutionary patterns can have large-scale spatial and temporal dimensions, spanning a wide range of phylogenetic groups, and with study objects distributed globally or across geological timescales. Harnessing support from the public is therefore a clear advantage of participatory science, allowing data collection efforts beyond the capabilities of individual researchers. However, participatory science has not been free from criticism. Despite its advantages, participatory science has faced criticism including concerns regarding its potential for neoliberalisation, exploitation of unpaid labour, and commercialisation of the collected data (Michelucci and Dickinson 2016; Vohland et al. 2019, 2021). Additionally, the top-down/scientist-driven approach of participatory science projects, where participants are relegated to mere data gatherers poses challenges to meaningful engagement (Powell & Collin 2009). However, for large-scale projects, it may be logistically impossible to include participants in study design, data analysis, and dissemination.

In a classroom context, it is desirable to engage students in research activities early in their careers. In fact, there is an ongoing call for and effort to embed active research in undergraduate courses (Boyer Commission 1998; Bransford et al. 1999; DfES 2003; National Research Council 2012; Corwin et al. 2015). Numerous studies have demonstrated the benefits of undergraduate research experiences resulting in the active learning of scientific practices, enhanced conceptual understanding, increased interest in science and research, and heightened self-confidence and self-efficacy (e.g. Hunter et al. 2007; Laursen et al. 2010; Thiry and Laursen 2011; Auchincloss et al. 2014; Linn et al. 2015; Thompson et al. 2016; Kinner and Lord 2018). Traditionally, undergraduate research experiences have been achieved through dissertation projects and/or research internships. While the first are obligatory for many undergraduate courses, the latter are often based on volunteering opportunities. In these scenarios, students receive one-to-one training in scientific methods from experienced research staff limiting the reach and the number of such research opportunities (Auchincloss et al. 2014; Shortlidge et al. 2016). In the last ten years, course-based undergraduate research experiences (CURE) have gained popularity to engage a larger number of students in research activities. Akin to participatory science, CUREs typically involve all students enrolled by embedding research into undergraduate courses (Auchincloss et al. 2014). In contrast to more traditional undergraduate courses, students are part of a knowledge creation process rather than consuming knowledge passively, have the flexibility to collaborate and work in teams, and have opportunities to contribute to research outputs as co-authors (Corwin et al. 2015). Further, many of the problems identified with participatory science projects can be avoided in undergraduate courses, as university students are not amateurs and already possess or are being taught the skills that could be relevant to research projects.

Given the clear benefits of CUREs and participatory science-style undergraduate education, a number of examples exist, predominantly in biology, life sciences and other STEM disciplines (Brownell and Kloser 2015; Wang 2017; Oliver et al. 2023; Smith et al. 2023; Watts and Rodriguez 2023), that follow that approach. Within other fields, such as Geosciences, the uptake has been considerably lower (Kortz et al. 2016; Kinner and Lord 2018), and in the context of evolution and palaeontology examples are equally rare (Kelley and Visaggi 2012). For example, CUREnet (https://serc.carleton.edu/curenet), a network and repository of CURE projects lists only four geoscience-themed projects (out of 58 in total) and only one that is focussed on palaeontology. While some projects involve topics around evolution, these are designed from a molecular and genomics aspect. Furthermore, all of the existing examples are from institutions in the US and a more global reach seems to be missing.

I here present a participatory science/CURE approach to research-informed teaching exemplified by a recent case study in palaeontology with the aim to foster an active understanding and comprehension of evolutionary theory. This approach allows introductory-level students to gain first-hand experience of a scientific research project with a positive impact on engagement and learning. Best practices are presented and advantages/disadvantages are discussed making this approach applicable and adjustable for other courses.

Case study: eye size of dinosaurs

Study design

The presented case study was integrated into a year 1 undergraduate course ("Geocience Project") introducing and cultivating foundational skills in research methods (e.g. data collection, analysis, and presentation) as part of a Geology and Palaeontology degree at a research-intensive UK university. The course spanned an entire teaching semester of eleven weeks comprising 2-hour practical sessions each week, accompanied by lectures and corresponding practicals on statistics and data analysis for the first three weeks. The practical components focussed primarily on data collection and analysis for a research project after an introduction to the topic and the research methods to be used were provided in the first two weeks. For the academic year of 2022/2023, the chosen topic focussed on collecting data on the orbit (=eye socket) size of dinosaurs and related groups and on estimating eye size to quantify visual capabilities (Lautenschlager et al. 2023). The topic was selected based on the following: (i) alignment with the instructor's research focus and expertise; (ii) availability of relevant measurements and data from the scientific literature; (iii) novelty of the research question, filling a considerable knowledge gap; (iv) an extensive dataset allowing for data collection by over 20 undergraduate students without unnecessary redundancy or overlap; (v) flexibility to accommodate students' learning styles.

Data collection

Required data included measuring the length of the orbit and the skull length from photographs, line drawings, and diagrams in peer-reviewed publications. All measurements were performed digitally using the software ImageJ (Rasband, 1997–2012). In addition, information pertaining to the phylogenetic relationship, the time range, and the diet of each fossil species from the same or other literature sources (Fig. 1) were collected. Each student was assigned a group of 20–30 species of the same phylogenetic group (e.g. ceratopsian dinosaurs, theropod dinosaurs, pterosaurs) to get them started. Each group was assigned twice so that the accuracy of the data could be compared afterward, and outliers identified. All data was entered on a shared Google spreadsheet accessible to the entire student group. This data subsequently formed the basis for a publication with all students included as co-authors (Lautenschlager et al. 2023).

Assessment

As a formal requirement for the degree programme, the course was assessed in the form of a 1500-word

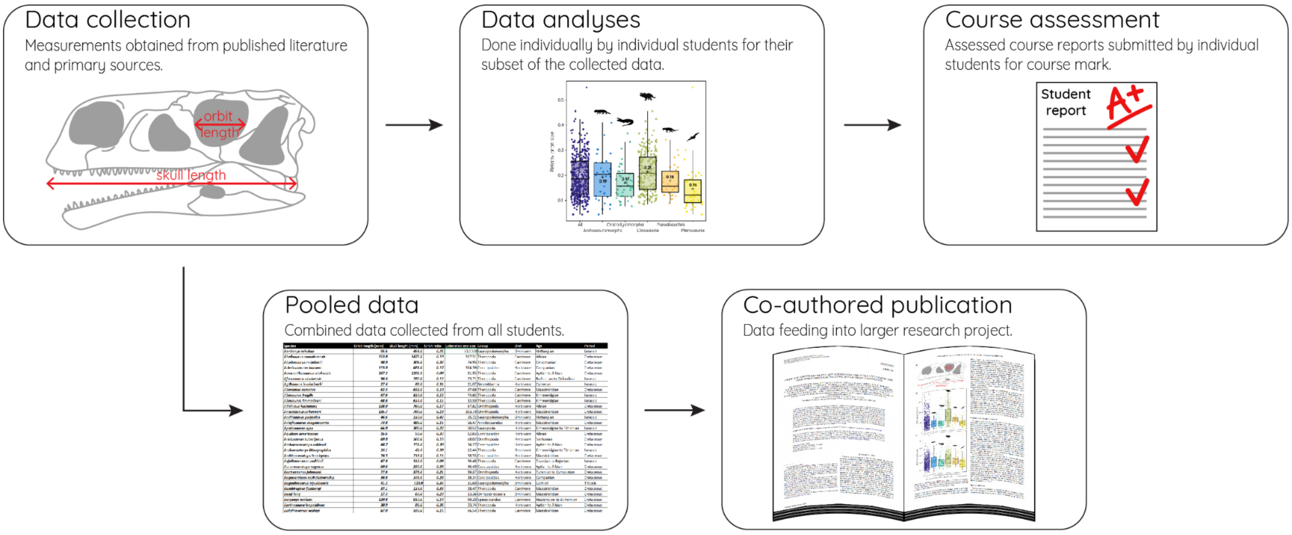

Fig. 1 Schematic overview of the presented participatory science-style teaching approach

research report and a presentation. Students were given the opportunity to submit a draft version of their reports which was not marked and only received formative feedback. Students were given flexibility in selecting a topic for both their reports and presentations, provided the collected data was integrated in some form. Similarly, there was flexibility to choose appropriate statistical tests and to select plots and figures to present the results. Training in relevant software (Excel, PAST, R) was provided as part of the practical components. Students were allowed to compare their data to the entire data set or to subsets collected by their peers as part of the assessment. This approach maximised the flexibility of the assessed work, fostering a collaborative environment for students to leverage collective insight and data.

Learning goals

The overarching aim of the presented approach was to create a learning scenario with students fully emerged into a research project with applicability beyond the lifetime of the course. This was achieved by individual learning goals:

- Conducting data collection within a realistic research setting.
- Applying appropriate statistical tests and data analyses.
- Communicating research findings effectively through written, graphical, and verbal format.
- Cultivating independence in quantitative research skills.
- Maximising learning and engagement with the subject.

Evaluation

In order to gain insight into how students perceived the participatory science/CURE-style approach they were sent a link to an anonymous online questionnaire. Students were asked to respond on a 5-level Likert-style scale (1=no, absolutely not, 2=no, 3=neutral/indifferent, 4=yes, 5=yes, very much) to the following statements:

(i) Data collected by students as part of the course was used for a research project and subsequent publication. Did this fact contribute to the course's/activity's appeal?
(ii) Did the data collection activity improve your engagement with the course?
(iii) Did the data collection activity foster your willingness to attend the course in person?
(iv) Did the data collection activity as part of a larger research project help you with understanding scientific concepts and methods?
(v) Did you find the data collection activity meaningful and relevant to your degree and career goals?
(vi) Would you recommend that the activity be repeated each year in this course (with different data and research questions)?

Results

Data collection

At the end of the 11-week course, students collected data for over 350 different species of fossil archosaurs. Upon checking for correctness only a few measurements (for 27 species) had to be repeated as a comparison between the two collected sets of data showed some discrepancies. A few additional specimens were added to the data set as students had not taken measurements due to not being able to find the respective publications, lack of scaling information for the specimens, and difficulties with taxonomic assignments. The final data set contained 382 specimens and formed the basis for a publication. A manuscript was submitted in July 2023 (approximately three months after the course had ended) with students included as co-authors and involved in manuscript generation. A manuscript was published in January 2024 following two rounds of minor revisions (Lautenschlager et al. 2023).

Student survey

The online questionnaire was completed by 16 out of 22 students representing a response rate of 72%. The 16 students responded to all six statements and responses are summarised in Fig. 2. All students agreed (5 students) or strongly agreed (11 students) that the data collection approach contributed to the course's appeal. Similarly, the majority of students agreed/strongly agreed that the activity improved their engagement with the course and positively impacted their willingness to attend. Students further agreed (8 students) or strongly agreed (8 students) that the data collection helped them with understanding scientific concepts and methods. With regard to the relevance of the data collection approach for their degree and career goals, students were a bit more ambivalent (6 students strongly agreed, 6 agreed, 2 were indifferent) but the vast majority agreed that the activity should be repeated each year.

Discussion

Benefits and disadvantages of a citizen science teaching approach

The participatory-science/CURE approach to teaching introduced here has several clear advantages. Survey responses demonstrate that students found the activity highly beneficial, particularly for understanding scientific concepts and methods; but also in terms of course engagement students rated the approach overwhelmingly positively. This aligns with research showing that students generally obtain a deeper understanding when applying their learning to real-world situations and tasks (Kuh 2009; Kortz et al. 2016; Rodenbusch et al. 2016; Kinner and Lord 2018). In the current example, students quickly became aware of what constitutes scientifically appropriate figures and illustrations to allow data collection (e.g. the requirements for scale bars for accurate measurements). Similarly, learned how to take measurements effectively and organise them in a systematic way. The report assignments required to pass the course further demonstrated how students had actively engaged with the topic and explored different ways to present their individual results. Although the overarching topic was the same for all students, individual reports differed substantially in the way data was presented, software tools used to create figures, and questions to be addressed (e.g. focussing on evolutionary trends in the context of phylogeny, different dietary adaptations, or geographical distribution of the studied dinosaur species). Similar, practical and research-focused approaches embedded into undergraduate curricula with a palaeontology focus have been shown to measurable improvements

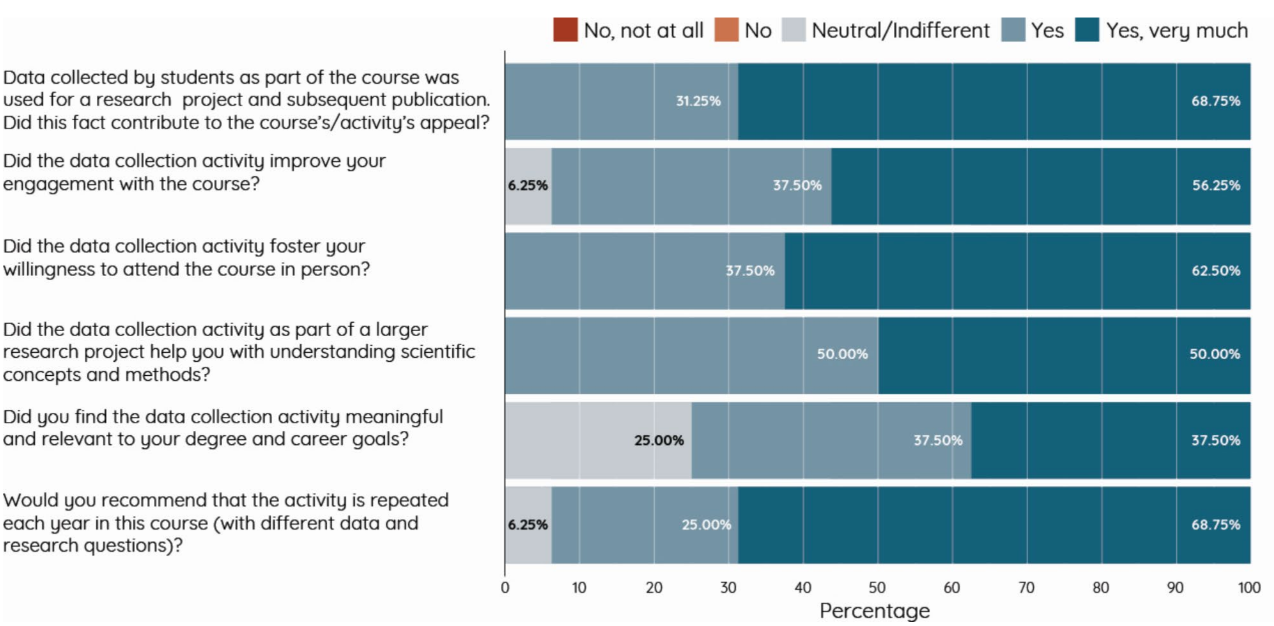

Fig. 2 Summary of student responses to the survey questions about the conducted participatory science-style project

in students' performance (reflected in their grades, efficiency in tasks, creativity in reports) (Montgomery and Donaldson 2014; Kelley 2018).

However, applicable and realistic activities do not automatically guarantee improved engagement; they need to be underpinned by explanations of the underlying principles and the introduction of core concepts (Collins 1991; Carroll et al. 2008). While it may be possible to achieve this using mock data and/or examples, a typical CURE approach provides a straightforward rationale by involving students in collaborative data collection as part of a larger research project. Furthermore, open-ended projects for which the results are unknown at the start of the course rather than traditional course tasks that follow a set recipe from start to result can improve student engagement (Brownell et al. 2015; Waterman and Heemstra 2018). Additionally, the presented approach allowed for accommodating different forms of student learning. Students were able to work independently or collaboratively discussing best approaches and comparing collected data. These findings match existing studies that demonstrated the potential of CURE-style projects to foster collaboration and teamwork (Shaffer et al. 2014; Ruth et al. 2023).

The experience gained from this activity can further be beneficial in a longer-term context, particularly for dissertation projects and possibly future careers. However, while student responses were generally positive, some were uncertain about the activity's relevance to their career goals. This uncertainty may stem from several reasons: The case study was designed within the context of academic work, primarily benefitting students aiming to pursue a subsequent PhD or further career in academia. Yet, not all undergraduate students necessarily have this goal, with many considering other career paths in the Earth Sciences sector available. While the applied methodology of the case study was transferrable to other questions, the overall approach can easily be adapted for a different context. However, CURE projects have been shown to increase interest in science careers, probabilities of graduation in STEM disciplines, shortened graduation times, and student retention (Kerr and Yan 2016; Rodenbusch et al. 2016; Rodrigo-Peiris et al. 2018; Dewey et al. 2022).

From a practical and strategic point of view, the successful completion of the data collection activity resulting in a scientific publication provides a further tangible advantage. In times when funding for post-graduate positions is dwindling and the job market is increasingly competitive, having a publication on one's CV is becoming essential (Berg 2015). A co-authored publication resulting from a CURE project could therefore be beneficial for career progression - however, not without the risk of exacerbating an already neoliberalised job market even further. This poses a major challenge for applicants from underrepresented and minority groups who face substantial hurdles in STEM subjects (Miller et al. 2019; Posselt et al. 2019). Extracurricular research, such as summer internships or fellowships, has been shown to be an effective tool to combat this attainment gap (Bruthers & Malays, 2020), but the lack of access to these can be another problem (Slovacek et al. 2011; Mogk 2021). Integrating research experiences directly into obligatory courses could partially mitigate these issues by providing students with research experience as part of the actual curriculum, eliminating the additional time and financial requirements often associated with external opportunities (Bangera and Brownell 2014).

From a teaching perspective, the benefits of incorporating a CURE approach in teaching are comparable to those of traditional participatory science projects. Data can be collected quickly and more effectively harnessing the efforts of multiple students. However, unlike the general public, undergraduate students already possess subject-specific knowledge. Furthermore, the required training can be highly interactive and specific, ensuring correctness and accuracy in data collection and with the added benefit of responding to the needs of individual students. A second, and not to be underestimated factor, is that multiple students collecting data alongside the expert teacher allows for the development and discussion of new ideas and feedback to improve the original project.

Despite these benefits, certain aspects warrant attention. As with traditional participatory science projects, there is a risk of exploiting cheap labour and issues with the recognition of knowledge creators and participants. For large-scale participatory science projects it is often impossible to include every single participant as a co-author (but see Sarna-Wojcicki et al. 2017). However, undergraduate courses in Earth Science disciplines are typically smaller making it feasible to manage co-authorship more effectively (nevertheless, student numbers should be taken into account when designing similar projects as outlined below). Professional ethics and standards for co-authorships, such as the Vancouver Protocol, which attributes authorship to the acquisition, analysis, or interpretation of data, should be followed here.

Further concerns may be raised with regard to data quality and integrity (Riesch and Potter 2014; Aceves-Bueno et al. 2017). However, the evaluation of public participatory science projects indicates that these concerns may be unwarranted (Resnik et al. 2015; Kosmala et al. 2016). This is in part due to the large amount of data collected redundantly to minimise erroneous entries or the application of software tools to identify outliers in the data (Kosmala et al. 2016). In a higher education setting, either similar approaches can be employed (see Considerations for study design below) or can be identified individually considering the smaller pool of participants.

Considerations for study design

The participatory science/CURE approach presented here focuses on a case study in a palaeobiology context but is applicable more broadly to other themes and topics in Earth Sciences. However, some aspects need to be considered when adopting this approach (compare Kosmala et al. 2016).

Data source

First and foremost, the data source needs to be considered carefully. The data to be collected has to be available relatively easily and not require complicated equipment or tools. This may rule out laboratory or field settings or data collection requiring high-spec computer equipment; although this may depend on the facilities and equipment available to teachers and students and there are a number of successful CURE examples in lab-based settings (Auchincloss et al. 2014; Kerr and Yan 2016; Mordacq et al. 2017; D'Angelo 2023; Watts and Rodriguez 2023). In the presented example, data was collected from published literature sources that are readily available to students (although paywalls could present problems as access to scientific literature is not distributed equally globally (Boudry et al. 2019). However, it is possible that data could also be collected from physical (e.g. fossil specimens, rock samples, maps, etc.) or digital sources (e.g. 3D models) if available in large enough quantities. The extent of the data collection will depend on the allocated time, which will dictate how many specimens or other sources can be analysed, the complexity of the measurements and analyses, and the sample size per student. Ideally, the data collection should be challenging enough to engage and motivate students throughout the course, but not so complex as to discourage participation.

Ensuring data accuracy

Accuracy and consistency in the data collection are further points that have to be considered carefully during study design. It is likely that students will be unfamiliar with the specific details of the data collection and subsequent analysis, although they will be more knowledgeable about the overall context compared to public participatory science projects. A comprehensive introduction to the topic and thorough training in the required tasks are therefore paramount and should precede any data collection (Prysby and Oberhauser 2004; Swanson et al. 2016). In the presented case study, the topical context and the methods were introduced in the first course session using an example of the process, which was simultaneously recorded as a video. This allowed students to revisit the example at any time. In addition, a concise handout describing all relevant data collection and analytical steps was created and provided for the students. While this procedure will form a solid basis for the data collection, it will not account for possible problems students may encounter. For example, the method may have to be adjusted or modified for specific samples (e.g. in the current example, eye socket position was not always lateral so some species required the measurements to be taken in dorsal view). Regular checks of the collected data will therefore be necessary. However, in contrast to traditional participatory science projects, students can ask questions and receive feedback on a continuous basis as part of the course. This will allow responding to problems and avoiding uncertainties during the data collection phase, which has been shown to improve data quality in other citizen science projects (Westphal et al. 2006).

A further measure to ensure the accuracy of the data is to implement a replication approach during the collection phase (Kosmala et al. 2016). In the current example, each sample specimen was assigned to two separate students, and comparing their data helped identify significant discrepancies. To avoid completely duplicating data sets for students and their assignments, the composition of the sample groups was varied; for example, the approximately 100 theropod dinosaurs in the sample were split into five groups of approximately 20 each first by taxonomic criteria and, for replication, by temporal distribution or randomisation. However, this approach may not always be possible if the number of students in the course (e.g. <10 students) does not permit duplicating the data collection tasks. In this case, it is advisable to either increase the sample size per student (time permitting) or to reduce the overall sample size. Conversely, with large course sizes (>150–200 students), data replication will be less of a problem but requires other measures to handle the increased data volume. However, possible problems could arise if students work together on the data and simply duplicate existing entries. In the current example, this was minimised by the requirement for each student to submit an individual report based on their own data collection and penalties for attempted plagiarism.

Student engagement

Student engagement is a key consideration. Participants of traditional participatory science projects actively seek out projects and want to contribute to the data collection. While teachers might expect the same from undergraduate students, realities may differ from this perception, especially in the context of mandatory courses. However, this is not a problem unique to the introduced teaching approach but applies to any learning and teaching method in (higher) education and a plethora of studies have attempted to tackle this issue (Hattie 2009; Fullan and Langworthy 2013). Learning catered around case studies has been found to have a positive affect on student engagement (Prince 2004; McMellon 2013) and is underpinning many CURE projects, which have been shown to effect student engagement and motivation positively (Dolan 2016; Olimpo et al. 2016).

Conclusions

Research-led/research-informed teaching has been at the centre of countless pedagogical initiatives to improve teaching and learning in higher education. Participatory science and CURE-style approaches to teaching embrace several key strategies at the heart of these pedagogical concepts, presenting a promising avenue for actively involving undergraduate students in research. The case study introduced here allowed students to develop a range of skills, including critical thinking, data collection and analysis, teamwork, and communication; but it also conveyed a deeper understanding of evolutionary processes and how these can be investigated and demonstrated through active data collection and analysis. The project was shown to enhance student engagement by providing meaningful, hands-on experiences that connect classroom learning to real-world applications with students often being more motivated when they understood that their work contributed to broader scientific endeavours. By integrating a case study in the context of an active research project into the curriculum, students were not only exposed to the practical aspects of research but also engaged in a meaningful investigation that contributed to the broader understanding of dinosaur evolution, biology, and behaviour. Such an approach integrated into higher education curricula can therefore play a key role in the teaching and learning of evolutionary theory and Earth Sciences more generally and bridging the gap between research and teaching, transforming students from passive audiences to active participants in both learning and research activities.

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Author contributions

SL designed the study, carried out the analyses and wrote the manuscript. The author read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The study was carried out in accordance with the ethics guidelines of the University of Bristol.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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