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Eight steps to facilitating more equitable education in undergraduate sciences

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Eight steps to facilitating more equitable education in undergraduate sciences

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Pedagogical practices can influence students' confidence and ability beliefs and affect their ambition to persevere in science. Given the continuing need to diversify science and retain students in scientific programmes, science education must be tailored to cater to the needs of varied student groups. Since early experience in university programmes can be decisive in determining students' further academic and professional choices, pedagogies employed in undergraduate science courses can be particularly influential in supporting science careers. Undergraduate science instructors are therefore encouraged to consider their approaches to teaching and learning from a variety of perspectives that could help empower students from under-represented groups.

Introduction

Although science graduates continue to be in high demand, a considerable proportion of students in scientific fields do not complete their degree programmes. The attrition rates are especially high for students traditionally under-represented in scientific disciplines, such as female, ethnic minority, first-generation, LGBT and mature students and students with disabilities. In this article, we explore how certain considerations regarding course structure, instructional style, activity selection and facilitation and student–instructor communication can help create equal learning opportunities and embrace diversity in science, and propose eight fundamental practices for science educators to incorporate into their undergraduate courses. We make these recommendations as a result of research into learning and teaching, as well as our own practice.

Establish a positive teaching and learning climate

Positive relationships with peers and instructors are essential for students to feel comfortable in the science classroom. Learner-centred pedagogies that engage students in organization, implementation and evaluation of teaching and learning facilitate positive relationships between instructors and students, while pedagogies that focus on student cooperation and involve collaborating on projects in small, consistent groups can help build student rapport. Research by Shibley and Zimmaro showed that when used in introductory chemistry, these approaches allowed students to feel very positively about engaging with peers and working in groups on laboratory assignments. Classroom activities promoting creative engagement with the course content, such as question and answer sessions, inquiry labs and conceptual problem assignments, also contribute to a positive class climate in introductory science. A positive classroom climate can help create a learning environment in which students feel comfortable expressing themselves and making contributions and is, therefore, a key consideration in promoting positive science learning experiences and helping under-represented students develop science identities.

Alleviate stress and anxiety

Students in the sciences are prone to academic anxiety because of the academically challenging and competitive environment of science courses. First-year students also struggle with low self-confidence and heightened anxiety due to a lack of study and time management skills applicable to higher education. Student groups under-represented in the sciences face additional challenges (Table 1) in their academic paths, which, according to England and colleagues, can negatively affect students' performance, and lead to disengagement and attrition in introductory science. To help students build a robust sense of science self-efficacy, instructors should try and moderate student anxiety through considerate pedagogical practice. In science classrooms, cold calling (being called upon to answer a question without having

Table 1. Unique challenges of marginalized student groups

Women and Gender Minority Students	Ethnic Minority Students	LGBT Students	First-Generation Students	Mature Students	Students with Disabilities
► Lack of confidence in scientific fields ► Stereotype threat ► Increased performance anxiety ► Implicit and explicit bias ► Discrimination ► Weak sense of belonging ► Feelings of exclusion in the classroom ► Lack of representation and positive role models	► Lack of confidence in HE settings ► Stereotype threat ► Perceived bias ► Weak sense of belonging ► Feelings of social exclusion ► Lack of support ► Lack of representation and positive role models ► Negative attitudes about academic potential ► Negative attitudes about professional prospects	► Lack of representation and positive role models ► Social stigma ► Discrimination ► Feelings of isolation ► Higher vulnerability to mental health issues ► Heteronormative culture in STEM	► Heightened fear of failure ► Heightened concern about financial aid ► Heightened pressure to succeed ► Feelings of academic inferiority in comparison to other students ► Lack of familial support ► Lack of basic knowledge about HE ► Difficulties adjusting to the university environment ► Weak sense of belonging	► Fear of returning to school ► Heightened performance anxiety ► Feelings of academic inferiority in comparison to other students ► Negative attitudes about academic potential ► Personal, professional and family commitments ► Stereotype threat	► Barriers to learning ► Weak sense of belonging ► Lack of confidence ► Non-accommodating learning environments ► Lack of cooperation from instructors ► Lack of support/ information about available support ► Feelings of exclusion

Sources: https://doi.org/10.1007/s10763-005-1080-3; https://doi.org/10.1371/journal.pone.0186419; https://doi.org/10.1080/00219266.2021.2012227; https://psycnet.apa.org/record/2002-02801-001; https://doi.org/10.1007/s10956-008-9141-3; https://eric.ed.gov/?id=EJ963594; https://doi.org/10.1080/0307507041000168259 2; https://doi.org/10.1021/acs.jchemed.1c00402 https://doi.org/10.4324/9780203088623-12; https://doi.org/10.4324/9781003001348; https://doi.org/10.1128/jmbe.v21i1.2075; https://doi.org/10.1103/PhysRevPhysEducRes.16.010118; https://doi.org/10.1177/0091552194022003 02; https://doi.org/10.1103/PhyRevPhysEducRes.14.020123; https://doi.org/10.1073/pnas.1211286109; https://doi.org/10.1002/j.2161-1882.2007.tb00002.x; https://doi.org/10.1177/104515950801900103; https://doi.org/10.1080/0305764X.2020.1831441; https://doi.org/10.1016/j.jesp.2012.04.012 https://doi.org/10.1177/0361684313482109

volunteered), random calling (being randomly selected from a list of students to answer a question), volunteering to answer questions and answering clicker questions (especially timed and graded) have been reported as especially anxiety inducing (Table 2), sometimes to a point of obstructing learning. By incorporating anxiety-mitigating practices (Table 3) in their pedagogies, instructors can help support the retention of under-represented students, and multiple-minority status students in particular.

Consider how you structure your courses

Course modularization or chunking and frequent assessment can help students in the sciences better cope with the extensive course material. By splitting the course up into a few thematic blocks and utilizing regular assessment, instructors can promote more effective, processual learning. In addition, cumulative evaluation favouring frequent assessment on diverse tasks over a few high-stake examinations can be more equitable than other modes of evaluation. For example, Ballen and colleagues found that women in introductory biology perform significantly better in courses utilizing mixed-method assessment. Utilizing class time for active engagement with the course material can also help make science education more equitable by increasing learning gains and reducing failure rates among vulnerable student groups. Increased course structure is of special interest to instructors seeking to enhance student learning and support students from disadvantaged backgrounds since it does not require additional financial resources, smaller class sizes or more class time. Research by Freeman and colleagues and Haak and colleagues show that highly structured courses that provide students with extensive active learning activities and regular assessments are particularly effective in reducing achievement gaps and improving retention in introductory biology courses.

Embed challenging, but achievable, tasks

Although creating productive tasks can be challenging, it is critical for instructors seeking to improve student engagement. While assignments requiring an extensive amount of time or effort to complete may undermine students' competence beliefs, tasks requiring low levels of cognitive processing for completion are not as effective in promoting student engagement, collaboration and knowledge construction. Therefore, instructors should incorporate multiple smaller-scale tasks that require higher-order cognitive thinking into their classes to promote effective science learning and help students become progressively more confident in their science ability. According to Hoof and colleagues, tasks based on productive (or generative) approaches to learning, such as summarizing, mapping, self-explaining, drawing, teaching others, self-testing, imagining and enacting, can be especially helpful in facilitating cognitive engagement and knowledge construction. Gallardo-Williams and colleagues also linked generative learning with better retention of course material, improved confidence and development of a wide variety of transferable skills. Although using productive learning strategies in undergraduate science courses is beneficial

Table 2. Anxiety associated with common pedagogical practices in science classrooms from low (green) to very high (red)

Lecturing	Out-of-class assignments	Ungraded individual assignments	Class/group discussions	Volunteering to answer a question	Personal response systems	Ungraded group assignments	Graded individual assignments	Graded group assignments	Timed and graded personal response systems	Random calling/ cold calling

Sources: https://doi.org/10.1128/jmbe.v21i1.2075; https://doi.org/10.1186/s40594-018-0123-6; https://doi.org/10.1371/journal.pone.0182506.

to all students, it is especially valuable to students from under-represented minority groups, who are at a higher risk of disengagement and can benefit from learning and confidence gains the most.

Provide sustained, extensive and timely feedback

For any pedagogical practice to have a positive effect on student achievement, it must provide students with sustained, extensive and timely feedback. Undergraduate science students predominantly rely on course achievement and instructor feedback to form beliefs about themselves. Since confidence in one's own ability can affect student effort, persistence and performance, instructors bear a responsibility to create plentiful opportunities for their students to succeed and receive performance-related feedback. Feedback can act as both an incentive and a deterrent, and it is therefore critical that instructors provide positive performance-related feedback, even on failed assignments, and practice error framing (a process whereby errors are identified and students primed to see errors as useful learning opportunities). This is particularly important for under-represented student groups, which suffer from negative self-perceptions. Ideally, feedback should be elaborate, highlight the importance of effort and perseverance and be provided regularly and on diverse tasks. For students in undergraduate science courses, it is especially important to have received extensive feedback before any major assessment, since it can help them self-evaluate, choose effective learning strategies and plan their studying more efficiently. Although providing students with frequent individual feedback might be challenging in large-enrolment undergraduate classes, various scaffolds can be utilized for this purpose. Sabel and colleagues, for example, found that providing students with advanced answer keys and reflection questions helps them self-generate feedback and improve their own learning.

Address social inequalities in higher education

Students' beliefs about themselves are strongly influenced by social messaging. Perceived inequalities in the sciences on the basis of gender identity, sexual orientation, ethnicity, socio-economic status, age or disability can affect student confidence and reinforce harmful stereotypes. A homogeneous environment in the sciences, lack of representation in the student body and the faculty, lack of positive role models, experienced exclusion and discrimination and perceived unavailability of academic and career opportunities can negatively impact student engagement, which, in turn,

Table 3. Strategies to alleviate student anxiety and maximize learning gains according to different task types aligned to associated anxiety levels; green (low) to red (high)

Individual Activities	Personal Response Systems	Group Activities	Random and Cold Calling
▶ Use instructional scaffolding to support independent learning ▶ Provide students with mentors and peer models ▶ Offer verbal persuasion ▶ Link mastery experiences with performance-related feedback ▶ Offer a diversity of assessment types ▶ Prioritize multiple low-stakes assessments over big projects and exams	▶ Award points for participation, not accuracy ▶ Allow students to confer ▶ Do not show response histograms when only a few students got the answer wrong ▶ Practice error framing and accent the inevitability and importance of making mistakes ▶ Avoid using personal response systems questions with unfamiliar topics ▶ Take time to discuss the solution after the answers have been submitted	▶ Provide clear structure and feedback ▶ Assign designated roles ▶ Allow students to self-select into groups ▶ Create many group-work opportunities with stable groups ▶ Allow students to get to know each other before working on a task together ▶ Utilize process-oriented rather than outcome-oriented tasks	▶ Explain the usefulness of random or cold calling ▶ Practice cold calling in small classes only ▶ Allow students to confer and call upon groups rather than individuals to answer questions ▶ Allow students time to think before answering ▶ Utilize cold calling often to de-sensitize students through gradual exposure

Sources: https://doi.org/10.1007/s10763-005-1080-3; https://doi.org/10.1371/journal.pone.0186419; https://doi.org/10.1128/jmbe.v21i1.2075; https://doi.org/10.1103/PhysRevPhysEducRes.16.010118; https://doi.org/10.1002/j.2161-1882.2007.tb00002.x; https://doi.org/10.1186/s40594-018-0123-6; https://doi.org/10.1371/journal.pone.0182506; https://doi.org/10.1037/stl0000147; https://doi.org/10.1371/journal.pone.0181336; https://doi.org/10.1088/1361-6404/ac51b1; https://doi.org/10.1103/PhysRevPhysEducRes.13.020140.

can have adverse effects on the academic performance and retention of minority groups. It is therefore of utmost importance that instructors explicitly address inequalities in higher education courses and create opportunities to openly discuss them with their students. Since minority students are more likely to identify members of the same marginalized group as their role models, instructors from marginalized communities should be open about their identities. In addition, instructors can promote diversity and endorse representation of minority groups in their classes by introducing strategically selected peer models and mentors, recommending reading from a diverse authorship and using imagery that is culturally accessible.

Ensure equitable participation

Unique student factors must be taken into consideration when organizing tasks to ensure equal opportunity for engagement and contribution. For instance, women may feel more comfortable contributing to group discussions in groups in which the majority of the participants are women. Similarly, students that might be reluctant to participate in group work due to a lack of confidence, such as first-generation students or low-achieving students, might benefit from tasks in which each student has an allocated role. While creating diverse groups might seem like an amiable practice that helps minority students integrate into majority student groups, a study by Theobald and colleagues suggests that it might inadvertently contribute to inequitable participation. Inequitable group work can have negative effects on students' sense of belonging as well as their learning and performance. Allowing students to choose who to collaborate with, on the other hand, helps students establish groups they are comfortable with and find their communities. Comfort and homogeneity within groups create a more equitable learning environment, which is less likely to trigger stereotype threat, promotes formation of confidence and competence beliefs and improves the odds of students taking science-related courses in the future.

Be knowledgeable of, and an advocate for, the student supports available

Undergraduate science courses should provide pedagogical assistance to students that are new to complex scientific problems. Educational support is especially important for introductory science classes, due to a large variation in prior instruction and ability. Most higher education institutions offer transitional

learning support and bridging courses to address skills or prior instruction gaps. In addition, support for students is generally available on general academic skills, such as study skills, time management, academic writing and public speaking, all of which might be directly related to course performance although not integrated in undergraduate science courses. Additionally, some students might require mental well-being supports. Research by Ramos-Sánchez and Nichols suggests that appropriate psychological support could be of special importance for the support and retention of first-generation students, many of whom are likely to come from ethnically diverse and low socio-economic backgrounds, while Kerr and colleagues found that some LGBT students in undergraduate courses may rely on mental health services more than heterosexual students. Therefore, to help endorse diversity in science education, teaching staff should make students aware of the counselling and guidance opportunities at their institution. A close cooperation between student counselling and guidance supports and teaching staff will ensure timely support for those students that would benefit.

Conclusion

The practices outlined in this article can play a decisive role in influencing the academic persistence and retention of undergraduate students, especially those from traditionally under-represented groups. To offer adequate instruction and support, instructors must be aware of how students' university experiences are mediated by their unique characteristics such as gender identity, sexual orientation, ethnicity, age, socio-economic background and generational status. While no single pedagogical approach offers a universal solution to inequalities in higher education, instructors that embrace cooperative pedagogies and a highly structured course design, provide sustained feedback and support and prioritize students' well-being can best contribute to creating a more inclusive learning environment in the sciences. ■

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Dr Barry Ryan was the recipient of the Biochemical Society's Teaching Excellence Award 2023. This award is given annually to an employee in higher education and recognizes individual excellence, commitment to continuing professional development and a commitment to students and colleagues. Barry Ryan is a biochemistry lecturer at Technological University Dublin and is currently on secondment leading the development of the university's Educational Model. Barry received his degree (biotechnology) and PhD (applied biochemistry) from Dublin City University. He is passionate about the practical implementation of research informed teaching and in supporting others in their personal development in this area. His teaching and learning philosophy promotes (co-)creation to empower and centralize all students across all levels within under- and post-graduate curricula. He is concurrently a Senior Fellow of the Higher Education Academy, a National Forum Teaching and Learning Research Fellow and a chartered science teacher. Email: barry.ryan@tudublin.ie

