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Active learning in the undergraduate laboratory: Giving students a safe space to experience low-stakes failure

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Abstract

As with COVID-19, and so with national and global economic, political and climate crises, it is our young people who are the most vulnerable. In the UK, young people are experiencing a mental health crisis, and schools and universities are reporting record low levels of student engagement. Here we present a case study from a large Foundation Year Biological Sciences module where we considered the potential for low-stakes failure teaching events to act as a tool for developing student confidence and resilience, whilst also developing scientific learning. Foundation Year university students had the opportunity to engage in a low-stakes formative laboratory session, where they developed their own microbiology experiments. This was followed by the opportunity to repeat the experiment three months later, as well as additional interactive workshops for analysis of the practical data and to reflect on their learning experience. The students took a variety of approaches to the practical experiment with the majority describing the experiment as a positive experience: 92% of student respondents felt the experience offered a safe space for experimenting with scientific techniques, and students reported developing subject-specific skills including pipetting, plating bacteria, experimental design, in addition to transferable skills such as teamwork, problem solving, and building confidence to try something new (experiment!). We discuss considerations for further research as well as the potential for embedding low-stakes failure within a programme of study within a Higher Education setting.

Keywords

learner agency, resilience, lab practicals, self-efficacy, expectancy value theory, low-stakes failure

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Introduction

In the UK, the COVID-19 pandemic and cost of living crisis continues to have an unprecedented global impact affecting all areas of society. However, it is our vulnerable young people who are paying the highest price. Pandemic disruption has affected young people directly and indirectly, with disruption to their education and wellbeing arguably the most concerning but difficult to resolve. In the UK, our teenagers have experienced three years of shifting goalposts: school grade inflation (Wyness et al., 2022), in and out of lock downs, changed arrangements for examinations and assessments (Kippin & Cairney, 2023), and promised help to catch up, e.g. the National Tutoring Programme in England, being so "haphazard and poorly planned" (Ofsted, 2022) that it is now widely regarded as a failure. In both schools and universities, further disruption has been caused by striking staff during the academic year. The combined impact of this disruption has widened existing social inequity, with young people from more deprived areas experiencing higher incidence of COVID-19 and more missed lessons (Northern Powerhouse Partnership (NPP), 2022).

In general, it is increasingly difficult to disentangle the negative impacts of COVID-19 from an economic crisis where young people see that struggling to make ends meet is a new normal, even for adults in employment and with career paths; with one in five working households using foodbanks (Trussell Trust, 2022) and a record 56% of university students in paid employment, working an average 14.5 hours per week (Neves et al., 2024). Furthermore, those who act as champions and supporters for young people have faced disruption. For some young people, their entire support network has been shattered, for example by the death or effects of long-COVID, loss of paid work or declining mental health of their family and guardians, or an inability to access mental health support from the overwhelmed National Health Service.

A consequence of this is that young people in the UK are now trying to find their place in the world during perhaps the most turbulent period in living memory. Many young people in the UK feel goal-less and demotivated: one in four say they will never recover from the emotional impact of the pandemic (Office for National Statistics (ONS), 2022; Prince's Trust, 2022), with university students having an even lower sense of personal well-being compared to the wider youth population (Student Minds, 2023). The record-low levels of mental health being reported amongst young people in the UK have consequences for their self-efficacy; the confidence one has in being able to master new tasks as well as their well-being and attainment (Watts & Robertson, 2011). When learners begin a new course of study, they experience steep learning curves for various academic and social skills. When mental well-being and self-efficacy are low and expectations high, an individual's emotional resilience and motivation to engage in studies, can plummet (De Caroli & Sagone, 2014). This is a pattern we currently see in the UK with record high (22.5%) levels of persistent absence in schools (Department for Education (DfE), 2023) and a significant number of university students not attending any in person teaching (Basken, 2023; Grove, 2024; ONS, 2022; Williams, 2022). What can educators do to improve educational engagement of these overwhelmed students? We must support them to regain a sense of control over their educational experience and rebuild their confidence. Here, we show that one way to do this is by providing opportunities for low-stakes failure (Edmunds & Leggett, 2022).

In their first semester at university, students engage in many new academic and non-academic learning experiences. From an academic perspective, failure can be experienced by students when they are unsuccessful in completing a task (e.g. arriving at a lecture theatre on time), when they are told that they are incorrect either by their course tutors (e.g. they receive direct feedback that their answer to a question is incorrect) or by their peers (e.g. during group discussions), when they perceive themselves to have under-achieved (e.g. they do not achieve their desired grade in a test) or when they perceive themselves to be under-performing compared to their peers (e.g. they take longer to complete a task relative to their peers). On a Biological Sciences course, many of these new learning experiences involve laboratory skills (e.g. using equipment) and experimental techniques (e.g. designing a rigorous experiment); both of which are forms of experiential learning. When trying something new it is inevitable that this may sometimes lead to failure (Kolb & Yeganeh, 2011) but the combination of experiential learning and learning through experiencing failure can result in a powerful learning opportunity (Lam, 2019; Phillips et. al., 2018). When a period of reflection is also applied to the learning experience it can result in a deeper understanding of the learning that has taken place and of the knowledge gaps that exist (Paris & Winograd, 2003; Tawfik et al., 2015).

Learning activities can be considered to be low-stakes if there are low or no consequences for the learner. Active learning emphasises cognitive development over memorising information and describes a situation where learners are actively engaged in thinking about what they are doing and why, rather than being a passive participant in pre-planned activities (Gogus, 2012).Successfully engaging students in active learning activities requires: i) ensuring that the task is pitched at an appropriate level so that students feel able to contribute/participate successfully; ii) ensuring that the students perceive value in engagement with the task and that doing so is unlikely to have negative impact on them, and iii) clarity that if perceived failure does occur, that this failure is low-stakes (Cooper et al., 2017). This mixture of perceptions of value and difficulty combined with a perceived likelihood of success is known as expectancy value theory and it has been previously linked to student engagement with learning (e.g. Cooper et al., 2017). If students see the value in engaging with and believe that they can benefit from investing effort in their learning, then they are more likely to persist with an activity (Wigfield & Eccles, 2020) and engage deeply with learning activities (Cooper et al., 2017). Expectancy value is influenced by students' demographic identity whereby students from under-represented groups (such as students over the age of 21 years on entry, care experienced, disabled, or from racially and/or ethnically minoritised groups, etc.) are more likely to expect failure and/or lack motivation in their attempts to complete a task (see e.g. Seo et al., 2019), though the research into academic motivational theories has a historic bias which focuses on more commonly represented student demographic groups (Wigfield & Koenka, 2020).

In this article, we present a small-scale case study of action research which explores how Foundation Year university students responded to a situation presented to them as a formative task offering the risk of experiencing failure within a low-stakes arena and how this can ultimately enhance their study experience. The specific aims of the project were to:

i. offer students the opportunity to conduct a low-stakes formative laboratory practical and in a deviation from the usual teaching mode, the focus was on the

students to conduct their own research of the literature to determine an appropriate methodology, prior to engaging in the laboratory practical;

ii. evaluate the impact of i) on student learning and the student experience and

iii. use information from i) and ii) to enable us to consider the potential for expanding this area of research as well as the potential for low-stakes failure as a tool that supports students as they develop vital personal skills to carry throughout their studies and beyond.

We argue that such transferable skills are equally as important within Higher Education (HE) curricula as discipline-based knowledge and that this importance is even greater for students who have been most impacted by COVID-19 and/or are from groups that are under-represented within HE.

Methods

Action research is a research method that aims to investigate an issue as it is solved (Burns, 2007). This study took place within an Introductory Biology module within the Science Foundation Year (FY) programme at the University of East Anglia. Like many other HE providers, the FY courses at UEA were developed to offer an entry-route into HE for students from groups which are under-represented within HE. This leads to a diverse student cohort of students from under-represented groups including mature students, those with disabilities or who are care experienced as well as students from minoritised ethnic, racial and/or socio-economic backgrounds. Following successful completion of their level 3 FY studies, students can progress onto one of the level 4-entry courses offered within the department and these courses include, e.g. Biomedicine, Biochemistry, Microbiology and Biological Sciences.

During the autumn semester of the academic year 2021/22, students were given the opportunity to develop a range of practical laboratory skills (e.g. becoming familiar with the use of lab equipment) as well as important scientific and transferable skills (e.g. working with others, making accurate measurements) through attending with two compulsory 90-minute lab practicals exploring the antibacterial properties of essential oils (EOs), taking place on consecutive weeks. These practicals were the third practical offered to the students during this semester; the first being an experimental practical exploring the movement of molecules in and out of cells, and the second being an observational practical where students had to evaluate and compare the skulls of different animals and discuss these with their peers. The EOs practical that formed part of this study asked students to test the antibacterial properties of different essential oils on the growth of the bacterium, *Escherichia coli*. Attendance in person at all lab practical sessions was compulsory. However, for the EOs practical, the students were not assessed; in this respect the labs were a low-risk opportunity to potentially experience failure (e.g. of their experiment, their ability to work in a group, or to attend and/or engage with the sessions).

Two weeks before the practical ran, students were given three pieces of information in-person during their pre-lab workshops. The associated resources were available throughout the semester on the Virtual Learning Environment (Blackboard):

i. the practical aim of ‘Determining the antibacterial properties of Essential Oils (EOs) against *E. coli*’;

ii. an equipment list consisting of *E. coli* in liquid culture; essential oils (x4 randomly selected from garlic, cumin seed, white thyme, tea tree and ginger); Luria Broth (LB) agar plates (x4); an antibiotic (ampicillin, in liquid form); filter paper discs; pipettes; tweezers and spreaders and

iii. the instruction that the practical would determine the antibacterial activity of EOs using the 'disc diffusion method' by measuring the diameter of the zone of no growth around a disc that had been soaked in solution (known as the zone of inhibition).

The students were asked to work in self-selected groups of typically three students per group since we had previously noticed that this cohort of students were not forming peer-support networks (Edmunds & Leggett, 2022). The students were advised to work as a group to research and plan how they were going to undertake the practical investigation so that they came to the first lab practical session with an experimental plan in place.

In the first lab practical session, students set up their essential oil disc diffusion assays and these were incubated for ~36 hours and then refrigerated until the next lab the following week. In the second lab practical session, the students reviewed their plates and recorded the diameter of the zone where no bacterial growth took place (the zone of inhibition) across each plate and entered these results into a shared spreadsheet of class data. The only guidance that the students received during either practical session was when it was needed to ensure that equipment was being used safely and correctly, though discussion and engagement with the teaching staff was actively encouraged. The teaching staff within the practical sessions were two female lecturers who the students were regularly taught by and two associate tutors, one male and one female.

These practical sessions were followed up with two workshops intended to guide the students to develop their own reflective practice, understand the science behind their results and statistically analyse the data. The first of these workshops made use of the class data on the zones of inhibition for the discs soaked in garlic oil and those soaked in cumin seed oil. The students were given clear guidance on performing simple statistical calculations on these data (exploring the mean and standard deviation and performing a t-test). The second workshop asked students to reflect on their experience during the practical and to explore images of the plates from other groups of students, which had all been uploaded to a Padlet (www.padlet.com) page by the staff team. This workshop taught students how to use ImageJ (https://imagej.net/ij/) software to measure the zones of inhibition for the discs on different plates and encouraged them to think about why different groups of students might have taken different approaches for their experimental design; and what they have learned (for example, what went well and what did not). Where computers were required, students could either use their own devices or the computers available in the room. In each case, there were enough computers for students to work individually, but at a maximum, there were no more than two students per computer.

During March 2022, following the completion of the in-class sessions, students were asked to provide feedback on the activities by answering a series of nine questions using the audience polling software, Poll Everywhere (see Appendix). The polling was undertaken as part of the mid-module review for the module. Students were not required to answer any of the questions and all responses were collected anonymously. Ethical approval was

sought and granted from the Science Faculty Research Ethics Committee, application ETH2223-2719.

Finally, following requests from the students during the workshops, a second run of the practical was organised for early in the Spring Semester as many students wanted the opportunity to learn from their mistakes and attempt the practical again.

Results

In total, 120/179 (67%) students enrolled on the module engaged in at least one of the essential oils laboratory sessions. Between them, these students produced 208 plates for incubation, taking a range of different approaches to the task (Figure 1). The plates show the discs which were soaked in the experimental substances (small, circular discs seen in plates a, b, d and e of Figure 1) as well as bacterial growth (the 'film' of cream-coloured growth across the surface of plates a, b, d and e of Figure 1 and the distinct circular zones of inhibition (region of no bacterial growth) that can be seen particularly clearly in plate a of Figure 1. Variation in the experimental approach taken that can be seen from the images of the plates in Figure 1 included whether a control plate was included (plate c, Figure 1), the number of discs tested per substances (all plates, Figure 1) and how many different substances were tested per plate (all plates, Figure 1). Variation in experimental approach that was not captured by the plates but that we are aware of from discussions with the students included: i) the volume of essential oil used per disc or plate; ii) how the essential oils were added to the disc (pipetting or immersion); iii) the preparation of the essential oils before application to the plate (some students chose to dilute the oil prior to use, others used the oil neat), and iv) the volume of bacterial culture applied to each plate.

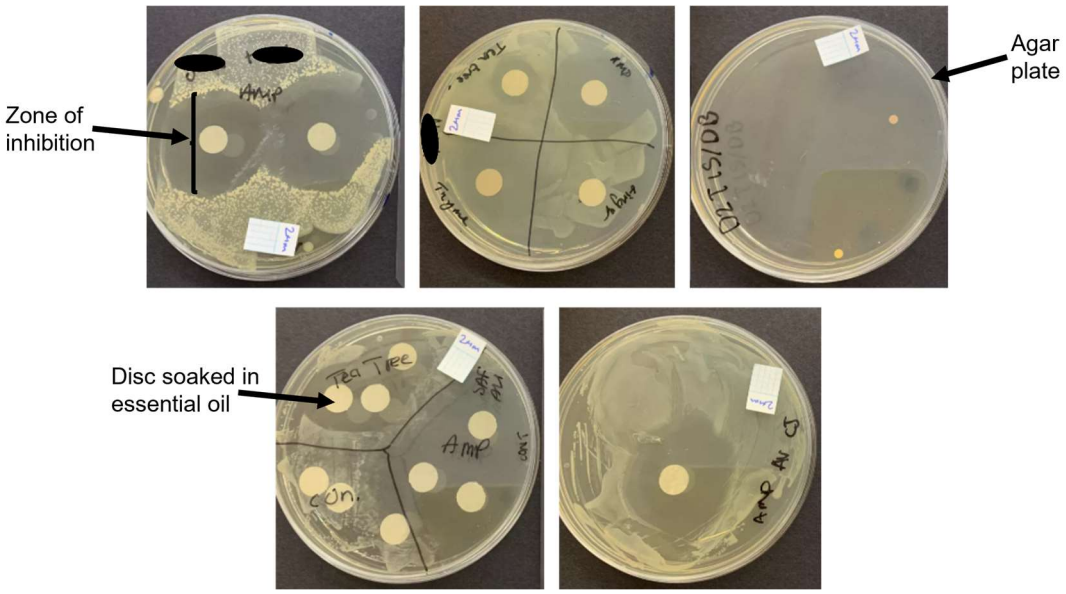

Figure 1. Examples of the variation in experimental set up produced by students studying on a Foundation Year Introductory Biology module. Two weeks before undertaking the experiment, the students were given an equipment list and the instruction that the practical would determine the antibacterial activity of EOs using the 'disc diffusion method' by measuring inhibition zone diameters. How the students chose to then set up

the experiment was up to them. Variation in the experimental approach included whether a control plate was included (plate c), the number of discs tested per substances (all plates) and how many different substances were tested per plate (all plates).

Response rates for the feedback element of this study ranged from 30-35% depending on the question asked. These response rates reflect the level of engagement within the module, where average attendance across the year was approx. 54% and where 30% of students completed the online mid-module review.

When asked to name one word which summed up their experience of the essential oils experiment, of the 39 students responding to the question (32.5% of the 120 students who had attended the practicals), 10 students (25.6%) said “useful / beneficial”, six students (15.4%) said “interesting”, a further six said “stressful” and three (7.7%) said “fun”. Other responses given were single answers including “phenomenal”, “simple”, and “eye-opening”.

When asked to name the skills that they had gained from engaging in the experiment, of the 58 responses to the question (48.3% of the 120 students who had attended the practicals), 13 students (22.4%) said “pipetting”, six students (10.3%) said “teamwork”, and a further six students said “planning”. Four students (6.9%) said “plating of bacteria” and three students each (5.2%) said “time-keeping” and “use of the laboratory” (Figure 2).

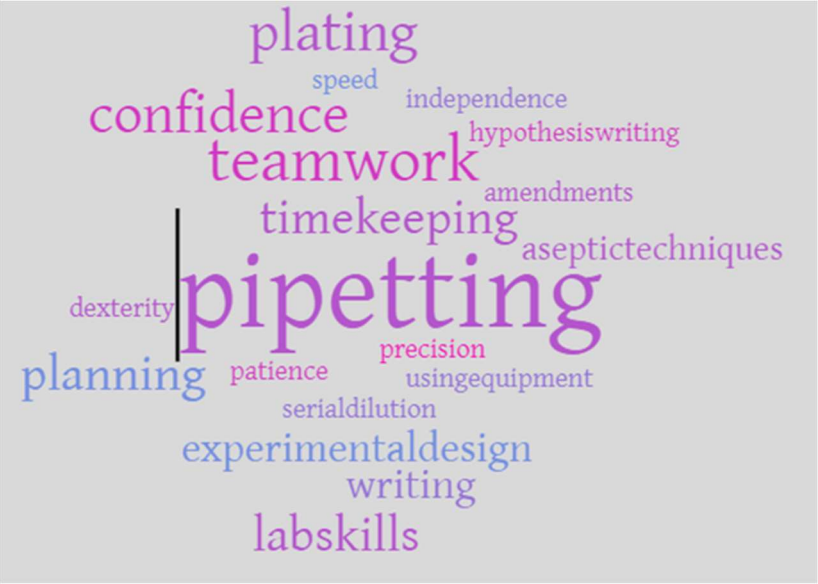

Figure 2. Word cloud created from the responses given by students studying on a Foundation Year Introductory Biology module when asked which skills they had developed during a practical biology experiment exploring the antibiotic properties of essential oils.

Overall, 73% of students agreed that the EO exercise was important, compared to 2% who disagreed (Table 1). While it was not possible to record data on all our observations, the improvement in the cohort – both their resilience and practical skills, between the first two labs and the final lab three months later – was vast. For example, students learned first-hand about the importance of labelling their experiments sensibly (e.g. label the bottom of the petri dishes and not the lids that can spin and get lost) and keeping detailed laboratory notes (and remembering to bring those notes to the lab!).

We found that most students described the EO task as a positive experience despite an almost 50:50 split of students at the beginning of the task being concerned about failing. Students reported developing skills in team building and teamwork, in addition to subject specific skills such as plating bacteria and designing an experiment. Ninety-two percent of student respondents found that the experiment offered a safe space for them to be able to experiment with scientific techniques.

Table 1. Summary of the responses from students studying on a Foundation Year Introductory Biology module to questions asked about their participation and engagement with a practical biology experiment exploring the antibiotic properties of essential oils.

Question / Statement	**No. respondents**	**Majority cohort**
How useful did you think Essential Oils practical would be for your current studies?	37	27 (73%) said they thought it would be useful
How useful did you think Essential Oils practical would be for your future studies?	39	24 (62%) said they thought it would be useful
Prior to taking part, how interested were you in the activities?	37	22 (59%) said they were interested in the activities
The Essential Oils practical was important	41	Strongly Agree 4 (10%) Agree 26 (63%) Neutral 10 (24%) Disagree 1 (2%) Strongly Disagree 0
The Essential Oils practical was stressful	40	Strongly Agree 2 (5%) Agree 6 (15%) Neutral 6 (15%) Disagree 21 (53%) Strongly Disagree 5 (13%)
I was concerned about failing the Essential Oils practical	42	Strongly Agree 3 (7%) Agree 13 (31%) Neutral 8 (19%) Disagree 14 (33%) Strongly Disagree 4 (10%)
Did the practical offer you a safe space in which to experiment with science?	39	Yes 36 (92%) No 3 (8%)

Discussion

Universities and schools in the UK are reporting an engagement crisis amongst their students. Simultaneously, young people in the UK are experiencing a mental health crisis. This study considers the potential for low-stakes failure teaching events as a tool to help students regain a sense of control over their education, rebuilding their confidence and resilience alongside an active learning experience. We gave Foundation Year university students an opportunity to engage in a low-stakes failure laboratory practical session, followed by workshops to compare and statistically analyse their data, and reflect on what they had learned (both personal and professional skills) during the process. Overall, the students found the experience overwhelmingly positive: despite 35% of students

initially fearing failing the task, 92% felt comfortable to experiment within the study and 62% believed this experience would help them in their future studies (Table 1).

University is an environment with abundant opportunities for learning, personal growth, experimentation and consequently, failure. Individuals vary in their response to the opportunity to try something new and the associated risk of failure. Some students fully embrace the opportunities that university offers but others can find the experience overwhelming. A student cohort drawn from a population experiencing a mental health crisis is unlikely to possess the resilience and confidence needed to cope with repeated exposure to failure. For many students, just the fear of failure is enough to cause them to disengage from their studies and to present as a barrier to their learning (Choi, 2020).

Expectancy value theory helps to explain some of this behaviour. With expectancy value theory, the engagement effort put in by an individual student is related to their perception of the cost to them of engaging balanced against the potential reward (Cooper et al., 2017; Wigfield & Eccles, 2000). If a person perceives that a task may be costly in terms of being too challenging and thus, have negative consequences for their self-confidence or self-esteem, or if they perceive that the time investment is disproportionate to the likely benefit, then they are less likely to engage well (Finn, 2015). Where the expected value is low, students are more likely to disengage (Groccia, 2018). Of course, this is linked to students' lived experiences. For instance, Black female students are more likely to experience harsher grading and disciplinary action in education compared to their White peers (Epstein et al., 2017) and thus may have higher expectations of failing. Similarly, students with below average mental health are almost twice as likely to report experiencing imposter syndrome compared to those who have average and above average mental health, and those who feel that they belong at university are more than twice as likely to feel confident in their academic abilities compared to those who do not feel a sense of belonging (Wonkhe & Pearson, 2022). Thus, low-stakes failure, when implemented thoughtfully, could improve students' value expectations, and so could be a tool to create more-inclusive teaching events and curricula that may help reduce degree awarding gaps between student groups.

An important factor to consider is that previous studies measuring motivation of university/college students have found that approximately 25% report making little to no effort when it comes to preparing for low-stakes assessment (e.g. Hoyt, 2001; Schiel, 1996) despite students who put in at least a reasonable amount of effort, performing better than students putting in little to no effort (Schiel, 1996; Wise & DeMars, 2005). Universities across the UK are reporting an engagement crisis, and the sessions involved in this study were no exception. Attendance at the taught components of this study were similar to those seen within the department at the time and reflect what has been seen across the HE sector (ONS, 2022; Wonkhe, 2022). Whilst the attendance levels for the sessions of this study were not unusual for the time, they were lower than would have been desired for the purposes of this study. One of the challenges of encouraging students to engage with sessions that do not link directly to assessment is ensuring that the learning outcomes are clear and accessible to students. While only anecdotal, we have since found that a powerful tool to encourage engagement is to share the data from this study with students, and to be transparent about our motivations for designing the lab sessions the way we have. For example, communicating to the next intake of students that 73% of students in their prior cohort found this session useful to their studies, seemed an important factor in the students' decisions to engage.

Our study would also have benefitted from the opportunity to conduct interviews with the students about the experience from their perspective, but due to the nature of action research, this was not possible. Further work in this area will embed learning opportunities such as these, which combine active learning with the potential for students experiencing low-stakes failure into the curriculum and will build on this study in terms of both frequency of these opportunities as well as the provision of follow-on reflective workshops for students.

The HE sector continues to adapt and evolve to meet the changing needs of our student cohorts among the ongoing unpredictable and volatile world. There is much which we and our students 'don't know about what they don't know' (e.g. Alscher et al., 2024). But what we do know is that well-being amongst young people in HE is at an all-time low. And unless we in the HE sector find ways to support our students through this, they will be poorly equipped in terms of their resilience, experiences, and responses to failure that they will undoubtedly experience in the post-graduation world. Our approach to this problem is to provide opportunities which enable and support our students to experience failure in a safe space and to then reflect and respond to that failure, which we hope will result in a powerful learning experience both from an academic and well-being perspective. Our long-term goal is to develop a toolkit for embedding low-stakes failure within programmes of study across different subject disciplines with the aim of supporting students to regain a sense of control over their university experience and rebuild their confidence.

Based on our experience, we would encourage others to embed opportunities for students to experience formative, active learning opportunities that present a risk of students experiencing low-stakes failure. We would recommend that these take place with: i) scaffolded tutor support; ii) with students working together in groups, and iii) to promote students developing their learner agency, giving students the freedom to make decisions about the format of their learning activity.

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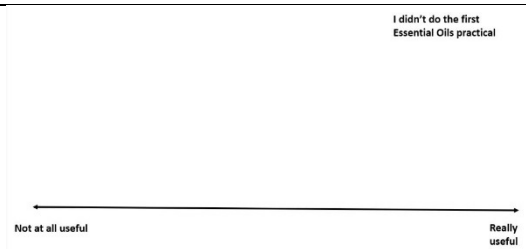
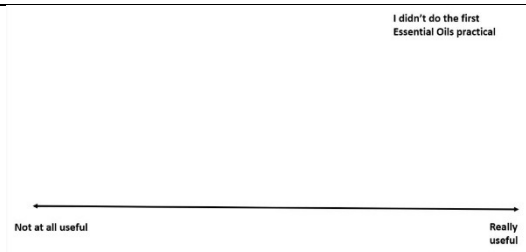
Appendix: Anonymous survey questions

The nine questions asked via anonymous survey to students who completed a laboratory practical microbiology experiment exploring the antibiotic properties of essential oils. The questions sought to understand student engagement, participation and perception of the new experimental microbiology sessions that had been developed within their Foundation Year Introductory Biology module.

Question	**Question Type**	**Screenshot of response screen**	**Number of responses received**
1. Prior to starting the first Essential Oils lab practical, how useful did you think the practical was likely to be for your current studies?	Clickable scale on image		37
2. Prior to starting the first Essential Oils lab practical, how useful did you think the practical was likely to be for your future studies?	Clickable scale on image		39
3. Prior to starting the first Essential Oils lab practical, how interested were you in the activities?	Clickable scale on image		37