Eight steps to facilitating more equitable education in undergraduate sciences

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Eight steps to facilitating more equitable education in undergraduate sciences

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.

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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 classroom 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
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 1. Unique challenges of marginalized student groups

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

For any pedagogical practice to have a positive effect on student achievement, it must provide students with sustained, extensive and timely feedback. Undergraduate students, especially those from under-represented minority groups, benefit the most from learning and confidence gains the most.

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

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

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

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**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)**

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

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.

Further reading


(Continued)
Further reading (Continued)


Gintarė Lübeck is a postgraduate research student at TU Dublin. She received her Master of Education (MEd) degree in education policy and administration from Vilnius University in 2021. Her research interests include academic well-being, diversity and inclusion, and political and organizational change within the sector of higher education. In her current research project, Gintarė is exploring how different pedagogical approaches can affect student self-efficacy and contribute to creating a more equitable learning environment in undergraduate STEM.

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