

2025-06-02

The Impact of Teaching Practice on Student Self-Efficacy in Undergraduate STEM Classrooms

Gintarė Lübeck

Technological University Dublin, Vytautas Magnus University, gintare.luebeck@gmail.com

Michael K. Seery

University of Bristol, michael.seery@bristol.ac.uk

Barry J. Ryan

Technological University Dublin, barry.ryan@tudublin.ie

Follow this and additional works at: <https://arrow.tudublin.ie/ijap>

Recommended Citation

Lübeck, Gintarė; Seery, Michael K.; and Ryan, Barry J. (2025) "The Impact of Teaching Practice on Student Self-Efficacy in Undergraduate STEM Classrooms," *Irish Journal of Academic Practice*: Vol. 13: Iss. 1, Article 2.

doi:<https://doi.org/10.21427/gwvz-rf82>

Available at: <https://arrow.tudublin.ie/ijap/vol13/iss1/2>

Creative Commons License



This work is licensed under a [Creative Commons Attribution-NonCommercial-Share Alike 4.0 International License](https://creativecommons.org/licenses/by-nc-sa/4.0/).

The Impact of Teaching Practice on Student Self-Efficacy in Undergraduate STEM Classrooms

Gintarė Lübeck

School of Food Science and Environmental Health, Technological University Dublin, Ireland

Faculty of Social Sciences, Vytautas Magnus University, Lithuania

Michael K. Seery

University of Bristol, United Kingdom

Barry J. Ryan

barry.ryan@tudublin.ie

School of Food Science and Environmental Health, Technological University Dublin, Ireland

Abstract

This quantitative study examined the impact of teaching practice on students' self-efficacy at the outset of their undergraduate STEM programmes, considering prior academic performance and class setting. Data were collected through a self-efficacy survey ($n = 483$) and 15 non-participatory classroom observations at a large, modern university in Ireland. Observed classes included lectures, laboratories, and tutorials across physics ($n = 3$), computing and digital skills ($n = 3$), engineering ($n = 2$), biology ($n = 3$), chemistry ($n = 2$), and mathematics ($n = 2$). Statistically significant connections were identified between students' past academic performance, the week of instruction, and their self-efficacy. Didactic teaching methods were linked to a higher prevalence of students with low confidence levels, both within lectures and practical classes, although this tendency was less pronounced in the case of lectures. Classification and Regression Tree (CRT) analysis indicated that optimal time management and

engagement in active learning exercises were the strongest predictors of higher student confidence in lecture settings. The study's findings hold significant implications for instructional strategies and practices, and these are briefly explored.

Keywords: self-efficacy, undergraduate STEM, student-centred teaching and learning

Introduction

Although interest in undergraduate STEM fields remains high in Ireland (Higher Education Authority, 2024) and worldwide (Australian Government, 2023; Burke et al., 2022; HESA, 2024), the challenge of high attrition rates persists (Gunter & Polidori, 2024; Seymour & Hunter, 2019). Notably, studies investigating the reasons behind undergraduate students' departure from STEM fields have yielded remarkably consistent findings over the years: the core issues identified by STEM students, ranging from an unwelcoming programme climate to deficiencies in course design and teaching quality, frequently lead to decisions to transition to non-STEM study paths (Hunter, 2019; Seymour & Hewitt, 1997). More recently, a decline in confidence has emerged as a significant factor contributing to this trend (Hunter, 2019). Addressing issues relating to student confidence in undergraduate STEM is therefore essential to help retain talent and ensure the development of a skilled workforce in STEM disciplines.

Various self-concepts related to students' confidence and motivational beliefs have been explored in relation to increasing student motivation and persistence in STEM fields. Among these, student self-efficacy, defined as perceived capability to utilise skills to successfully perform academic tasks, has received considerable attention. Self-efficacy has been found to

predict academic and professional aspirations, enhance motivation, increase persistence in achieving goals, foster perseverance when faced with obstacles, and improve the ability to cope with challenges (Bandura, 1977, 1986, 1997), all of which have been linked to favourable academic outcomes. Notably, students with robust self-efficacy view obstacles in their academic journeys as conquerable hurdles and dedicate greater effort to their pursuits (Bandura, 1986; Lent et al., 1994; Zeldin et al., 2008). Therefore, self-efficacy is often associated with increased persistence in STEM fields (Kalender et al., 2017; MacPhee et al., 2013; Zeldin & Pajares, 2000), and improved performance, in both general STEM (Lent et al., 1984; MacPhee et al., 2013), and individual disciplines, such as chemistry (Moreno et al., 2021; Villafañe et al., 2016), astronomy (Bailey et al., 2017), physics (Fencl & Scheel, 2005; Kalender et al., 2020), and engineering (Mamaril et al., 2016). Evidently, self-efficacy plays an important role in increasing students' chances of achieving their academic goals and progressing through their study programmes successfully, highlighting its importance for pedagogical practice in undergraduate STEM.

Self-efficacy is known to stem from four main sources: performance accomplishments, vicarious experience, verbal persuasion, and physiological states. While all four sources are important, performance accomplishments in particular have been widely explored in pedagogical research. Often seen as the most direct proof of one's ability (Bandura, 1997), performance feedback can reinforce students' confidence in their suitability and potential for success in their chosen field. Therefore, study courses designed to actively engage students in the learning process and provide multiple achievement opportunities, such as frequent formative assessments, can significantly improve students' self-efficacy (Bailey et al., 2017; Dunlap, 2005; Fencl & Scheel, 2005). This

is particularly true when achievement opportunities are coupled with ample feedback and support (MacPhee et al., 2013), helping students gain self-efficacy through verbal persuasion.

Additionally, considerate assessment practices that reduce stress, such as low-stakes assessments (Malespina et al., 2024; Malespina & Singh, 2022), can help address the physiological states aspect of self-efficacy.

Vicarious experience is often less easily influenced through self-efficacy interventions, as it relates to students' perceptions of their own potential for success through comparisons to similar others, which is often affected by perceivable inequalities in the educational environment (Greaves et al., 2022; Sheu et al., 2018). However, research suggests that pedagogical practice related to self-efficacy increases can also affect perceived course climate (Fencl & Scheel, 2005) and social belonging (Ballen et al. 2017). Therefore, previous research demonstrates that pedagogical self-efficacy interventions can effectively address all four sources of self-efficacy beliefs, making them attractive contenders for enhancing STEM confidence and providing optimal support to students at the beginning of their STEM journeys.

This study aimed to examine how pedagogical practice influenced students' confidence in their capabilities to succeed in their STEM courses during the early stages of their undergraduate programmes, a critical period during which students' confidence is often in flux (Casanova et al., 2022). Particular emphasis was placed on identifying instructional strategies that fostered confidence in diverse learning environments. In light of previous findings linking previous academic performance to self-efficacy beliefs (Ainscough et al., 2016; Dalgety & Coll, 2006;

Kalender et al., 2020) and regarding decreasing student self-efficacy among lower-performing student groups in undergraduate STEM (Obrentz, 2012), this study also considered prior academic performance to identify whether specific student groups relied more heavily on pedagogical interventions targeting self-efficacy. By exploring the relationships between previous performance, class setting, pedagogical practice, and self-efficacy, this study sought to contribute to the growing body of literature on self-efficacy in STEM education and to inform teaching practices that promote student success and support retention in STEM fields.

Consequently, this study focused on addressing the following research questions:

1. How robust is the initial self-efficacy of students embarking on their undergraduate STEM programmes?
2. How is student self-efficacy influenced by their previous academic achievements?
3. How is student self-efficacy affected by different class settings (class type, class size, and instructional week)?
4. Which teaching and learning approaches have a positive impact on student self-efficacy during the initial stages of their undergraduate STEM programmes?

Methods

This study employed a case study methodology to explore the relationships between previous performance, class setting, pedagogical practices, and self-efficacy at a single higher education institution. Case studies are known to help provide specific examples to more global issues and facilitate exploration of causal relationships (Cohen et al., 2018). Following a quantitative design and utilising a combination of survey data and structured classroom observations, this study

sought to provide insights into context-specific practices while contributing to broader discussions on STEM education.

A survey assessing the self-efficacy of students during the early weeks (weeks 2, 3 and 4) of their programmes was used to address RQ1. The survey also included a question on students' prior academic performance to address RQ2. Classroom observations, which captured data on both the classroom setting and teaching and learning activities, were combined with survey responses to address RQ3 and RQ4. Purposive sampling was utilised to recruit participants. Instructors from 15 first-year undergraduate courses, including physics ($n = 3$), computing and digital skills ($n = 3$), engineering ($n = 2$), biology ($n = 3$), chemistry ($n = 2$), and mathematics ($n = 2$), voluntarily agreed to participate in the study. Students and academic staff both received study information sheets outlining the nature of the research, including the researcher's contact details for any questions or concerns. Informed consent, covering both survey participation and classroom observations, was obtained from all participants. The survey was administered during class time, at the beginning of each session, to encourage high participation, and it was followed by a classroom observation.

The survey received a total of 483 responses from students across 27 different study programmes, which were broadly categorised into biology and health, engineering and computing, chemistry, physics, and interdisciplinary fields. The exact response rate could not be determined due to the large size of some lecture classes and the digital format of the survey, which did not allow for a definitive count of non-participants. Students were explicitly informed that their participation in the study was entirely voluntary, though highly appreciated. The researcher collecting data had no prior acquaintance with either the teaching staff or the students

involved. To maintain objectivity, observation data were not shared with instructors. While some classes were taught by the same teaching staff, and some students may have participated in multiple observed sessions, this is unlikely to have affected validity, since this study measured class-specific self-efficacy, with instructors employing different teaching practices across courses and students rating their confidence differently depending on the subject and setting of the class.

Instruments

Self-efficacy survey

The self-efficacy survey consisted of four Likert-type scale questions designed to gauge class-specific self-efficacy. Recognising the validity of simplified Likert-type scales in capturing confidence differences (Maurer & Andrews, 2000), the survey utilised a four-point Likert scale developed and validated by Han et al. (2021). Originally designed for both humanities and quantitative classes, Han et al.'s survey proved versatile for various STEM contexts. Minor adjustments were made to two items related to assessment modes to ensure clarity for participants. Survey items were tailored to the specific class context (see Table 1). The scale was tested for internal consistency using Cronbach's alpha. Internal consistency helps identify whether the items on the scale are related to each other and thus can be assumed to measure the same construct. The coefficient alpha value was 0.887, which suggested that the items were strongly related to each other and that the adapted scale was internally consistent.

In selecting the optimal approach for gathering information about students' previous academic achievements, two primary considerations emerged: the reliability of self-reported prior performance and the most appropriate performance indicator. Previous research investigating the

Table 1 *Self-Efficacy survey items*

Original (Han et al., 2021)	Adapted
How confident are you that you can do the following tasks in your [quantitative/humanities] classes, which include subjects such as [subject names]?	How confident are you that you can do the following tasks in your [class name] class?
1. understand the most difficult concepts taught in my [quantitative/humanities] classes	1. understand the most difficult concepts taught in your [class name] class
2. master the skills taught in my [quantitative/humanities] classes	2. master the skills taught in your [class name] class
3. do well on the assignments in [quantitative/humanities] subjects	3. do well on the assignments (continuous assessment, as well as ungraded homework and in-class activities) in your [class name] class
4. do well on tests in [quantitative/humanities] subjects	4. do well on exams in your [class name] class

connection between academic self-efficacy and prior academic performance revealed that both performance in relevant academic subjects and standardised achievement test scores could predict self-efficacy in undergraduate courses (Hackett 1985). Despite certain doubts expressed in prior meta-analyses of self-efficacy studies regarding the accuracy of self-reported achievement scores, Honicke and Broadbent (2016) determined that the nature of student achievement reporting, whether self-reported or official, did not significantly impact the relationship between performance and self-efficacy. Furthermore, although examination scores are not always the most appropriate measures of student performance, Marshman et al. identified substantial disparities between self-efficacy and performance that persisted “regardless of whether performance was measured through research-validated instruments or through the

performance indicators provided to students (i.e., grades)” (2018, p. 12). Based on this evidence, the question relating to students’ previous performance was designed to capture data on self-reported Leaving Certificate scores, and the self-efficacy survey was supplemented with the question: “*Irish Leaving Certificate points (if applicable)*.” Recognising that not all students would have completed the Leaving Certificate examinations, answering this question was optional. In total, 394 students provided valid responses regarding their Leaving Certificate performance.

Class observations

Fifteen non-participatory observations were conducted in undergraduate STEM courses, covering lectures, laboratories, and tutorials. A structured approach was adopted for the observations due to its systematic nature, which facilitates the collection of numerical data for subsequent quantitative analysis (Cohen et al., 2018). In keeping with guidelines for structured observations, a non-participatory role was adopted by the researcher during data collection. This approach helped enhance the validity and reliability of the data, as “although data collected through observation is always selective to a certain degree, it is generally agreed that low interference observation is ‘safest’ in terms of objectivity” (Cohen et al., 2018, p. 182).

The Classroom Observation Protocol for Undergraduate STEM (COPUS) was employed to guide the observations. This protocol “captures the actions of both instructors and students but does not attempt to judge the quality of those actions for enhancing learning” (Smith et al., 2013, p. 621). Observations about teaching and learning activities were coded at fixed two-minute intervals. In addition, data regarding class type, class size, and instruction week were collected as part of the observation.

Data analysis

Survey and observation results were analysed using IBM SPSS Statistics. Chi-square tests were utilised to explore relationships between self-efficacy and past performance, class type, class size, and instruction week. Classification tree analysis was employed to explore which teaching practice can predict a larger number of confident students in a lecture setting. The student self-efficacy variable was transformed into a new variable consisting of two categories only ('not confident' and 'confident') to help provide a more distinctive analysis of what pedagogical approaches lead to the student classification into the target group ('confident'). CRT (Classification and Regression Tree) was selected as the growing method, for its acknowledged applicability to pedagogical research (Seftor et al., 2021). The analysis was cross validated with 10 sample folds and produced seven nodes (minimum number of cases in parent node = 100, minimum number of cases in child node = 50, minimum improvement = 0.0001). To estimate the tree's predictive accuracy, the risk estimate was calculated. The risk estimate was 0.331, which means that the teaching practices listed in the nodes of the model could accurately predict student confidence in 66.9% of the cases.

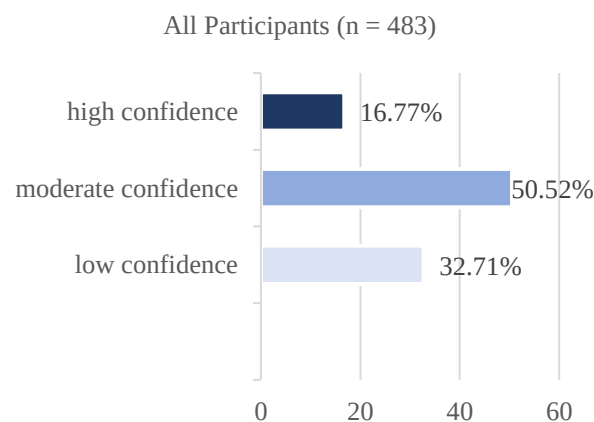
Results

Each research question is addressed in turn in this section, with the relevant results presented and discussed. Quantitative analyses focus on two primary data sources: the self-efficacy survey and classroom observations. The survey results are analysed to examine initial self-efficacy levels among students, as well as the influence of their prior academic performance. Observational data are then integrated to assess the effects of class setting and teaching practices on self-efficacy.

RQ 1: How robust is the initial self-efficacy of students embarking on their undergraduate STEM programmes?

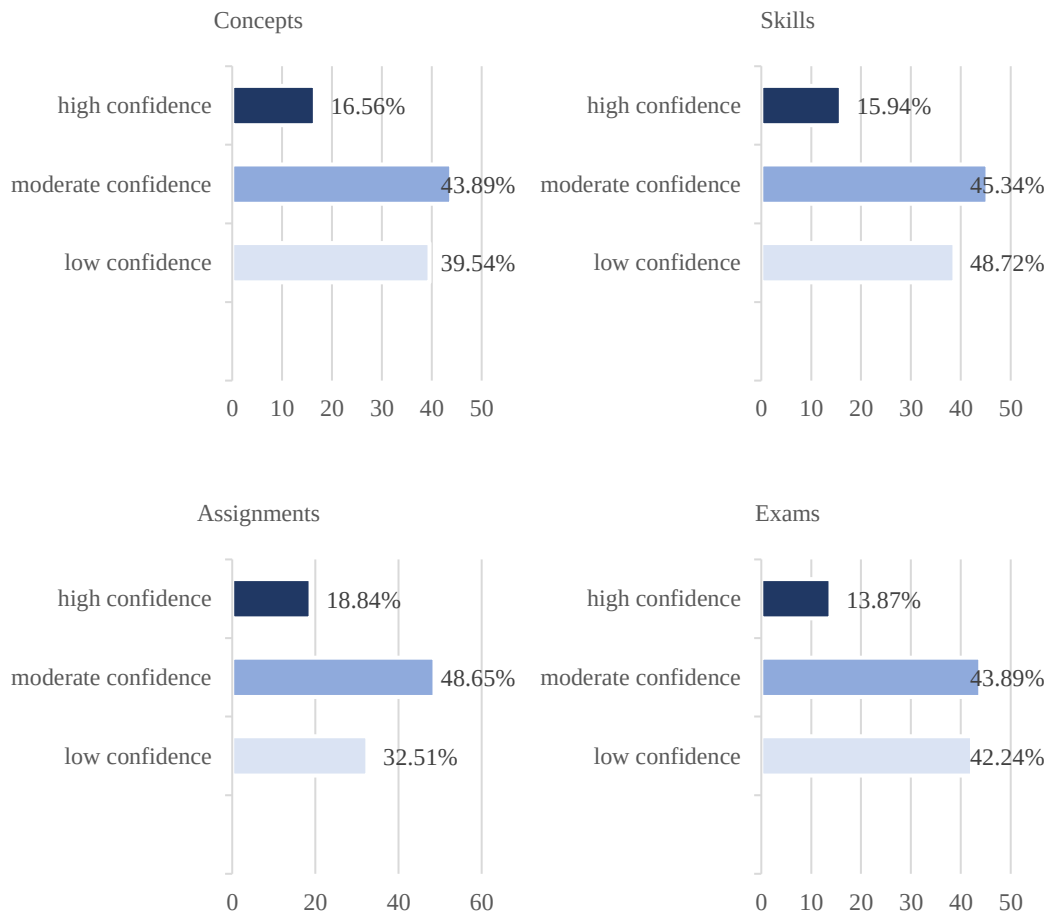
Participants in the survey ($n = 483$) were asked to rate their confidence on a 4-point scale (1 - not at all confident, 2 - somewhat confident, 3 - mostly confident, 4 - completely confident). The survey items assessed students' confidence in understanding the most difficult concepts, mastering the skills, doing well on the assignments, and doing well on exams in their classes. Due to a very low number of 'not at all confident' responses, categories 'not at all confident' (4-5/16 total points on the self-efficacy scale) and 'somewhat confident' (5-9/16) were collapsed into a 'low confidence' category (4-9/16). Categories 'mostly confident' (10-13/16 points) and 'completely confident' (14-16/16) were relabelled 'moderate confidence', and 'high confidence', respectively. The cumulative results of student answers to the self-efficacy survey are illustrated in Figure 1. On average, the survey participants were rather confident. The mean self-efficacy score among all participants was 10.94 out of 16 ($SD = 2.702$), and most students (50.51%) fell into the moderate confidence category.

Figure 1 Results of the self-efficacy survey ($n = 483$) showing the extent of confidence among all participants



Regarding the individual items on the self-efficacy survey, students displayed the highest confidence in their capability to do well on continuous assessment tasks, and the lowest confidence in their capability to do well on exams (Figure 2). Student self-efficacy towards understanding the most difficult concepts and mastering the skills taught in their classes was similar.

Figure 2 Results of the self-efficacy survey ($n = 483$) showing the extent of student confidence for understanding the concepts, learning the skills, and performing well on assignments and exams in undergraduate STEM classes

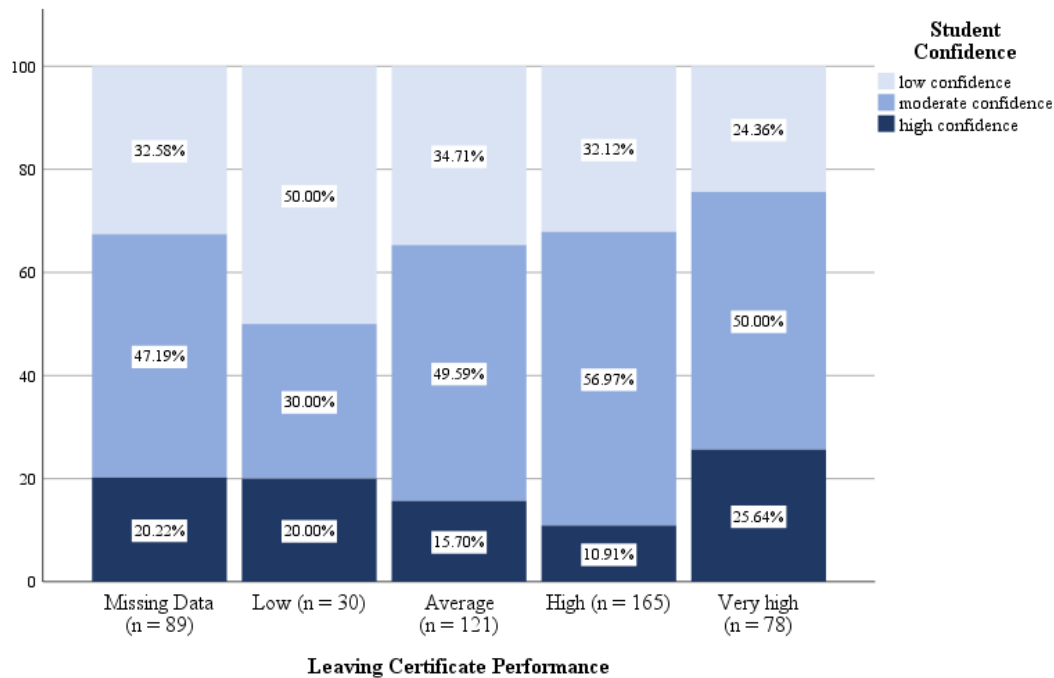


RQ 2: How is student self-efficacy influenced by their previous academic achievements?

To explore how student self-efficacy is influenced by their past performance, students were asked to indicate their Leaving Certificate results when filling in the self-efficacy survey. To utilise as many responses as possible, and to include those indicating an approximate number of points in the analysis, student answers were assigned to four distinct performance categories, guided by the theoretical upper limit of the Leaving Certificate score, which stood at 625 points at the time of this study. These performance categories were defined as ‘very high’ (>525 points), ‘high’ (426-525 points), ‘average’ (326-425 points), and ‘low’ (<326 points), yielding a dataset comprising 394 valid responses. Eighty-nine participants either did not respond to the question, indicated completing terminal post-primary school exams abroad, or provided invalid values (double digits), presumably either by mistake, or by confusion as whether to report total points or subject-specific scores.

A clear indication of an association between previous performance and academic self-efficacy could be observed in the student responses. The low-performing student group had the largest share (50%) of low confidence and the lowest share (20%) of high-confidence students, while the very-high-performing group had the lowest share (24%) of low-confidence students and the highest share (26%) of high-confidence students (Figure 3). The relationship between previous performance and student self-efficacy was statistically significant ($\chi^2(6, n = 394) = 15.866, p = 0.014, \phi = 0.201$). Students who did not provide valid prior performance data most resembled the students in the average performance group.

Figure 3 Results of the self-efficacy survey ($n = 483$) showing the extent of student confidence across low, average, high, and very high prior performance groups, including students with missing prior performance data



RQ 3: How is student self-efficacy affected by different class settings (class type, class size, and instructional week)?

In total, 15 class observations were performed. Observed classes included the following subjects: physics ($n = 3$), computing and digital skills ($n = 3$), engineering ($n=2$), biology ($n = 3$), chemistry ($n = 2$), and mathematics ($n = 2$). The means of student self-efficacy scores were subsequently compared with regard to class characteristics (Table 2).

Table 2 Means of student self-efficacy across various subject areas, class types (lecture, laboratory, tutorial), class sizes (small, medium, large), and instructional weeks (2, 3, 4)

Self-Efficacy: Means		Mean ¹	N	Std. Deviation
<i>Subject area</i>	Physics	10.35	108	2.533
	Computing & digital skills	11.62	90	2.758
	Engineering	11.15	33	2.373
	Biology	11.27	153	2.659
	Chemistry	10.10	61	2.580
	Mathematics	10.79	38	3.121
<i>Class type</i>	Lecture	11.00	375	2.720
	Laboratory	10.46	84	2.539
	Tutorial	11.58	24	2.858
<i>Class size</i>	Small (≤ 40 students)	10.42	104	2.538
	Medium (41–70 students)	10.88	133	2.666
	Large (> 70 students)	11.19	246	2.767
<i>Instruction week</i>	2	12.14	80	2.690
	3	10.81	221	2.638
	4	10.57	182	2.654

Note 1: The maximum possible self-efficacy score is 16.

Students were least confident in a laboratory setting, although class type had no significant correlation with student self-efficacy. Students were most confident in large size classes, but this relationship, again, was not statistically significant. A decline in mean self-efficacy scores could be observed as the semester progressed, with students scoring lowest on the 4th week of instruction: a statistically significant relationship was found between instruction week and student self-efficacy ($\chi^2(4, n = 483) = 25.699, p = 0.000, \phi = 0.231$).

RQ 4: Which teaching and learning approaches have a positive impact on student self-efficacy during the initial stages of their undergraduate STEM programmes?

The observational data collected were compared with the self-efficacy survey results for each class. To explore how well the instructional practices employed in each of the observed classes work for the majority of the students and help identify practices that contribute to higher percentages of confident students, classes were compared by the percentage of students in the ‘low confidence’ category.

Practice-based classes

In practice-based classes (laboratories/tutorials), many more students fell into the ‘low confidence’ category if the structure of the class resembled a lecture. The classroom activities for the laboratories and the tutorials with the highest and lowest numbers of low-confidence students are presented in Figure 4 and Figure 5. The laboratory with the lowest share of low-confidence students (15%) was primarily based on group work (students were engaged in group work for 91% of the class time). The instructor, although engaged in some administrative tasks, offered a wide range of support to students, including extended one-on-one discussions.

The laboratory with the most low-confidence students (63%) primarily focused on lecturing and real-time writing as means of instruction. Here, students spent the majority of the class time in a passive role—listening and taking notes, which accounted for 90% of the class duration. While students were given tasks that required individual thinking (the student code ‘individual thinking’ (Ind) was present for 14% of the class time), these exercises lacked instructor feedback. The instructor moved around the class (MG) for 5% of the class time, which meant minimal supervision was offered on individual tasks. While there was some communication between the

students and the instructor in this class, not a single instance of one-on-one discussion was recorded.

Figure 4 A comparison of the prevalence of codes (from COPUS) in high and low-efficacy laboratories

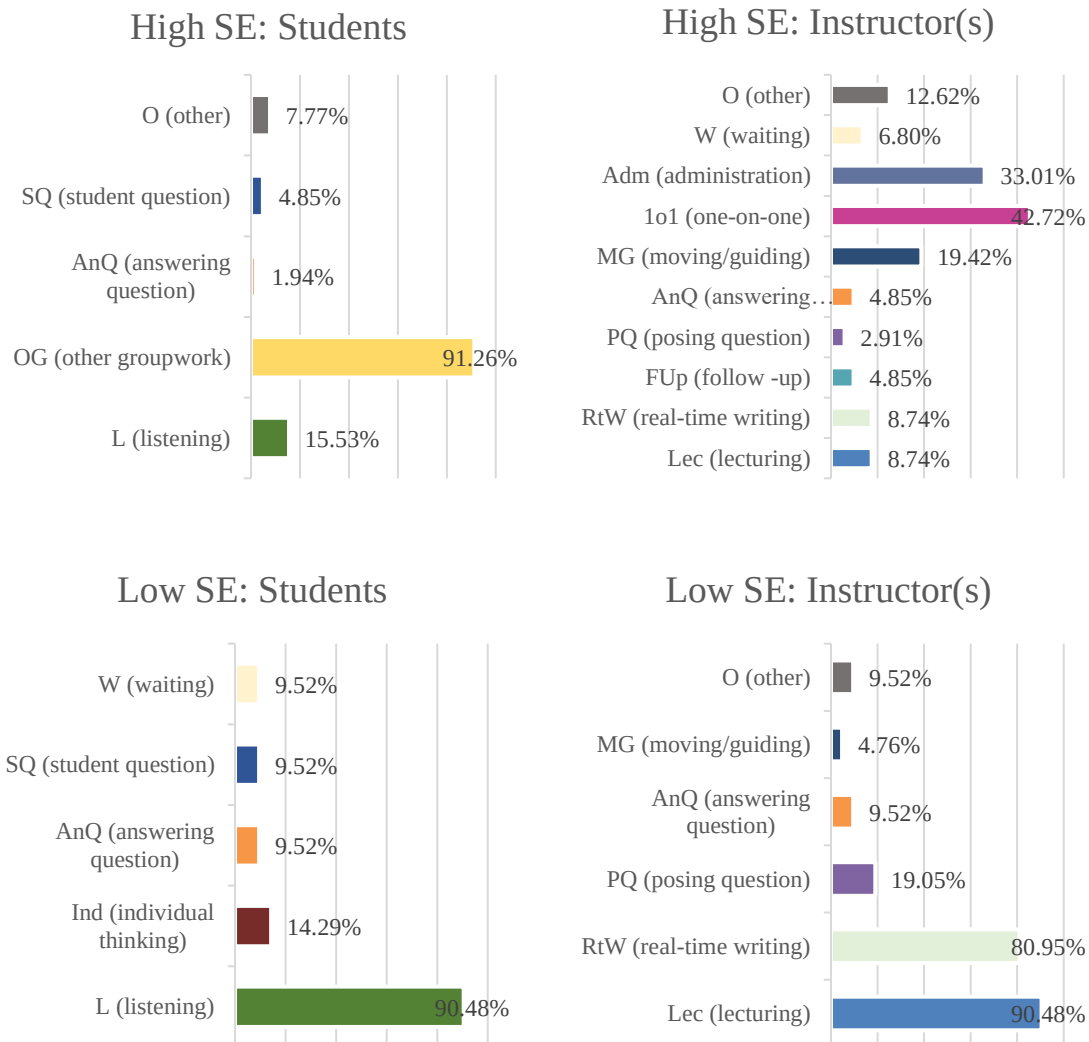
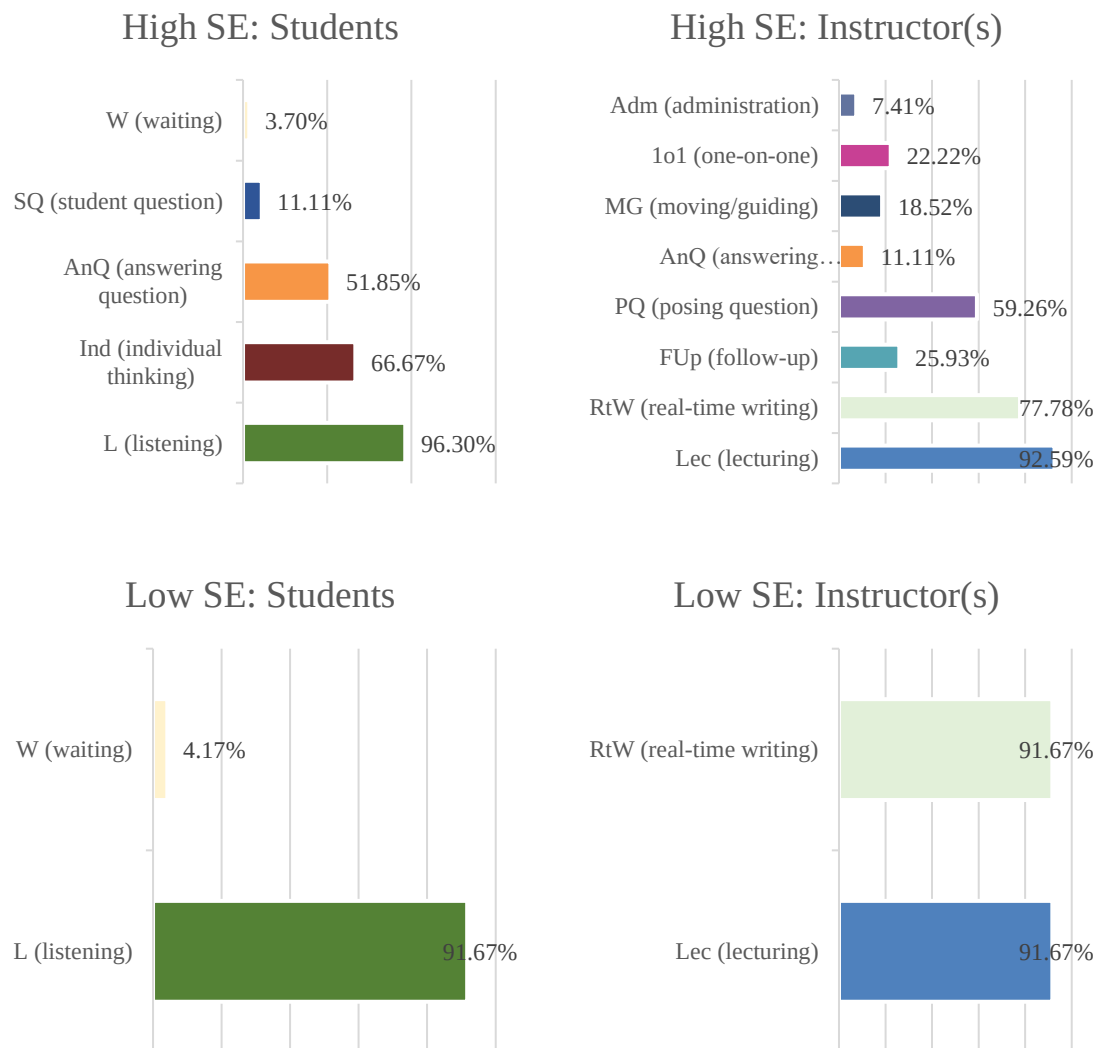


Figure 5 A comparison of the prevalence of codes (from COPUS) in high and low-efficacy tutorials



Student confidence within tutorial classes also heavily depended on the degree of class interactivity. The tutorial that had the lowest percentage (20%) of low-confidence students, despite including a notable amount of lecturing (Lec), presented numerous opportunities for individual thinking (Ind). This tutorial exhibited substantial student-instructor interactions, with the instructor code ‘posing questions’ (PQ) present for 59% of the class time and the student

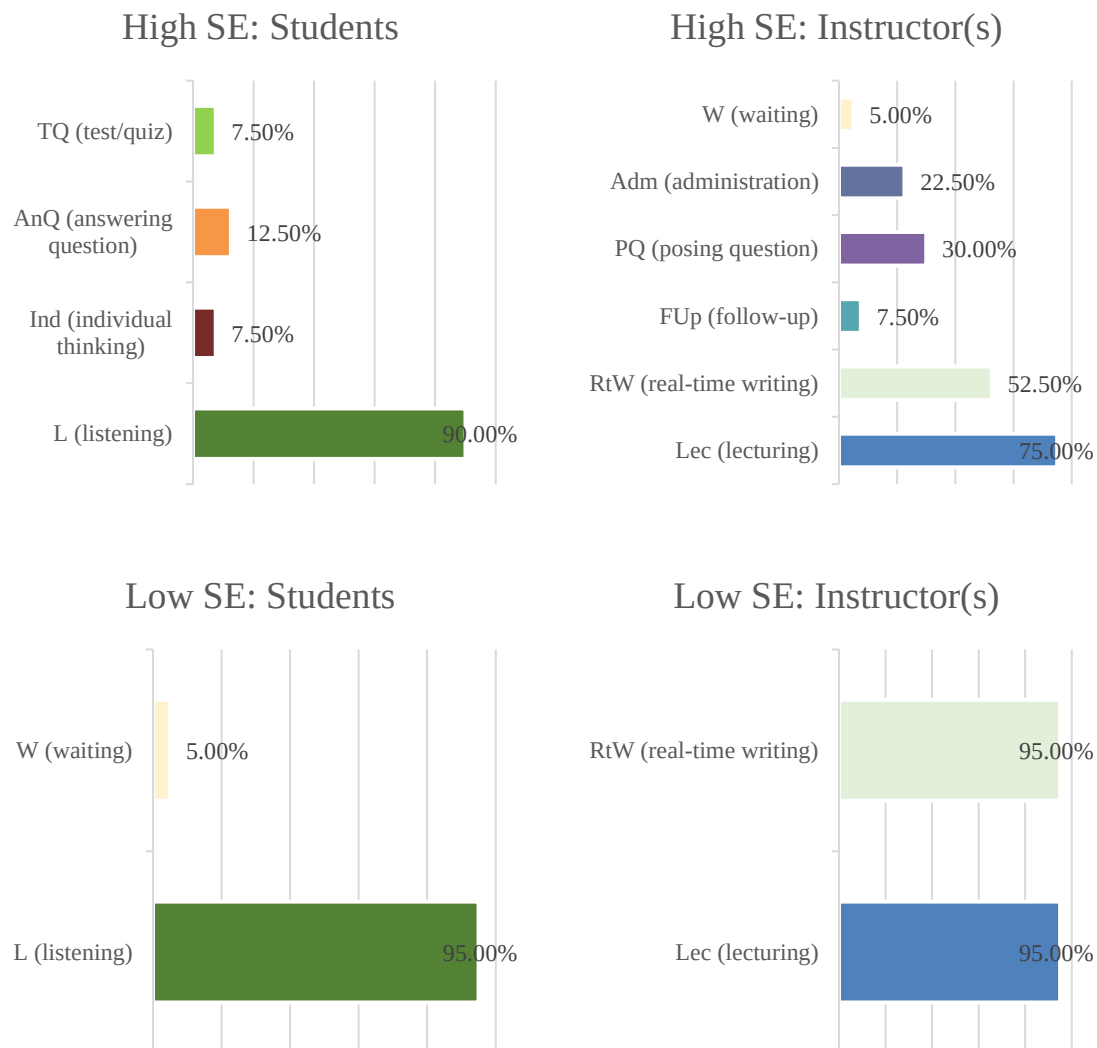
code ‘answering questions’ (AnQ) present for 52% of the class duration. Supervision of individual thinking tasks was evident (the instructor code ‘moving and guiding’ (MG) was present for 19% of the class time), followed by instructor feedback (the instructor code ‘follow-up’ (FUp) was present for 26% of the class time). Tasks involving individual thinking received individualized attention (the student code ‘one-on-one discussion’ (1on1) was present for 22% of the class time).

Conversely, the tutorial with the highest percentage of low-confidence students (50%) stood out for its lack of interactivity. ‘Lecturing’ (Lec) and ‘real-time writing’ (RtW) were the only instructor codes used when observing this tutorial. The students in this class were engaged in listening and taking notes (L) for the majority of the class time. Not a single (non-rhetorical) student-instructor interaction regarding the class topic was observed.

Lectures

Interestingly, the lectures with the highest and the lowest number of low-confidence students were in the same subject of computing and digital skills. In these lectures, employment of active learning approaches and student-instructor interaction were found to be of vital importance to student confidence. In the lecture with the lowest percentage (18%) of low-confidence students, students were asked to apply the material learnt in class to practice by completing an individual assignment (student code ‘individual thinking’ (Ind) was present for 8% of the class time) in the middle of the lecture and a quiz (student code ‘test or quiz’ (TQ) was present for 8% of the class time) before the end of the class (Figure 6). Both the individual assignment and the quiz were followed up with instructor feedback (instructor code ‘follow-up’ (FUp) was present for 8% of the class duration).

Figure 6 A comparison of the prevalence of codes (from COPUS) in high and low-efficacy lectures



The instances of student-instructor interaction in this class involved instructor questions (instructor code ‘posing question’ (PQ) was present for 30% of the class time) and student answers (student code ‘answering question’ (AnQ) was present for 13% of the class time). Although this lecturer primarily relied on lecturing as an instructional approach (instructor code ‘lecturing’ (Lec) was present for 75% and ‘real-time writing’ (RtW) was present for 53% of the class time), it seems that any use of student-centred practices makes a notable difference to student self-efficacy in lectures concerning computing and digital skills in this study. In

comparison, the computing and digital skills lecture that did not involve active learning and had no recorded instances of (non-rhetorical) student-instructor interaction, had a much higher percentage of low-confidence students (50%). The lecture with the second highest number of low-confidence students (47%) was a high-engagement physics class, while the class with the second lowest number of low-confidence students (24%) was rather instructor-centred, although students in this class were provided with opportunities to engage with the lecturer (instructor code ‘posing question’ (PQ) was present for 32% of the class duration, ‘answering question’ (AnQ) was present for 24% of the class time and student codes ‘student question’ (SQ) and ‘answering question’ (AnQ) were both present for 24% of the class time). Given that the relationship between pedagogical practices and student self-efficacy appeared to vary among lectures in different disciplines, further data analysis was deemed necessary to draw conclusive findings and CRT analysis was employed.

Lectures: CRT Analysis

Pedagogical practices within the observed lectures underwent further investigation through the application of the decision tree method to the data collected. The analysis produced seven nodes (minimum number of cases in parent node = 100, minimum number of cases in child node = 50, minimum improvement = 0.0001). Gains for each node are represented in Table 3. Two student codes (‘waiting’ and ‘individual thinking/problem solving’) and one instructor code (‘real-time writing’) helped predict the category of student confidence (Figure 7).

Table 3 *Gains for node¹*

(target category: confident)

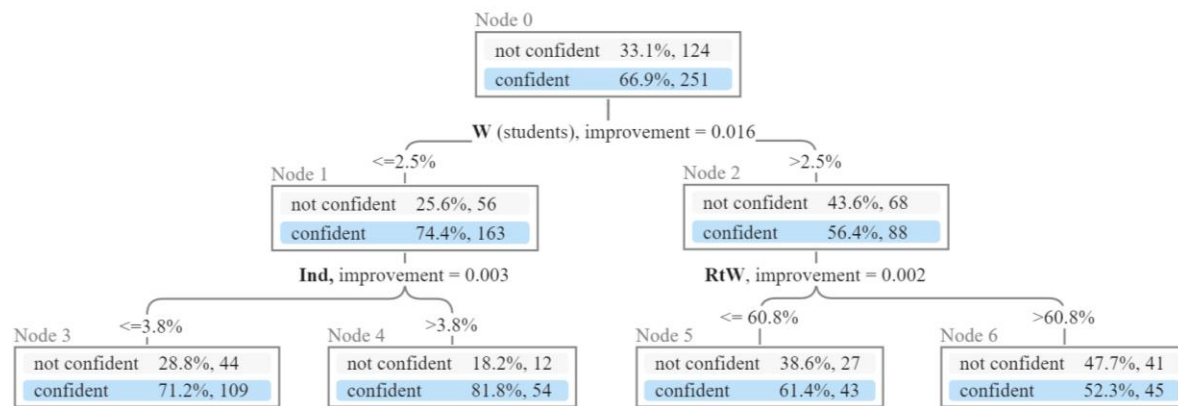
<i>Node</i>	<i>Node</i>		<i>Gain</i>		Response	Index ▼
	N ²	Per cent	N ³	Per cent		
4 (Ind > 3.8%)	66	17.6%	54	21.5%	81.8%	122.2%
3 (Ind ≤ 3.8%)	153	40.8%	109	43.4%	71.2%	106.4%
5 (RtW ≤ 60.8%)	70	18.7%	43	17.1%	61.4%	91.8%
6 (RtW > 60.8%)	86	22.9%	45	17.9%	52.3%	78.2%

Note 1: Only terminal nodes which represent the best classification predictions are listed in the table.

Note 2: Total number of cases in the node

Note 3: Number of cases classified as 'confident'

In instances where the student code 'waiting' (instructor late, working on fixing AV problems, instructor otherwise occupied, etc.) exhibited minimal presence ($\leq 2.5\%$ of the class), students were predicted to be much more confident than in classes where the students had to wait more, signifying that the effective utilisation of class time significantly influenced student confidence in this study. In classes where the students waited less, individual thinking/problem solving activities could also predict student confidence. Low prevalence of the 'individual thinking/problem solving' code ($\leq 3.75\%$) could predict lower percentage of confident students. The use of individual thinking and problem-solving activities in the classroom could predict the highest percentage of confident students (Table 3). In classes where student code 'waiting' was more prevalent ($> 2.5\%$), the prevalence of the instructor code 'real-time writing' (real-time writing on board, doc. projector, etc.) was of significance. When 'real-time writing' dominated a substantial portion ($> 60.8\%$) of the class duration, students were predicted to exhibit significantly lower confidence levels, revealing that students were less likely to hold high confidence beliefs in lectures based on traditional lecturing methods in this study.

Figure 7 CRT Analysis: Pedagogy $\times$ Student Confidence: Lectures

Discussion

This study sought to identify self-efficacy patterns among students in the early stages of their undergraduate STEM programmes. While students participating in the study were fairly confident overall ($M = 10.94/16$, $SD = 2.702$), student confidence was found to depend on their previous academic performance as well as the pedagogical approaches employed in their courses.

Students who self-reported achieving higher scores in their Leaving Certificate (LC) were also more confident about their capabilities to perform well in their university classes, while those who reported low scores exhibited significantly lower self-efficacy, with the relationship between previous performance and academic self-efficacy being statistically significant ($\chi^2(6, n = 394) = 15.866$, $p = 0.014$, $\phi = 0.201$). The low-performing student group (<326 LC points) had the largest share (30%) of low confidence, while the very-high-performing group (>525 LC

points) had the lowest share (14%) of low-confidence students and the highest share (31%) of high-confidence students.

While students had highest self-efficacy for large-enrolment classes and lowest self-efficacy for laboratories, neither class size nor class type had a statistically significant relationship with self-efficacy. Instruction week, however, had a statistically significant modest relationship with student self-efficacy ($\chi^2(4, n = 483) = 25.699, p = 0.000, \phi = 0.231$) and students' confidence levels were found to decline progressively with each new week between the 2nd and the 4th week of the semester. Previous studies have similarly observed that self-efficacy levels can decline over time, particularly among average- and low-performing students (Obrentz, 2012), as well as among groups underrepresented in STEM, such as racial and ethnic minorities (Hood et al., 2020). Given the established links between self-efficacy and academic persistence, future research should investigate the impact of pedagogical methods on the development of self-efficacy in these groups over extended periods and focus on ensuring that pedagogical practices actively support and sustain these students' self-beliefs, particularly in the early stages of their academic journeys.

Lower proportions of low-confidence students could be observed in laboratories and tutorials that were student-centred and in which students were engaging with individual and group tasks for the majority of the class. Conversely, laboratories and tutorials with the highest percentages of low-confidence students were based on didactic instruction. While large enrolment settings can present challenges for effective student engagement, research indicates that transitioning from traditional lecturing to active learning can significantly improve student confidence.

Strategies such as incorporating pre-lecture assignments and quizzes, implementing collaborative problem-solving activities, using personal response systems, and rewarding ongoing participation rather than relying solely on exams have been shown to yield substantial gains in self-efficacy (Ballen et al., 2017).

Lecture observations, however, produced less decisive results, with a highly interactive physics class having one of the lowest average self-efficacy scores among all observed classes and a low-participation biology lecture having one of the highest self-efficacy scores and one of the lowest shares of low-confidence students. It is worth noting that biology consistently ranks as the most popular higher-level Leaving Certificate science subject in Ireland (CareersPortal.ie, 2023), which may partly explain these higher self-efficacy scores. Nevertheless, a more comprehensive analysis of pedagogical practices within the lecture context was deemed imperative to help establish generalisable conclusions across different STEM subjects.

The classification and regression tree analysis was employed to help gain a better insight into which pedagogical practice can best predict the share of confident students in first-semester STEM lectures. Three codes were found to predict student confidence in a lecture setting: student codes ‘waiting’ and ‘individual thinking/problem solving,’ and instructor code ‘real-time writing.’ Reduced waiting and more individual thinking/problem solving opportunities correlated with higher confidence. Students were predicted to be the least confident in classes in which ineffective use of class time (prevalence of code ‘waiting’ >2.5%) collated with instructor-centred teaching methods (prevalence of code ‘real-time writing’ >60.8%). Although the lower self-efficacy results observed in the highly interactive physics class could partly be attributed to

the class being at a fundamental level, likely meaning that students in this class lacked prior experience in physics, the CRT analysis provided additional explanation. Despite the presence of diverse instructional strategies and ample individual-thinking opportunities (student code ‘individual thinking/problem solving’ present for 65% of the class), the prevalence of the student code ‘waiting’ (5% of the class) and the instructor code ‘real-time writing’ (65% of the class) indicated that the session was not as well-structured, or student-centred, as it could have been.

For undergraduate students in STEM, negative learning experiences often result in a loss of confidence (Seymour & Hunter, 2019), which can have severe implications for their academic and professional development. Based on the findings of this study, STEM students lose confidence progressively during the first weeks of their undergraduate programmes, highlighting the importance of early intervention. Engaging students through effective pedagogical practices during this critical period is essential to help sustain and further develop their self-efficacy. Moreover, the significant relationship observed between prior academic performance and self-efficacy suggests that lower-performing students are particularly likely to benefit from targeted self-efficacy supports.

Implications for Learning and Teaching Practice

Instructors concerned with facilitating positive learning experiences among their students and promoting student retention should be aware of instructional practices identified as relating to student disengagement. Instructor-centred teaching has been found to cause student disinterest, lack of motivation, and difficulties in engaging with the course content (Seymour & Hunter, 2019) and result in lower self-efficacy (Bailey et al., 2017) in previous research and this is

echoed in this study also. Conversely, student-centred pedagogies were found to positively correlate with student confidence beliefs in all class types.

This study ascertains that a heightened prevalence of pedagogical approaches centred around students, including collaborative group tasks, individual thinking and problem-solving exercises, as well as evaluative assessments such as tests and quizzes, correlates positively with elevated self-efficacy levels among students. Furthermore, classes characterised by ample student-instructor interactions and instructor support manifesting as active oversight of both individual and group activities, engaging in follow-up discussions about class activities, and providing individual feedback, contribute significantly to fostering enhanced self-efficacy among students. Conversely, classes centred around instructor-driven methodologies like didactic instruction and instructional writing on board, coupled with an absence of student-instructor interaction, and suboptimal use of class time, tend to correlate with reduced student confidence. Practical considerations for learning and instruction based on these findings are presented in Table 4.

Table 4 *Implications for learning and instruction*

	Findings	Recommendations for instruction	Examples of effective practices in undergraduate STEM
Student-centred teaching	Student-centred teaching methodologies exert a positive influence on student self-efficacy in introductory STEM classes across different disciplines and in all class types (lectures, tutorials, and laboratories).	Avoid over-reliance on instructor-centred teaching methods such as traditional lecturing and unilateral delivery of content; incorporate diverse instructional strategies that encourage active student participation and interaction; prioritise integrating collaborative group activities, individual thinking, and problem-solving tasks into introductory classes; incorporate evaluative assessments (tests and quizzes) to foster a more engaged and confident student body.	Problem based learning activities (Mataka & Kowalske, 2015) Collaborative learning activities, especially ones promoting equitable distribution of tasks (Doucette & Singh, 2022) Frequent low-stake quizzes, especially with a retake element (Vyas et al., 2023), or based on mastery-based testing approach (Collins et al., 2019)
Student-instructor interactions	Introductory STEM classes characterised by ample student-staff interactions exhibit diminished shares of low-confidence students and can be especially effective in classes in which didactic delivery of instructional material cannot be avoided.	Create an environment that facilitates open dialogue, where students feel comfortable asking questions and participating in discussions. Make time for conversation and welcome student questions to help students feel more engaged in the learning process.	Interactive question sessions, including online inquiry (Jansson et al., 2021) Guided collaborative inquiry tasks (Kiselyov & Schunn, 2024)
Providing support	Student-centred pedagogical practices have the best effects on student self-efficacy in classes in which the students receive timely feedback and support.	Be actively involved in overseeing and guiding both individual and group activities. Follow-up learning activities with discussions to help promote student learning and engagement. Include personalised feedback opportunities to help address individual learning needs and provide timely guidance.	Supplementing scaffolded activities with formative feedback (Vijayan et al., 2024) Providing positive, rather than only objective personalised feedback (Park et al., 2024)
Effective use of class time	Suboptimal class-time management can predict higher proportions of low-confidence students in introductory STEM classes.	Optimise the productive use of class time by maintaining a seamless flow of activities, thereby minimising instances of student waiting and ensuring sustained active student engagement.	Flipped classroom model (Lahdenperä et al., 2019) Lecture chunking (Grando, 2023); multimedia approach, e.g. recorded lectures and online quizzes (Dimas et al., 2014) or quick reference videos (Thompson et al., 2024)

Conclusion

The demand for STEM professionals remains high (European Commission, 2024), making it a priority to retain undergraduate students in STEM fields. However, research suggests that there is significant uncertainty among undergraduate STEM students regarding their academic and professional trajectories. Many students report contemplating switching to a different STEM subject (Rosenzweig et al., 2024) or leaving STEM altogether (Seymour & Hunter, 2019), while a substantial number of graduates pursue careers only indirectly related or entirely unrelated to STEM (Deitz & Freyman, 2024). Enhancing self-efficacy does not only affect student motivation and persistence, but also positively influences their performance, and higher performance in STEM subjects has been linked to better STEM employment opportunities after graduation (Meoli et al., 2024), suggesting that self-efficacy interventions can play a critical role in addressing the loss of STEM talent.

Attracting students to STEM fields is already a significant challenge, and universities must make concerted efforts to maintain students in these programmes by supporting their progress and success. With previous research suggesting that the majority of students (96%) who leave STEM cite problems with teaching, particularly in introductory STEM courses (Hunter, 2019), it is imperative to adopt effective pedagogical practices early in students' academic journeys to support their transition to university education. This study reveals that students' confidence at the beginning of their studies is significantly affected by their previous academic experiences, and therefore pedagogical interventions aimed at improving self-efficacy, while offering benefits to all students, are especially critical for students at the highest risk of attrition, namely those with lower prior academic performance and lower initial self-efficacy. By equipping these students

with the skills and confidence to persevere through early challenges, self-efficacy-focused teaching can contribute significantly to reducing dropout rates and fostering equitable success.

We hope that the findings of this study, along with the practical recommendations for instruction provided, will inspire instructors in undergraduate STEM to adopt pedagogical approaches that actively support self-efficacy development and, in turn, contribute to the retention and success of students in STEM fields.

Declaration of interest statement

The authors claim no conflicts of interest.

Ethics statement

This study adhered to ethical guidelines outlined by the British Educational Research Association (BERA 2018) and received ethical clearance from the university (REIC-21-139). All participants were provided with study information sheets, informed about voluntary participation and withdrawal options, and required to sign a consent form indicating their willingness to participate in data collection, subsequent analysis, and dissemination.

References

- Ainscough, L., Foulis, E., Colthorpe, K., Zimbardi, K., Robertson-Dean, M., Chunduri, P., & Lluca, L. (2016). Changes in Biology Self-Efficacy during a First-Year University Course. *CBE Life Sciences Education*, 15(2), ar19. <https://doi.org/10.1187/cbe.15-04-0092>
- Australian Government. (2023). *STEM Equity Monitor: University enrolment and completion in STEM and other fields*. <https://www.industry.gov.au/publications/stem-equity-monitor/higher-education-data/university-enrolment-and-completion-stem-and-other-fields>

- Bailey, J. M., Lombardi, D., Cordova, J. R., & Sinatra, G. M. (2017). Meeting students halfway: Increasing self-efficacy and promoting knowledge change in astronomy. *Physical Review. Physics Education Research*, 13(2).
<http://dx.doi.org/10.1103/PhysRevPhysEducRes.13.020140>
- Ballen, C. J., Wieman, C., Salehi, S., Searle, J. B., & Zamudio, K. R. (2017). Enhancing Diversity in Undergraduate Science: Self-Efficacy Drives Performance Gains with Active Learning. *CBE Life Sciences Education*, 16(4). <https://doi.org/10.1187/cbe.16-12-0344>
- Bandura, A. (1977). *Social learning theory*. (pp. viii, 247). Prentice-Hall.
- Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Prentice-Hall.
- Bandura, A. (1997). *Self-efficacy: The exercise of control*. W H Freeman & Co.
- Burke, A., Okrent, A., & Hale, K. (2022). *Science and Engineering Indicators 2022: The State of U.S. Science and Engineering* (NSB-2022-1). National Science Board, National Science Foundation. <https://nces.nsf.gov/pubs/nsb20221>
- CareersPortal.ie. (2023). *Subject Grades Explorer*.
https://cc.careersportal.ie/school/lc_marks_distribution.php
- Casanova, J. R., Gomes, A., Moreira, M. A., & Almeida, L. S. (2022). Promoting Success and Persistence in Pandemic Times: An Experience With First-Year Students. *Frontiers in Psychology*, 13. <https://doi.org/10.3389/fpsyg.2022.815584>
- Cohen, L., Manion, L., & Morrison, K. (2018). *Research Methods in Education* (8th ed.). Routledge. <https://go.exlibris.link/Rr455ZLx>
- Collins, B. J., Harsy, A., Hart, J., Anne Haymaker, K., (Armstrong) Hoofnagle, A. M., Kuyper Janssen, M., Stewart Kelly, J., Tyler Mohr, Austin, & OShaughnessy, J. (2019). Mastery-Based Testing in Undergraduate Mathematics Courses. *PRIMUS*, 29(5), 441–460.
<https://doi.org/10.1080/10511970.2018.1488317>
- Dalgaty, J., & Coll, R. K. (2006). Exploring First-Year Science Students' Chemistry Self-Efficacy. *International Journal of Science and Mathematics Education*, 4(1), 97–116.
<https://doi.org/10.1007/s10763-005-1080-3>
- Deitz, S., & Freyman, C. (2024). *Science and Engineering Indicators 2024: The State of U.S. Science and Engineering* (NSB-2024-3). National Science Board, National Science Foundation. <https://nces.nsf.gov/pubs/nsb20243>
- Dimas, D. J., Jabbari, F., & Billimek, J. (2014). *Using Recorded Lectures and Low Stakes Online Quizzes to Improve Learning Efficiency in Undergraduate Engineering Courses*. 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana.
<https://doi.org/10.18260/1-2--23274>
- Doucette, D., & Singh, C. (2022). Share It, Don't Split It: Can Equitable Group Work Improve Student Outcomes? *The Physics Teacher*, 60(3), 166–168.
<https://doi.org/10.1119/5.0033824>
- Dunlap, J. C. (2005). Problem-based learning and self-efficacy: How a capstone course prepares students for a profession. *Educational Technology Research and Development*, 53(1), 65–83. <https://doi.org/10.1007/BF02504858>
- European Commission. (2024). *Employment and Social Developments in Europe: Upward social convergence in the EU and the role of social investment*. <https://doi.org/10.2767/91555>
- Fencl, H., & Scheel, K. (2005). Engaging Students: An Examination of the Effects of Teaching Strategies on Self-Efficacy and Course Climate in a Nonmajors Physics Course. *Journal*

- of *College Science Teaching*, 35(1), 20–24. JSTOR.
<http://www.jstor.org.tudublin.idm.oclc.org/stable/42992548>
- Grando, D. (2023). What chunking of microbiology learning materials looks like today using technology and learning objects. *Microbiology Australia*, 44(3), 127–130.
<https://doi.org/10.1071/MA23037>
- Greaves, R., Kelestyn, B., Blackburn, R. A. R., & Kitson, R. R. A. (2022). The Black Student Experience: Comparing STEM Undergraduate Student Experiences at Higher Education Institutions of Varying Student Demographic. *Journal of Chemical Education*, 99(1), 56–70. <https://doi.org/10.1021/acs.jchemed.1c00402>
- Gunter, A., & Polidori, G. (2024). STEM Graduation Trends and Educational Reforms: Analyzing Factors and Enhancing Support. *American Journal of STEM Education*, 1. <https://doi.org/10.32674/4wpaxt10>
- Han, J., Usher, E. L., & Brown, C. S. (2021). Trajectories in quantitative and humanities self-efficacy during the first year of college. *Learning and Individual Differences*, 91, 102054. <https://doi.org/10.1016/j.lindif.2021.102054>
- HESA. (2024). *Higher Education Student Statistics UK: 2022/23*.
<https://www.hesa.ac.uk/news/08-08-2024/sb269-higher-education-student-statistics>
- Higher Education Authority. (2024). *Key Facts and Figures: Overall Trends in Enrolments A*.
<https://hea.ie/statistics/data-for-download-and-visualisations/key-facts-figures/>
- Honicke, T., & Broadbent, J. (2016). The influence of academic self-efficacy on academic performance: A systematic review. *Educational Research Review*, 17, 63–84.
<https://doi.org/10.1016/j.edurev.2015.11.002>
- Hood, S., Barrickman, N., Djerdjian, N., Farr, M., Gerrits, R. J., Lawford, H., Magner, S., Ott, B., Ross, K., Roychowdury, H., Page, O., Stowe, S., Jensen, M., & Hull, K. (2020). Some Believe, Not All Achieve: The Role of Active Learning Practices in Anxiety and Academic Self-Efficacy in First-Generation College Students. *Journal of Microbiology & Biology Education*, 21(1), 21.1.19. <https://doi.org/10.1128/jmbe.v21i1.2075>
- Hunter, A.-B. (2019). Why Undergraduates Leave STEM Majors: Changes Over the Last Two Decades. In E. Seymour & A.-B. Hunter (Eds.), *Talking about Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education* (pp. 87–114). Springer International Publishing. https://doi.org/10.1007/978-3-030-25304-2_3
- Jansson, M., Hrastinski, S., Stenbom, S., & Enoksson, F. (2021). Online question and answer sessions: How students support their own and other students' processes of inquiry in a text-based learning environment. *The Internet and Higher Education*, 51, 100817. <https://doi.org/10.1016/j.iheduc.2021.100817>
- Kalender, Z. Y., Marshman, E., Nokes-Malach, T. J., Schunn, C., & Singh, C. (2017). *Motivational characteristics of underrepresented ethnic and racial minority students in introductory physics courses*. 204–207. <https://doi.org/10.1119/PERC.2017.PR.046>
- Kalender, Z. Y., Marshman, E., Schunn, C. D., Nokes-Malach, T. J., & Singh, C. (2020). Damage caused by women's lower self-efficacy on physics learning. *Physical Review. Physics Education Research*, 16(1).
<http://dx.doi.org/10.1103/PhysRevPhysEducRes.16.010118>
- Kiselyov, K., & Schunn, C. D. (2024). Peer-reviewed presentation exchange in an undergraduate classroom. *Journal of Microbiology & Biology Education*, 25(1), e00067-23. <https://doi.org/10.1128/jmbe.00067-23>

- Lahdenperä, J., Postareff, L., & Rämö, J. (2019). Supporting Quality of Learning in University Mathematics: A Comparison of Two Instructional Designs. *International Journal of Research in Undergraduate Mathematics Education*, 5. <https://doi.org/10.1007/s40753-018-0080-y>
- Lent, R. W., Brown, S. D., & Hackett, G. (1994). Toward a Unifying Social Cognitive Theory of Career and Academic Interest, Choice, and Performance. *Journal of Vocational Behavior*, 45(1), 79. <https://doi.org/10.1006/jvbe.1994.1027>.
- Lent, R. W., Brown, S. D., & Larkin, K. C. (1984). Relation of self-efficacy expectations to academic achievement and persistence. *Journal of Counseling Psychology*, 31(3), 356–362. <https://doi.org/10.1037/0022-0167.31.3.356>
- MacPhee, D., Farro, S., & Canetto, S. S. (2013). Academic self-efficacy and performance of underrepresented STEM majors: Gender, ethnic, and social class patterns. *Analyses of Social Issues and Public Policy (ASAP)*, 13(1), 347–369. <https://doi.org/10.1111/asap.12033>
- Malespina, A., Seifollahi, F., & Singh, C. (2024). Bioscience Students in Physics Courses with Higher Test Anxiety Have Lower Grades on High-Stakes Assessments and Women Report More Test Anxiety than Men. *Education Sciences*, 14(10). <https://doi.org/10.3390/educsci14101092>
- Malespina, A., & Singh, C. (2022). Gender differences in test anxiety and self-efficacy: Why instructors should emphasize low-stakes formative assessments in physics courses. *European Journal of Physics*, 43(3), 035701. <https://doi.org/10.1088/1361-6404/ac51b1>
- Mamaril, N. A., Usher, E. L., Li, C. R., Economy, D. R., & Kennedy, M. S. (2016). Measuring Undergraduate Students' Engineering Self-Efficacy: A Validation Study. *Journal of Engineering Education*, 105(2), 366–395. <https://doi.org/10.1002/jee.20121>
- Marshman, E. M., Kalender, Z. Y., Nokes-Malach, T., Schunn, C., & Singh, C. (2018). Female students with A's have similar physics self-efficacy as male students with C's in introductory courses: A cause for alarm? *Physical Review. Physics Education Research*, 14(2). <http://dx.doi.org/10.1103/PhysRevPhysEducRes.14.020123>
- Mataka, L. M., & Kowalske, M. G. (2015). The influence of PBL on students' self-efficacy beliefs in chemistry. *Chemistry Education Research and Practice*, 16(4), 929–938. <https://doi.org/10.1039/C5RP00099H>
- Maurer, T. J., & Andrews, K. D. (2000). Traditional, Likert, and Simplified Measures of Self-Efficacy. *Educational and Psychological Measurement*, 60(6), 965–973. <https://doi.org/10.1177/00131640021970899>
- Meoli, A., Piva, E., & Righi, H. (2024). Missing women in STEM occupations: The impact of university education on the gender gap in graduates' transition to work. *Research Policy*, 53(8), 105072. <https://doi.org/10.1016/j.respol.2024.105072>
- Moreno, C., Pham, D., & Ye, L. (2021). Chemistry self-efficacy in lower-division chemistry courses: Changes after a semester of instruction and gaps still remain between student groups. *Chemistry Education Research and Practice*, 22(3), 772–785. <https://doi.org/10.1039/D0RP00345J>
- Obrentz, S. B. (2012). Predictors of science success: The impact of motivation and learning strategies on college chemistry performance. *Ph.D. Thesis*. <https://ui.adsabs.harvard.edu/abs/2012PhDT.....1O>
- Park, L. E., Ward, D. E., Moore-Russo, D., Rickard, B., Vessels, V., & Hundley, J. (2024). Positive Feedback as a Lever to Boost Students' STEM Outcomes. *Personality and*

- Social Psychology Bulletin*, 01461672241265954.
<https://doi.org/10.1177/01461672241265954>
- Rosenzweig, E. Q., Chen, X.-Y., Song, Y., Baldwin, A., Barger, M. M., Cotterell, M. E., Dees, J., Injaian, A. S., Weliweriya, N., Walker, J. R., Wiegert, C. C., & Lemons, P. P. (2024). Beyond STEM attrition: Changing career plans within STEM fields in college is associated with lower motivation, certainty, and satisfaction about one's career. *International Journal of STEM Education*, 11(1), 15. <https://doi.org/10.1186/s40594-024-00475-6>
- Seftor, N., Shannon, L., Wilkerson, S., & Klute, M. (2021). *Branching out: Using decision trees to inform education policy choices*. <http://ies.ed.gov/ncee/edlabs>
- Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Westview Press.
- Seymour, E., & Hunter, A.-B. (Eds.). (2019). *Talking about Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education*. <https://doi.org/10.1007/978-3-030-25304-2>
- Sheu, H.-B., Lent, R. W., Miller, M. J., Penn, L. T., Cusick, M. E., & Truong, N. N. (2018). Sources of self-efficacy and outcome expectations in science, technology, engineering, and mathematics domains: A meta-analysis. *Journal of Vocational Behavior*, 109, 118–136. <https://doi.org/10.1016/j.jvb.2018.10.003>
- Smith, M. K., Jones, F. H. M., Gilbert, S. L., & Wieman, C. E. (2013). The Classroom Observation Protocol for Undergraduate STEM (COPUS): A New Instrument to Characterize University STEM Classroom Practices. *CBE—Life Sciences Education*, 12(4), 618–627. <https://doi.org/10.1187/cbe.13-08-0154>
- Thompson, J. C., Griffin, J. H., & Link, R. D. (2024). Evaluating Student Engagement with Quick Reference Videos for Common Organic Chemistry Laboratory Techniques. *Journal of Chemical Education*, 101(12), 5240–5250. <https://doi.org/10.1021/acs.jchemed.4c00619>
- Vijayan, V., Fang, S., Barclay, S. A., Reissman, M. E., & Reissman, T. (2024). Impact of scaffolding and hands-on assignments within mechatronics on student learning outcomes of KEEN's entrepreneurial mindset. *International Journal of Mechanical Engineering Education*, 03064190241240463. <https://doi.org/10.1177/03064190241240463>
- Villafañe, S. M., Xu, X., & Raker, J. R. (2016). Self-efficacy and academic performance in first-semester organic chemistry: Testing a model of reciprocal causation. *Chemistry Education Research and Practice*, 17(4), 973–984. <https://doi.org/10.1039/C6RP00119J>
- Vyas, V. S., Nobile, L., Gardinier, J. R., & Reid, S. A. (2023). Impact of a Low-Stakes Assessments Model with Retake in General Chemistry: Connecting to Student Attitudes and Self-Concept. *Education Sciences*, 13(12). <https://doi.org/10.3390/educsci13121235>
- Zeldin, A. L., Britner, S. L., & Pajares, F. (2008). A comparative study of the self-efficacy beliefs of successful men and women in mathematics, science, and technology careers. *Journal of Research in Science Teaching*, 45(9), 1036–1058. <https://doi.org/10.1002/tea.20195>
- Zeldin, A. L., & Pajares, F. (2000). Against the Odds: Self-Efficacy Beliefs of Women in Mathematical, Scientific, and Technological Careers. *American Educational Research Journal*, 37(1), 215–246. <https://doi.org/10.3102/00028312037001215>