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Engineering self-efficacy development in undergraduates: evolving sources

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ABSTRACT

Self-efficacy has been previously associated with a wide range of desirable traits and behaviours within engineering education environments. In this study, we examine the self-efficacy beliefs of first- and final-year undergraduate students using a multi-methods approach (*N* = 205). The Engineering Self-efficacy Scale is combined with open items that are thematically analysed. The results suggest that the sources drawn on to form engineering self-efficacy change over the course of a degree. Enactive experiences are highly valued by participants and these are centred on applied modules with design and manufacture elements. Professional placement experiences are reported as the main source of later-stage self-efficacy development for student engineers and are similarly valued due to their provision of enactive mastery experiences. The factor structure of the survey instrument is evaluated for use within the current context and suggestions for future research, practitioner considerations for strategy selection, policy development and course design are discussed.

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Self-efficacy; engineering; retention; social learning theory; engagement

Introduction

Self-efficacy, situated within Bandura's Social Cognitive Theory, is the belief a person holds regarding their ability to achieve a successful outcome in a specific situation or task (Bandura 1997). This differs from confidence as it focuses on a specific domain. Someone could be described as being generally confident, however general self-efficacy without a defined domain is widely considered a misnomer (Bandura 2000, 2012). For example, an engineering student could have high self-efficacy for an applied manufacturing task, while simultaneously having low self-efficacy for an analytical task. The broader the domain of self-efficacy, typically the lower its value in terms of prediction and reliability (Bandura 2000, 2012). Self-efficacy has been of interest to educators for some time due to its consistent links to positive student outcomes including academic performance, resilience, and retention (Panadero, Jonsson, and Botella 2017; Power 2018; Power, Lynch, and McGarr 2019; Stajkovic and Luthans 1998; Usher and Pajares 2008).

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Previous examinations of student self-efficacy in engineering undergraduate programs have identified associations with academic performance and retention (e.g. Concannon and Barrow 2009). Vogt, Hocevar, and Hagedorn (2007) reported connections between self-efficacy and positive behaviours, such as self-regulation and seeking help, ultimately resulting in improved learning outcomes. In their comprehensive analysis of 104 studies spanning 37 years, Sheu et al. (2018) identified significant variations when examining disparate groups within STEM learning environments. Links to a sense of social belonging and intent to persist have also been reported within an engineering education context (Marra et al. 2009).

Bong (2001) emphasised connections between final exam scores and intentions for future enrolment. Similarly, Hunsu et al. (2023) reported that even when accounting for previous knowledge and attendance, self-efficacy continued to be a notable predictor of academic performance. They suggest that initiatives aimed at boosting self-efficacy might result in a more substantial influence on achievement compared to endeavours targeting contemporary theories.

Fantz, Siller, and Demiranda (2011) found that the development of self-efficacy in engineering is heavily influenced by pre-university engineering courses and recommend directing resources towards this domain if there is a systemic intention to enhance representation through the development of self-efficacy. When considering research both within the context of engineering education, and more broadly, it is clear that self-efficacy has been repeatedly linked with positive behaviours, traits and outcomes. This should prove reassuring to educators, as Ponton et al. (2001) outline how they can influence students self-efficacy beliefs through their teaching activities. This influence is not limited to direct interactions, and can be further enhanced through strategic program developments related to pedagogy and assessment practices. Specific consideration should be given to design decisions that result in highly competitive environments as males and females can interpret and experience these social comparisons in markedly different ways (Chen et al. 2023; Godwin et al. 2016). Related research highlights that highly competitive environments are disadvantageous for minority students (Canning et al. 2020; Diekman et al. 2010).

Higher level social and cultural factors have also been shown to impact self-efficacy development (Bandura 2012), further stressing the importance of context when considering self-efficacy development. This context dependency is reflected in research that is focused on instrument development and validation (Bandura 2006). The current study utilises a scale developed by Mamaril et al. (2016) in light of the complex design and validation considerations. Although this instrument is widely used internationally, the current use can be considered disparate in terms of cultural, social, systemic context. This requires careful consideration of scale validity and reliability (Mamaril et al. 2016, 338).

The vast majority of examinations of self-efficacy have focused on singular cross sectional designs, frequently employing self-efficacy scales that use a singular domain focus (Sheu et al. 2018). While these studies offer valuable insights regarding the relationship between self-efficacy and a host of desirable student traits and behaviours, they do not allow for a consideration of how self-efficacy may evolve over time. This highlights a gap in the literature, and a scarcity of evidence, that could potentially be addressed to enhance pedagogical strategy selection and curricular design. A need to focus future research on the evolution of self-efficacy has been identified in the extant literature (Honicke and Broadbent 2016). Existing research suggests that self-efficacy is malleable, and that it can be influenced by factors that are within the sphere of influence of the educator (Ponton et al. 2001). As such, unique evidence exploring the potential evolution of self-efficacy could support future efforts to enhance this critical construct and impact associated outcomes such as retention, engagement and academic performance. This study offers evidence of this nature by examining self-efficacy levels of first and final year undergraduate engineering students. While limited in that it was not longitudinal and both cohorts are independent, the evidence provided does shed light on how self-efficacy is interpreted at different stages of engineering education and sources of effect on self-efficacy at these different stages. As educators increasingly seek to enhance the student learning experience through the design of self-efficacy enhancing learning activities, evidence relating to how self-efficacy formation varies is critical for optimisation of pedagogical strategy selection and associated curricular development.

Theoretical framework

Self-efficacy is a core construct within Bandura's broader theoretical framework, Social Cognitive Theory (SCT), which emphasises the dynamic interplay of personal, behavioural, and environmental factors in human functioning (Bandura 2005). The interplay of these factors is referred to as Triadic Reciprocal Causation (Bandura 2001, 2005). Self-efficacy operates as a personal factor, mediating the relationship between environmental inputs (like social feedback) and behaviours (like persistence in tasks). For example, individuals with high self-efficacy are more likely to persist in challenging tasks because they believe in their ability to succeed. SCT emphasises human agency, where individuals are active participants in shaping their lives (Bandura 2001). Self-efficacy beliefs are central to this agency because they influence whether people feel capable of exercising control over events that affect their lives (Bandura 2000). High self-efficacy promotes goal-setting, resilience, and proactive behaviours, reflecting a sense of agency (Bandura 1997; Caprara et al. 2008). Bandura stressed that self-efficacy is context dependent. An individual might have high self-efficacy in one area (e.g. technical engineering tasks) but low self-efficacy in another (e.g. public speaking). This specificity underscores the importance of targeted examinations of self-efficacy (Bandura 2006, 2012).

When considered within the broader theoretical framework self-efficacy is conceptualised a product of, and a contributor to, the broader framework of SCT, mediating how individuals perceive and respond to challenges, learn from their environment, and regulate their behaviours to achieve personal goals (Bandura 2005).

Sources of self-efficacy

Bandura's original conception of self-efficacy described how individuals would form these performance related beliefs from four informational sources: *Mastery Experiences* (e.g. successful past performance), *Social Persuasions* (e.g. coaching, feedback), *Vicarious Experiences* (e.g. observations, role modelling, imitation), and *Physiological State* (e.g. heart rate, sweating) (Bandura 1977). In line with Bandura's original model, sources are considered to have a bi-directional relationship with self-efficacy (Bandura 1994, 1997). While additional, and alternative, sources have been proposed, the majority of instruments and research efforts still follow this original structure (Alqurashi 2016; Blackmore et al. 2021; Usher and Pajares 2008; Yokoyama 2019). Bandura (2006) provides guidance on the design and use of self-efficacy scales that builds upon the original model. It should be noted that some theorists dispute Bandura's conceptualisation on multiple points. Yeo and Neal (2013) provide a response to Bandura's position and includes a considerable list of critiques related to the theory as a whole. This debate has continued (Bandura 2012), even beyond the original authors death. Wyatt (2014) offers an overview of quantitative approaches to examining self-efficacy and related shortcomings. The current study, while acknowledging the differing perspectives, subscribes to the four informational source model of self-efficacy (Bandura 2012).

Mastery Experiences are based on previous successful outcomes in a comparable activity (Bandura 1997). For example an undergraduate student who had previously completed design and manufacturing tasks in a second level (high-school) environment and achieved a successful outcome would likely have a higher sense of self-efficacy when encountering a design and build style module in their first year of undergraduate study. Equally they could be drawing from home activities with a parent/guardian where they created a manufactured solution (Chen et al. 2023). This prior *Mastery Experience* would have little benefit when encountering their first assignment from an 'Intro to Calculus' module as the student would likely not perceive them to be a similar activity (Talsma et al. 2018; Zimmerman, Bandura, and Martinez-Pons 1992). This is reflected in the majority of engineering course designs where students initially engage in small discreet activities to build knowledge and beliefs surrounding their capability, and later engage in larger Problem Based Learning (PBL) projects where they have to draw on multiple broad areas of knowledge. This approach to curricular design and pedagogy is often referred to as 'scaffolding' and is uniquely apt in the context of engineering education (Atman Uslu, Yildiz Durak, and AY 2022; Pajares and Miller 1995; Pleiss, Perry, and Zastavker 2012; Power 2018). Conversely, a series of failures in an activity that the individual perceives to be related would result in lower self-efficacy for a given task. Low self-efficacy has been associated with a range of negative outcomes and behaviours including poor academic performance, low resilience, low goal setting, dropout and reluctance to engage with support structures (Chen et al. 2023; Hunsu et al. 2023; Power 2018; Power, Lynch, and McGarr 2019).

Social Persuasions play a role in the development of self-efficacy development. This source can be drawn from interactions with fellow students, instructors, industry partners or even individuals not directly associated with an individual's education such as a parent/guardian (Ahn, Bong, and Kim 2017). Positive feedback on an individual's performance or capability within an engineering context will predictably positively impact self-efficacy development, while negative feedback will tend to lower self-efficacy beliefs (Chen et al. 2023; Marra et al. 2009; Power, Tanner, and Buckley 2024). The impact of this source is mediated by an individual's perception of the epistemic authority of the informational source. Positive feedback from a Professor on a formal activity would likely be of much greater value when compared to well-meaning advice from a parent/guardian who has no background in engineering (Zeldin and Pajares 2000). The necessarily broad and dynamic interplay of multiple forms of knowledge, and their proven connectivity to ideologies, have shown how complex this area of expert and situated knowledge and value orientations is, and gives rise to concerns in relation to epistemic (in)justice in teaching disciplinary knowledge in higher educational settings (Fricker 2007).

This highlights how decisions that an educator makes in terms of course design, feedback systems and pedagogical strategy selection can impact student self-efficacy beliefs. The use of instructor feedback, peer-based feedback, team based tasks, and industry partner briefings all have the potential to support self-efficacy development. Physiological State refers to cues that individuals take from their own body and emotional conditions (Bandura 2012; Usher and Pajares 2008). This could include cues such as elevated heart rate prior to a presentation in front of a class (Bandura 2012). It should be noted that research highlights the broader context and dispositional dependency of physiological cues (Bandura 2006; Pfitzner-Eden 2016; Schunk and Pajares 2009; Zhou et al. 2023). A physiological cue such as an elevated heart rate could be positively interpreted by someone with high self-efficacy as excitement. In this instance it would further add to self-efficacy beliefs. However, an individual with low self-efficacy could negatively interpret elevated heart rate as anxiety and this would negatively impact self-efficacy beliefs.

Vicarious experiences are based on observing how others complete similar tasks or achieve similar outcomes. The value of this source is influenced by how similar the individual considers themselves relative to their model in terms of ability. If an engineering student was tasked with designing and manufacturing a device to meet a specific brief and observed a classmate achieving a positive outcome, they would likely draw considerable value from this observation. Alternatively, if they observed an instructor completing a similar activity, or displaying a solution that they had generated earlier, it would likely have much lesser value in terms of self-efficacy development (Ahn, Bong, and Kim 2017).

Development of self-efficacy

Engineering self-efficacy begins to develop long before a student enters an undergraduate program. Experiences throughout childhood, personal life and school, inform individuals' beliefs around their capability in engineering. However, it is also worth considering that pre-university students can frequently hold inaccurate impressions of engineering as a profession which can result in unreliable self-evaluations of capability (Chen et al. 2023; Fantz, Siller, and Demiranda 2011; Pajares, Britner, and Valiante 2000; Pajares and Miller 1995; Pérez 2021; Power, Tanner, and Buckley 2024; Zeldin and Pajares 2000). STEM subjects in second level (high-school) have been linked to engineering self-efficacy and this highlights the importance of these subjects in helping students form accurate beliefs regarding the nature of engineering professions as the basis for self-evaluations (Buckley et al. 2018; Pérez 2021; Usher and Pajares 2008). Talsma et al. (2018) conducted a meta-analysis that indicates a positive impact of self-efficacy on academic performance. The study emphasises the reciprocal nature of this relationship, forming a feedback loop that can be either positive or negative. This underscores the risk of persistent experiences of failure in academic settings. The research suggests that individuals hold pre-existing beliefs about their capacities when entering university, influenced by a variety of experiences.

Although the majority of studies in the broader self-efficacy literature suggest significant relationships with desirable traits and behaviours including academic performance, retention, and engagement (Honicke and Broadbent 2016); it is worth considering studies which have reported non-significant findings (Cho and Shen 2013; Crippen et al. 2009; Gębka 2014; Khan et al. 2013; Neuville, Frenay, and Bourgeois 2007; Phan 2010). In their meta-analysis examining 51 studies, Honicke and Broadbent (2016) concluded that each of the non-significant reports ' … differed in study design characteristics, and hence a single explanation for their non-significance cannot be readily identified'.

Aim of the study

In the context of consistent links between self-efficacy and desirable educational outcomes, this study aims to examine the reports of engineering self-efficacy from students in their first and final year of an undergraduate engineering program in order to explore potential variances. To achieve this aim, the study has been designed around the following research questions:

1. How, if at all, do self-reported engineering self-efficacy levels differ between first and fourth year of undergraduate education?
2. How, if at all, do reports of experiences that support self-efficacy development qualitatively differ across first and fourth year of undergraduate education?

Methodology

The researchers selected a Critical Realist paradigm for the study allowing a more complex and critical interplay between the underpinning theoretical and methodological aspects of the study, the findings and potential limitations (Shipway 2010). This aligns with the selection and justification of a multi-methods approach and acknowledges the complexity of research within this context. The study therefore utilises a multi-methods approach to critically scrutinise how students – in the initial stage and in the final stage of their study – form their engineering self-efficacy beliefs in an undergraduate engineering programme in one higher education setting. As outlined by Creswell (2015), the distinction of multi-methods as compared to mixed methods is a matter of ongoing debate and development. For the purposes of the current study the definition provided by Johnson, Onwuegbuzie, and Turner (2007) has been adopted: 'Multimethod research is when different approaches or methods are used in parallel or sequence but are not integrated until inferences are being made' (119). The Engineering Self-efficacy Scale by Mamaril et al. (2016) was deployed in Semester 1. Qualitative data was gathered through open ended questions in digital form format. The origin and development of each of these components are outlined below. Descriptions of analysis techniques, statistical approaches and a positionality statement in relation to the research team are provided in order to inform the reader of potential biases that may have influenced the study.

Positionality

The first author is from a social science background and now primarily researches factors that impact student learning in STEM. The second author is from a predominantly engineering background with previous industry and senior academic experience. The third author is an experienced engineering educator with a background in fluid mechanics. The fourth author is a STEM education professor with a background in research and teaching in science and general education and critical interrogation of the connectivity with STEM education, ethics, democracy, social and epistemic justice. The last author primarily works within technology education with primary research interests in meta-research, learning from a cognitive lens, and educational assessment. The authorship team consists of three researchers who identify as male and two researchers who identify as female. All authors are committed to enhancing the learning experience of engineering students, with a specific focus on historically underrepresented groups including women, socio-economically disadvantaged and people with additional learning needs.

Aligning with the previously stated Critical Realist paradigm, the authors recognise that there is a reality independent of human perceptions, but that this reality is only imperfectly understood through human experiences and interpretations (Tikly 2015). This paradigm blends aspects of realism (there is a real world that exists) with constructivism (our knowledge of this world is socially constructed). The adoption of this paradigm impacted both the research instrument selection and data analysis of the current study. Critical Realism encourages multi-method approaches (Tikly 2015). Researchers might use quantitative instruments to capture aspects of the external, objective reality, and qualitative instruments to explore the underlying mechanisms and subjective interpretations of that reality. Instruments were selected to suit the specific context and phenomena being studied. There is recognition that no single method or instrument can fully capture the complexity of reality. This leads to the use of flexible instruments that allow for capturing both measurable outcomes and deeper, context-specific processes. Data analysis within a Critical Realist framework focuses on understanding three layers of reality: Empirical, Actual, and Real. Analysis, therefore, seeks not just to describe surface-level observations but also to uncover deeper causes and relationships.

Validity considerations

In evaluating internal validity for the current study, several points related to design and analysis should be noted. The study relies on a cross-sectional design, which inherently limits its ability to infer causation or account for changes in self-efficacy over time. The authors acknowledge this limitation, noting that the same participants were not surveyed at multiple stages, potentially introducing cohort effects that could confound comparisons between first and final year students. To enhance internal validity, the use of a validated measurement instrument (the Engineering Self-Efficacy Scale) and rigorous statistical analyses such as confirmatory factor analysis and measurement invariance testing have been included. The potential for self-report bias and unmeasured external influences (e.g. socio-economic variables) impacting self-efficacy should be acknowledged as threats to validity. Future research employing longitudinal designs or more controlled experimental setups could mitigate these limitations and offer causal insights.

Participants

Participants were enrolled in either the first or final year of their engineering program at the time of data collection within a University in the Republic of Ireland ($N = 205$). A total of 115 first year students ($n_{\text{male}} = 90$, $n_{\text{female}} = 25$) and 90 final year students ($n_{\text{male}} = 76$, $n_{\text{female}} = 14$) took part in the study. Participants were provided with a link to a Microsoft Forms version of the survey. This included an information sheet and a consent form. Participants were repeatedly made aware of the voluntary nature of participation and that no consequence would arise should they choose to no longer participate at any stage.

Self-efficacy scale

Students completed the Engineering Self-efficacy Scale developed by Mamaril et al. (2016). The finalised condensed version of the scale consists of 17 items. The scale is comprised of four subscales. General Engineering Self-Efficacy (GEN) contains five items and is considered unidimensional. The original measurement model for the five-item General Engineering Self-Efficacy reported by (Mamaril et al. 2016, 379) had good model fit (χ^2 (5) = 7.873, CFI = .997, RMSEA = .038, RMSEA 90% CI: (.000, .085), SRMR = 0.012). Engineering Skills Self-Efficacy (SKILLS) is considered multidimensional and is comprised of three factors; (1) Experimental Self-efficacy (SKILLS_EXP: 4 items), (2) Tinkering Self-efficacy (SKILLS_TIN: 4 items), and (3) Design Self-efficacy (SKILLS_DES: 4 items). The original measurement model for the 12-item Engineering Skills Self-Efficacy Scale also had good model fit (X^2(51) = 183.468, CFI = .94, RMSEA = .080, RMSEA 90% CI: (.068, .093), SRMR = .041) (Mamaril et al. 2016, 379). When constructing the scale Mamaril et al. (2016) drew items from, or were informed by, previously developed self-efficacy instruments that had each undergone considerable validation studies and were used in studies across numerous academic domains. These included ABET (2013); Baker and Krause (2007); Bong (2001); Carberry, Lee, and Ohland (2013); Power, Tanner, and Buckley (2024); Schreuders, Mannon, and Rutherford (2009); Schubert, Jacobitz, and Kim (2012).

In order to further explore potential factors that influenced self-efficacy development, three open-ended questions were included. These items are based on those developed by Chen et al. (2023) and data collection was also completed through a survey mechanism. These items included:

1. 'What events have affected your confidence in your engineering skills? How did the event(s) affect your confidence?'
2. 'Can you think of a specific event that made you feel more confident in your engineering capabilities?'
3. 'Has anyone encouraged or inspired you to be an engineer? If so, who? How did they encourage or inspire you?'

Analysis

The qualitative data was analysed using Braun and Clarke's six-step framework (Braun and Clarke 2006, 2012). This process began with an initial examination of the data to acquaint the researchers with the complete dataset and create preliminary notes. Subsequently, a peer consensus approach was employed to review and address any disparities in the assigned codes. During stage 3, a deductive approach was applied to assign all codes to specific themes, which were derived from Bandura's four hypothesised sources of self-efficacy (Bandura 1997). The second author conducted an independent review of each theme and its corresponding codes to verify accurate alignment and agreement. Finally, the findings were organised into a thematic map and supplemented with participant quotes, providing a structured and comprehensive understanding of the data in the context of self-efficacy development among engineering students.

The quantitative data for the Year 1 cohort was collected as part of a separate study (Blinded for peer review). The current study applied the same methodology to a 4th year cohort in order to explore potential variances and facilitate cross-sectional comparisons. The quantitative data were analysed using the R programming language, v4.2.2 (The R Foundation for Statistical Computing 2022) in the RStudio environment according to the presented research questions. Initially, group differences between the two cohorts were examined through Wilcoxon signed rank tests due to the assumption of normality being violated. This was followed by a series of multigroup confirmatory factor analyses (CFA) to examine how self-efficacy was conceived by each cohort in an effort to understand its longitudinal development at a more nuanced level. The full anonymous data set is available through the Open Science Framework (OSF) for the purposes of independent verification (Power 2021a), potential future systematic review and meta-analysis (Borrego et al. 2021; Power

2021b): https://osf.io/nd245/?view_only = 0801a61fbc1c455094c0a8d45d15c20c. A codebook for the quantitative variables is also available as appendices in the OSF repository.

Results

Prior to presenting the study results relative to each research question, descriptive statistics for both groups are presented in Table 1 for replicability and to provide contextual understanding of the characteristics of the sample and the distribution of the data. It should be noted, as described in the footnote of Table 1, that there are composite variables (GEN, SKILLS, SKILLS_EXP, SKILLS_TIN, and SKILLS_DES) which were computed first as simple averages of observed variables. Reliability values are presented later in the results section with respect to analyses pertaining to the different factors of the scale, but for convenience are summarised here. For the 1st year cohort, reliability was high for general engineering self-efficacy ($\alpha_{GEN} = 0.9$), and for each of the engineering skills self-efficacy dimensions ($\alpha_{SKILLS\_EXP} = 0.84$; $\alpha_{SKILLS\_TIN} = 0.84$; $\alpha_{SKILLS\_DES} = 0.84$). Reliability was also high for the 4th year cohort for general engineering self-efficacy ($\alpha_{GEN} = 0.9$), and for each of the engineering skills self-efficacy dimensions ($\alpha_{SKILLS\_EXP} = 0.91$; $\alpha_{SKILLS\_TIN} = 0.92$; $\alpha_{SKILLS\_DES} = 0.94$)

How, if at all, do reported engineering self-efficacy levels differ across first and fourth year of undergraduate education?

Group difference statistical testing was conducted to determine whether there were any significant differences between the 1st and 4th year students in any of the dimensions of self-efficacy. Prior to each test the assumption of normality of residuals was first checked, and it was violated in each case ($p > 0.05$). As such, Wilcoxon rank sum tests were conducted. Non-significant results were observed

Table 1. Descriptive statistics.

	Group: 1st Year (n = 115: $n_{males} = 90$, $n_{females} = 25$)			Group: 4th Year (n = 90: $n_{males} = 76$, $n_{females} = 14$)			
	Mean (SD)	Skewness	Kurtosis	Mean (SD)	Skewness	Kurtosis	SE
GEN_1	4.42 (0.91)	−0.42	−0.08	4.39 (1.04)	−1.12	0.85	0.11
GEN_2	3.94 (0.96)	−0.24	0.23	3.86 (1.06)	−0.45	0.02	0.11
GEN_3	4.69 (0.79)	−0.68	1.15	4.68 (0.97)	−1.01	0.83	0.1
GEN_5	4.75 (0.87)	−0.46	0.34	4.77 (0.95)	−1.17	2.42	0.1
GEN_6	4.67 (0.82)	−0.36	0.08	4.63 (1.03)	−0.93	1.12	0.11
SKILLS_1	4.57 (1)	−0.23	−0.62	4.39 (1.12)	−0.65	0.36	0.12
SKILLS_2	4.7 (0.9)	−0.45	0.09	4.64 (1.05)	−0.86	0.26	0.11
SKILLS_3	4.7 (0.92)	−0.34	−0.4	4.54 (1.13)	−0.75	0.15	0.12
SKILLS_4	4.75 (0.87)	−0.3	−0.21	4.73 (0.99)	−1.09	1.7	0.1
SKILLS_8	4.74 (1.21)	−0.77	−0.24	4.77 (1.29)	−1.06	0.41	0.14
SKILLS_9	3.8 (1.3)	−0.03	−0.62	3.98 (1.37)	−0.35	−0.37	0.14
SKILLS_12	5.02 (0.95)	−0.71	−0.15	5 (1.2)	−1.35	1.62	0.13
SKILLS_13	5.13 (0.96)	−0.97	0.48	5.16 (1.14)	−1.69	2.92	0.12
SKILLS_16	4.41 (0.89)	−0.43	0.04	4.51 (1.14)	−0.58	−0.33	0.12
SKILLS_17	4.5 (0.92)	−0.52	0.29	4.57 (1.17)	−0.62	−0.09	0.12
SKILLS_18	4.31 (0.89)	−0.13	−0.02	4.56 (1.15)	−1.05	1	0.12
SKILLS_19	4.47 (0.88)	−0.21	−0.09	4.51 (1.25)	−0.85	0.48	0.13
GEN	4.49 (0.73)	−0.34	0.51	4.46 (0.85)	−1.03	0.85	0.09
SKILLS	4.59 (0.65)	−0.41	0.22	4.61 (0.93)	−1.45	2.45	0.1
SKILLS_EXP	4.68 (0.76)	−0.31	−0.31	4.58 (0.95)	−0.92	0.91	0.1
SKILLS_TIN	4.67 (0.96)	−0.67	0.05	4.72 (1.12)	−1.17	1.3	0.12
SKILLS_DES	4.42 (0.78)	−0.47	0.4	4.54 (1.09)	−0.95	0.63	0.12

Notes: SD = Standard deviation. Variable GEN is a simple average of variables GEN_1 to GEN_6. Variable SKILLS is a simple average of variables SKILLS_1 to SKILLS 19. Variable SKILLS_EXP is a simple average of variables SKILLS_1 to SKILLS 4. Variable SKILLS_TIN is a simple average of variables SKILLS_8 to SKILLS 13. Variable SKILLS_DES is a simple average of variables SKILLS_16 to SKILLS 19. A full codebook describing each variable is available on the project OSF repository: https://osf.io/nd245/?view_only=0801a61fbc1c455094c0a8d45d15c20c.

for differences between 1st and 4th years for each of general engineering self-efficacy ($W = 4955$, $p = .601$, $r = 0.037$, 95%CI [0.003, 0.17]), design skills self-efficacy ($W = 4459$, $p = .088$, $r = 0.119$, 95%CI [0.009, 0.26]), experimental skills self-efficacy ($W = 5332$, $p = .709$, $r = 0.026$, 95%CI [0.003, 0.17]), and tinkering skills self-efficacy ($W = 4821.5$, $p = .400$, $r = 0.059$, 95%CI [0.003, 0.19]). Based on these results, there is no evidence that self-efficacy ratings across these dimensions differs between 1st and 4th year engineering students (Figure 1).

General engineering self-efficacy

While there were no statistically significant differences in magnitude between 1st and 4th year ratings of self-efficacy, it was of interest to examine whether how self-efficacy is conceived differed between groups. First, based on the work of Mamaril et al. (2016), latent variable models of general engineering self-efficacy were computed for each group (Figure 2).

To qualify if models were of acceptable fit, CFI, TLI, RMSEA, and SRMR values were examined. For both the CFI and TLI indices, larger values indicate better fit, with values > .90 indicating reasonable fit but ideally > .95 for an indication of good fit (Kline 2023). For RMSEA, values < .08 indicate reasonable fit (Kline 2023) with values < .05 indicating great fit (Hu and Bentler 1999). For SRMR, a cut-off value of < .08 indicates a good fit (Hu and Bentler 1999). Based on model fit indices, the 1st year model was a good fit across each metric, whereas the 4th year model was acceptable based on CFI and SRMR only. Both the 1st year and 4th year models indicated high reliability ($\alpha = 0.9$).

To determine whether the groups differed in how they conceived general engineering self-efficacy, a multi-group CFA was conducted. Several measurement invariance models were sequentially tested: configural invariance (no constraints imposed), metric invariance (factor loadings were constrained to be equal across groups), scalar invariance (factor loadings and intercepts were constrained to be equal across groups), and residual invariance (factor loadings, intercepts, and residual variances were constrained to be equal across groups). The results of these sequential comparisons are presented in Table 2. No model significantly differed from the previous, supporting the

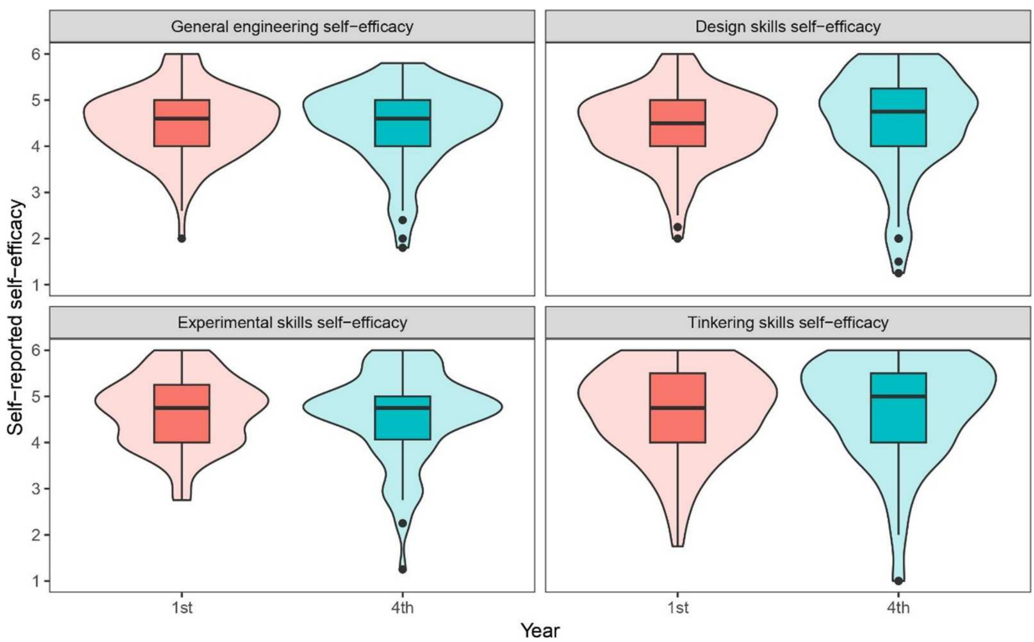

Figure 1. Comparisons of reports 1st and 4th year self-efficacy.

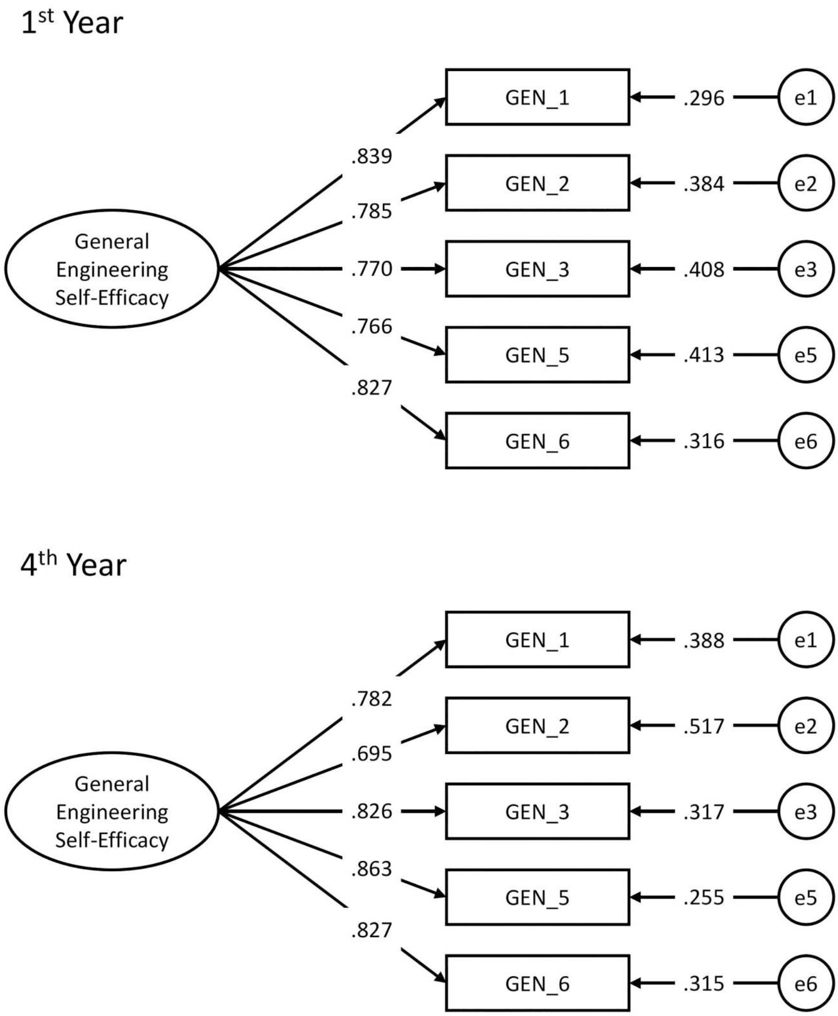

Figure 2. Latent variable models for general self-efficacy of 1st years ((n = 115). X^2 (5) = 7.471, p = .19; CFI = .992, TLI = .985, RMSEA = .066, 90% CI [.000, .156], SRMR = .024) and 4th years ((n = 90). X^2 (5) = 26.756, $p < .05$; CFI = .992, TLI = .843, RMSEA = .22, 90% CI [.143, .305], SRMR = .060). Solid lines indicate statistically significant paths ($p < 0.05$).

interpretation of equivalence of the general engineering self-efficacy construct across both 1st and 4th year groups, i.e. that the groups did not differ in how they conceived general engineering self-efficacy.

Engineering skills self-efficacy – experimental, tinkering and design skills

Next, CFA models were computed for each group to describe the relationships between the three dimensions of engineering skills self-efficacy. The specified models were identical. The model for

Table 2. Measurement invariance test results for multi-group CFA analysis of a latent variable model of general self-efficacy.

Model	Df	AIC	BIC	χ^2	$\Delta\chi^2$	RMSEA	Δdf	p
Configural invariance	15	222.3	2305.4	48.540				
Metric invariance	19	2217.2	2287	51.362	2.821	0	4	.588
Scalar invariance	23	2210	2266.5	52.154	0.793	0	4	.939
Residual invariance	23	2210	2266.5	52.154	0	0	0	NA

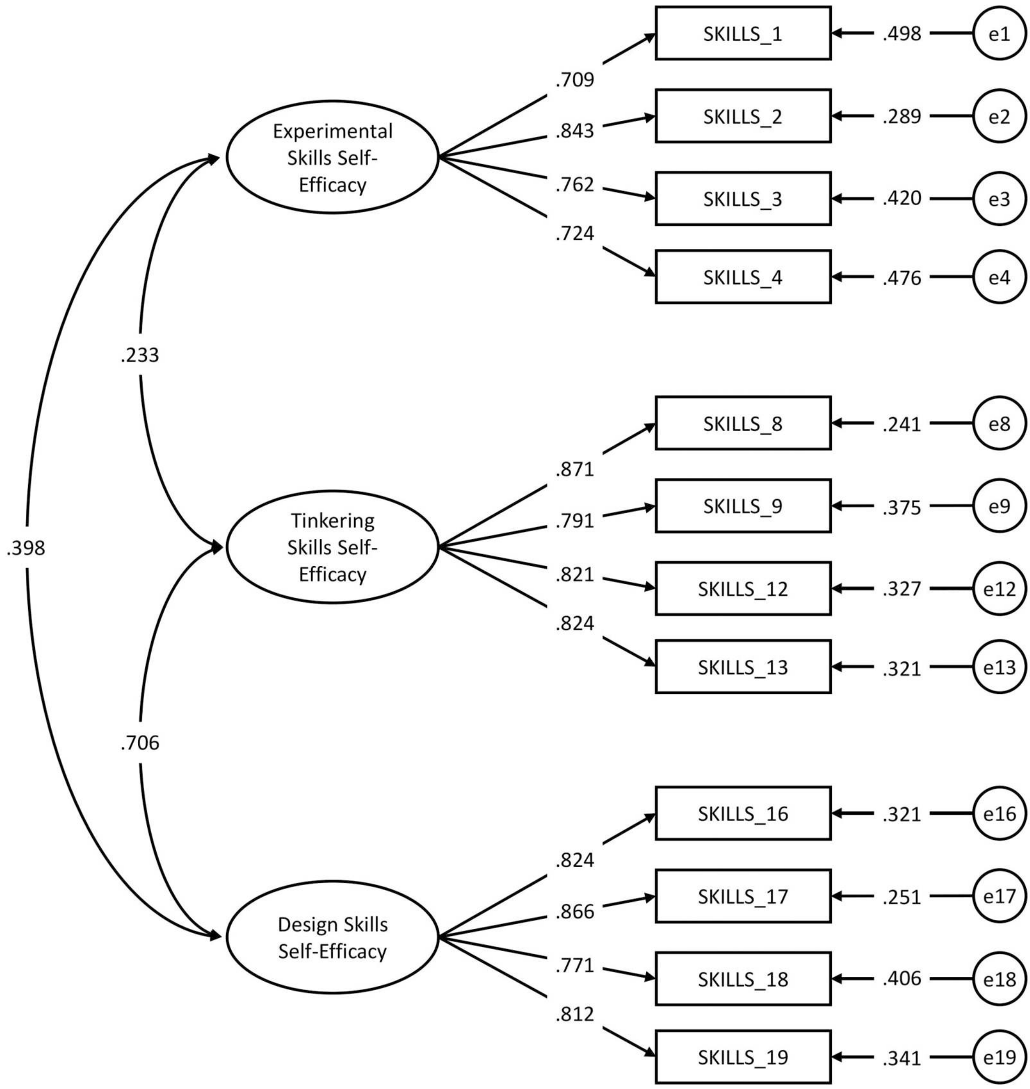

Figure 3. CFA for 1st Year students engineering skills self-efficacy (n = 115). X^2 (51) = 101.32, $p < .001$; CFI = .939, TLI = .921, RMSEA = .093, 90% CI [.066, .119], SRMR = .063. Solid lines indicate statistically significant paths ($p < 0.05$).

1st year students (Figure 3) showed acceptable model fit with respect to the CFA, TLI, and SRMR indices, but not for RMSEA. Reliability was high for each of the three latent variables ($\alpha_{\text{experimental skills self-efficacy}} = 0.84$; $\alpha_{\text{tinkering skills self-efficacy}} = 0.84$; $\alpha_{\text{design skills self-efficacy}} = 0.84$).

The same CFA model for 4th year students (Figure 4) similarly showed acceptable model fit based on CFI, TLI, and SRMR indices, but not the RMSEA index. Reliability for each of the latent variables was slightly higher than for the 1st year students ($\alpha_{\text{experimental skills self-efficacy}} = 0.91$; $\alpha_{\text{tinkering skills self-efficacy}} = 0.92$; $\alpha_{\text{design skills self-efficacy}} = 0.94$).

A multi-group CFA was again conducted to determine if model invariance was observable as an indicator of similar conceptions of each latent variable between groups. Again, configural, metric, scalar, and residual invariance models were compared. The results of these comparisons are presented in Table 3, and illustrate that no model significantly differed from the previous. These result suggest that the groups did not differ in how they conceived the three engineering skills

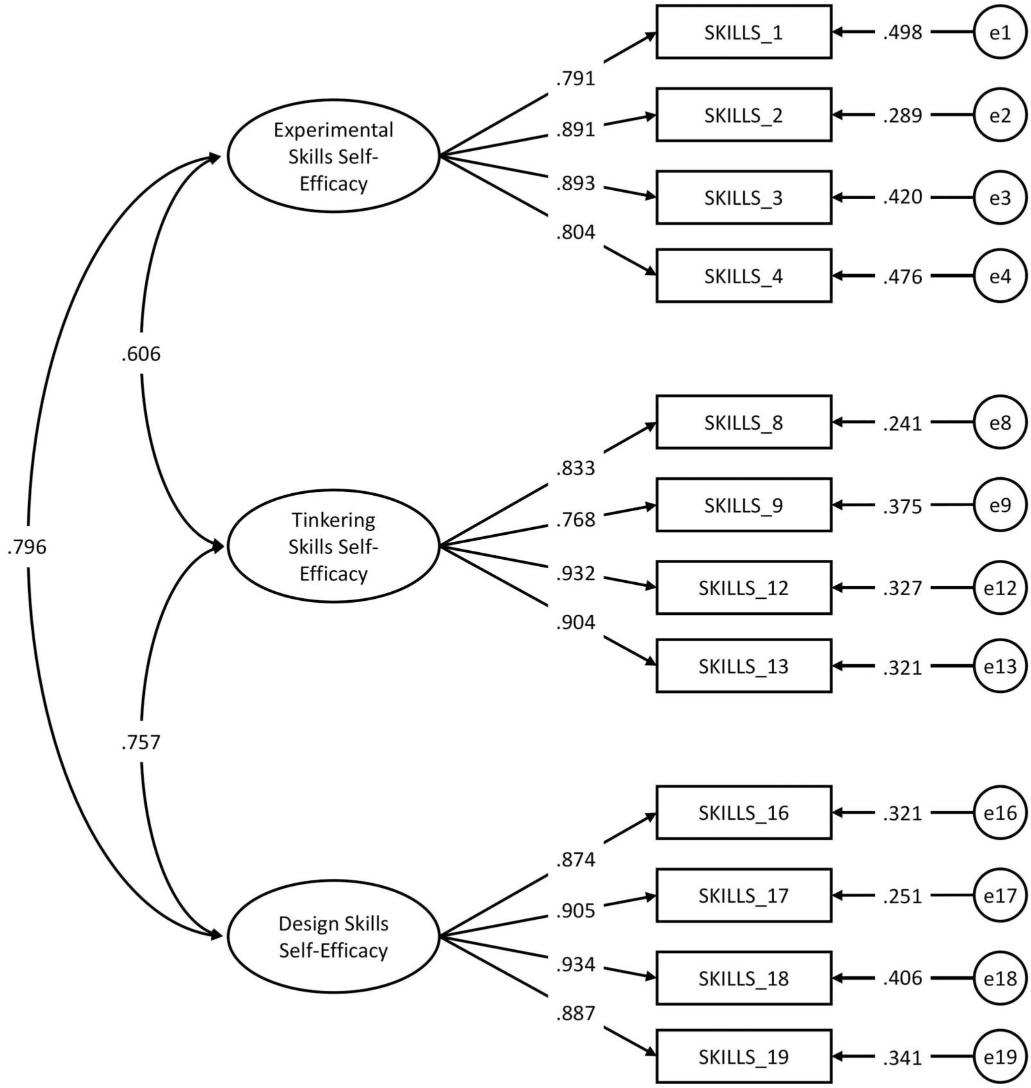

Figure 4. CFA for 4th Year students engineering skills self-efficacy (n = 90). X^2 (51) = 116.261, $p < .001$; CFI = .938, TLI = .919, RMSEA = .119, 90% CI [.091, .148], SRMR = .043. Solid lines indicate statistically significant paths ($p < 0.05$).

self-efficacy variables. It is thus interesting to note that for both groups there was a similarly strong correlation between design and tinkering skills self-efficacy, but for the 4th year students the relationships between experimental skills and design and tinkering skills self-efficacy were notably stronger than for the 1st year group.

Finally, given the indication that the two cohorts held shared conceptions for general engineering self-efficacy and the three measured dimensions of engineering skills self-efficacy, it was of interest to examine how each of the dimensions of engineering skills self-efficacy related to general engineering self-efficacy. Specifically, it was of interest to determine whether there were any differences in how general engineering self-efficacy was formulated between groups. For this analysis, structural equation modelling was used with the same model specified for both groups. The model for 1st year students (Figure 5) showed an acceptable model fit for all four fit indices (n = 115). X^2 (113) = 182.578, $p < .001$; CFI = .942, TLI = .930, RMSEA = .073, 90% CI [.053, .092], SRMR = .066. It indicates that experimental skills self-efficacy and tinkering skills self-efficacy were significant predictors of

Table 3. Measurement invariance test results for multi-group CFA analysis of a engineering skills self-efficacy.

Model	Df	AIC	BIC	χ^2	$\Delta\chi^2$	RMSEA	Δdf	*p*
Configural invariance	114	5547.8	5767.2	228.66				
Metric invariance	123	5538.4	5727.9	237.25	8.591	0	9	.476
Scalar invariance	132	5529.8	5689.3	246.6	9.344	0.019	9	.406
Residual invariance	132	5529.8	5689.3	246.6	0	0	0	NA

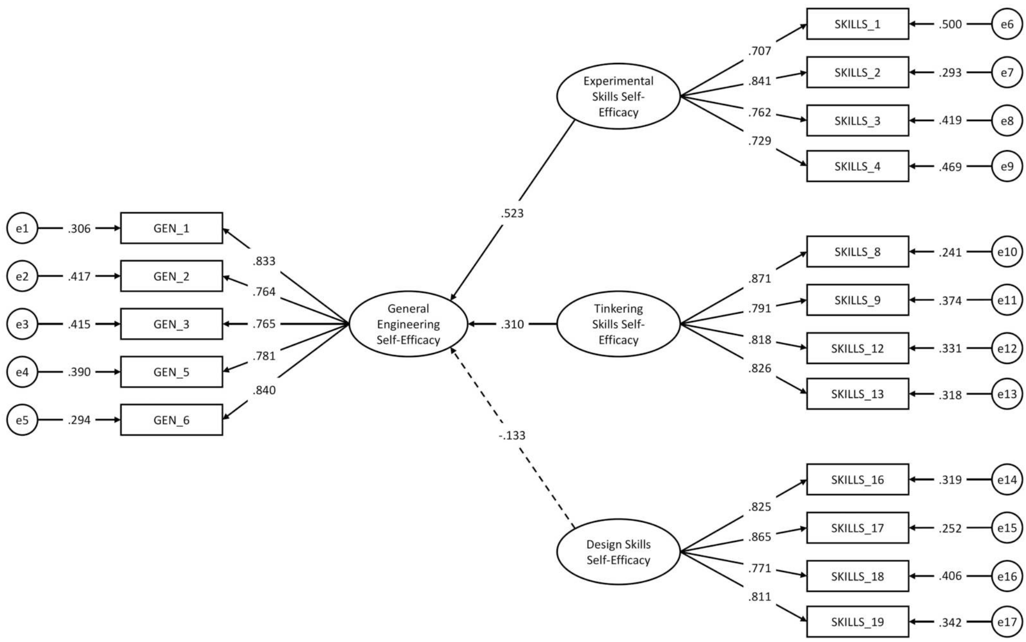

Figure 5. SEM for 1st Year students examining the dimensions of engineering skills self-efficacy as predictors of their general engineering self-efficacy. Solid lines indicate statistically significant paths ($p < 0.05$). Dashed lines indicate non-significant paths ($p > 0.05$).

general engineering self-efficacy. No evidence was observed to suggest that design skills-self-efficacy was related to how the 1st year students formulated their sense of general engineering self-efficacy.

The model for the 4th year students (Figure 6) showed acceptable model fit in terms of CFI, TLI, and SRMR indices but not in terms of RMSEA (n = 90) X^2 (113) = 223.939, $p < .001$; CFI = .921, TLI = .905, RMSEA = .104, 90% CI [.084, .124], SRMR = .055.

For the 4th year students only experimental skills self-efficacy is a significant predictor of their formulation of general engineering self-efficacy. While this inference is limited in that the results come from a repeated cross-sectional study with non-equivalent groups rather than from a true longitudinal study, this result indicates that self-efficacy related to tinkering skills is perhaps no longer viewed as central to success in engineering at the latter stages of the degree programme and is thus less relevant to student self-efficacy. Again, configural, metric, scalar, and residual invariance models were compared. The results of these comparisons are presented in Table 4, and illustrate that no model significantly differed from the previous. These result suggest that the groups did not differ in how they conceived the relationships amongst the three engineering skills self-efficacy variables as predictors of general engineering self-efficacy.

Based on this, the regression coefficients indicating how the three dimensions of engineering skills self-efficacy related to general engineering self-efficacy were compared between groups when factor loadings were constrained as equal. Although differences were observed between

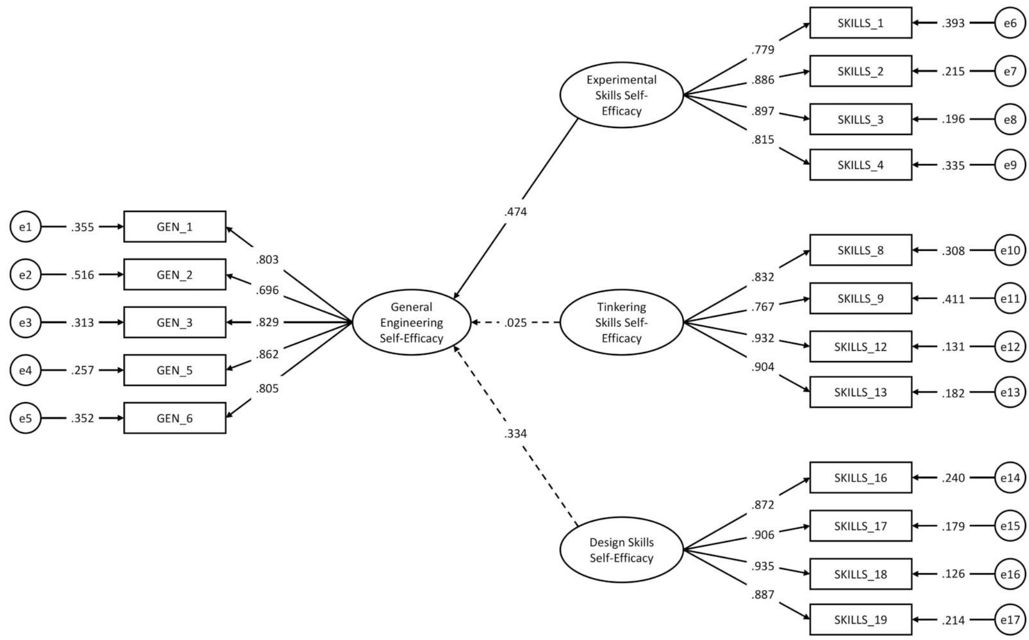

Figure 6. SEM for 4th Year students examining the dimensions of engineering skills self-efficacy as predictors of their general engineering self-efficacy. Solid lines indicate statistically significant paths ($p < 0.05$). Dashed lines indicate non-significant paths ($p > 0.05$).

Table 4. Measurement invariance test results for multi-group SEM analysis of the dimensions of engineering skills self-efficacy as predictors of their general engineering self-efficacy.

Model	Df	AIC	BIC	χ^2	$\Delta\chi^2$	RMSEA	Δdf	*p*
Configural invariance	243	7678.4	8000.7	432.55				
Metric invariance	256	7663.5	7942.7	443.73	11.182	0	13	.596
Scalar invariance	269	7647.7	7883.6	453.9	10.174	0	13	.680
Residual invariance	269	7647.7	7883.6	453.9	0	0	0	NA

groups in terms of which relationships were significant and which were not, significant differences were not observed in effect size magnitude between groups for the relationships between general engineering self-efficacy and experimental skills self-efficacy ($z = 0.312$, $p = 0.75$), tinkering skills self-efficacy ($z = 1.127$, $p = 0.26$), or design skills self-efficacy ($z = -1.079$, $p = 0.28$).

How, if at all, do reports of experiences that support self-efficacy development qualitatively differ across first and fourth year of undergraduate education?

Using a deductive approach, themes were defined using Bandura's originally proposed four sources of self-efficacy (Bandura 1994, 1997). Codes were assigned to relevant themes and are presented within a Thematic Map (See Figure 7). Individual responses are coded based on the year of the respondent (Yr1 or Yr 4), the question that they were responding to (1-3), and the corresponding row within the OSF hosted dataset: https://osf.io/nd245/?view_only = 0801a61fbc1c455094c0a8d45d15c20c.

Results from analysis of the qualitative data highlight activities that are considered 'applied', 'practical' and 'related to engineering'. First Year respondents focused on personal experiences, such as hobby activities or DIY, and early university experiences that emphasised design and manufacture. These university experiences are typified by Project Based Learning modules with a collaborative learning focus (e.g. Yr1-1-70, Yr4-1-33, Yr4-1-44, Yr4-2-86) (See Table 5).

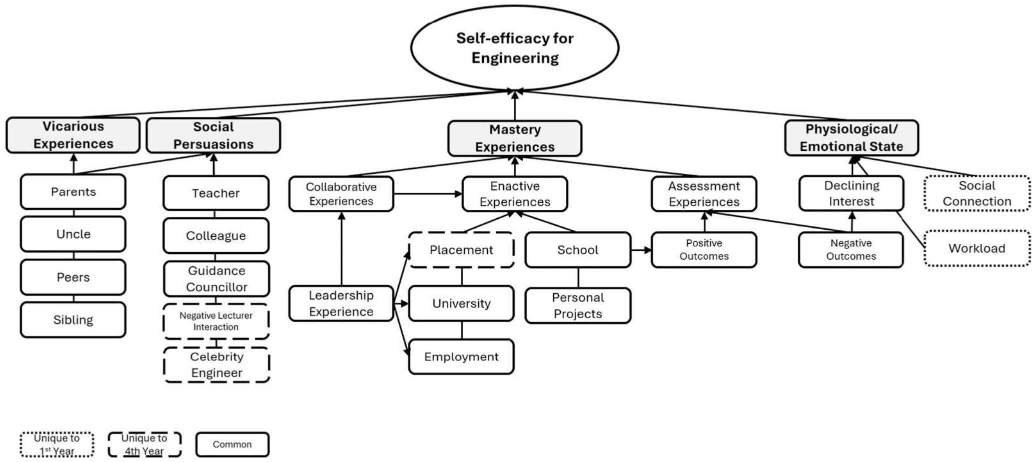

Figure 7. Thematic map.

Perceived relevance of activities, whether in university based experiences or in later industry placements, is consistently highlighted as important in terms of mastery experiences.

4th Year engineering students also reported Project Based Learning experiences as considerable sources of Self-efficacy. These reports focused on enactive mastery experiences and drew comparisons to real world complex problems (e.g. Yr4-1-33, Yr4-1-44, Yr4-2-86). Conversely a lack of enactive mastery experience was highlighted as negatively impacting self-efficacy development (e.g. Yr4-1-79, Yr4-1-25, Yr4-1-90). In contrast to 1st Year students, 4th Year students placed the greatest emphasis on professional placements in industry (e.g. Yr4-1-16, Yr4-1-54). This is cognisant of how, in the SEM model comparisons, evidence only indicated experimental skills self-efficacy as relating to general engineering self-efficacy in final year students, whereas for first year students there was also evidence of tinkering skills self-efficacy being associated with their general engineering self-efficacy. In engineering practice, and from a student perspective, this type of experience would be gained from professional placements. There is less emphasis on the tinkering type activities that would be typical of their early engineering education experiences. It would seem that over the course of their programme of study, with experiences such as professional placements, students are developing a sense of engineering work more reflective of practice, and their self-efficacy conception evolved accordingly. This poses a challenge for educators as first year engineers may hold misconceptions about the requirements a professional engineer (Winters et al. 2013). Arguably analytical or computational activities are more common in a typical engineering workplace, but 1st Year engineering students report an overwhelming focus on design and manufacturing activities. This is of particular relevance to curricular designers as it suggests that placements are affording contextually relevant experiences which can necessarily bridge the gap between engineering education and practice, at least in terms of awareness (Buckley et al. 2023). The attributes associated with these placements were similar to the Project Based Learning Experiences, but had a notable framing of application and experimentation in contrast to exploratory tinkering. These reports, which highlight an opportunity to apply their skills and overcome complex challenges, align with the mastery source of self-efficacy (e.g. Yr4-1-16, Yr4-1-54) (See Table 5).

Placement experiences were also frequently linked to the Social Persuasions source. Affirmation of workplace performance and value from colleagues were referenced (e.g. Yr4-2-84, Yr4-2-88).

Experiences that were centred on the Social Persuasions source were also linked with collaborative experiences. Group work and peer assessment facilitated experiences for students to draw information related to their competence and conduct that were broadly positive (e.g. Yr1-2-47) (See Table 6). Numerous references to peer feedback activities were observed suggesting that this

Table 5. Mastery sample responses.

Theme	Code(s)	Sample participant response
Mastery	University/ Enactive Experiences	Yr1-1-70: 'Taking Part in Design-Build-Compete improved my confidence in applying technical skills to real life cases'
	University/ Enactive Experiences	Yr4-1-33: 'Different design projects helped confirm my abilities and helped me learn how to do better next time. Overall has boosted my confidence.'
	University/ Enactive Experiences	Yr4-1-44: 'The more practical modules like the Design build fly module in Year 4 gave me confidence in my engineering skills. It gave me confidence in my ability to apply my engineering skills into solve various different engineering problems.'
	University/ Enactive Experiences	Yr4-2-86: 'I feel that engaging in lab work and project work helps to build confidence in engineering skills. While I feel that some students will find this work daunting, especially if it is a larger project, applying the skills that I learned throughout my time as a student and using them to solve tangible problems boosts my confidence in my engineering capabilities.'
	Placement/ Enactive Experiences	Yr4-1-16: 'Placement made me more confident in my engineering skills. It showed me that I can apply what I've learned in a workplace'
	Placement/ Enactive Experiences	Yr4-1-54: 'Co-op placement as a junior design engineer. It allowed me to utilise skills I picked up in college and develop my CAD skills to a higher level. Made me more confident in CAD softwares.'
	Assessment	Yr1-1-34: 'Last semester's results affected confidence badly. Wasn't used to having to work hard in school for good results.'

Table 6. Social persuasions sample responses.

Theme	Code(s)	Sample participant response
Social Persuasions	Peer/Assessment Experience	Yr1-2-47: 'In the design for manufacture module we had to do a peer assessment by commenting on other peoples drawings. We then got to look back on the feedback given to us and most of mine was very positive so it gave me confidence in the design aspect of engineering.'
	Peer	Yr4-1-89: 'Classmates have made me less confident in my own abilities'
	Peer	Yr4-1-76: 'Negativity from my male peers has greatly affected my confidence in my own abilities, often having ideas or suggestions dismissed only for them to decide to use them weeks later when someone else suggests them. It's assumed that as a girl I don't know what I'm talking about and it's always discouraged me from fully participating in something or speaking up.'
	Parent	Yr4-3-73: 'My dad was the one person who encouraged me the most after having a lot of negative experiences with peers and career guidance around the idea of me doing engineering despite my good results in science and maths subjects. he's always been extremely supportive of me in my studies'

particular pedagogical strategy selection facilitated Social Persuasions experiences. Reports of negative impacts on self-efficacy development include frequent references to poor assessment outcomes and associated grades, further highlighting the importance of feedback and assessment strategy selection within engineering education environments. Reports of negative peer interactions were also evident, with some references to gender based negative interactions (e.g. Yr4-1-89, Yr4-1-76) (Table 7).

Responses linked to the Physiological/Emotional State source were relatively scarce when compared to the previously considered sources. All observed codes were drawn from the 1st year cohort and were negative. Research suggests that the transition to University level contributes to

Table 7. Physiological/emotional state sample responses.

Theme	Code(s)	Sample participant response
Physiological/Emotional State	Workload difficulties	Yr1-1-8: 'Build up of work feel overloaded'
	Stress	Yr1-2-2: 'Being under stressful situations to solve a problem'
	Lack of interest/ motivation	Yr1-1-40: 'Lost interest in the course. Not much motivation to work.'
	Illness	Yr1-1-4: 'Being ill'

Table 8. Vicarious experience sample responses.

Theme	Code(s)	Sample participant response
Vicarious Experience	Parent	Yr1-1-32: 'I grew up building and fixing things with my dad, so I have a good understanding of technical things.'
	Peer	Yr1-1-71: 'Working in teams in the lab and seeing where my classmates are in terms of engineering ability and comparing myself to that sort of standard. I am very confident that I am able to perform to a level on par or above my peers in some aspects but maybe not in others'
	Peer	Yr1-1-75: 'Being Team Leader for the DBC project. Gave me more confidence in my own ability and helped me to learn from others and my own mistakes'
	Parent	Yr4-3-66: 'My Father - he graduated from [University] in production engineering class of 96. Grew up around him fixing cars and heavy machinery and took an interest to all the things he would do in his spare time. He is a senior engineer in a [Regional] Medical device plant'
	Peer	Yr4-3-82: 'Fellow classmates have inspired me to continue with my level of study in the library as we all work together towards a common goal'

feelings of stress or overload, and has been strongly linked to dropout (Meyer and Marx 2014; Sultana, Khan, and Abbas 2017). It is possible that 4th year students have adapted to University workloads over time, and that a survivor bias is impacting responses (Ioannidis et al. 2014).

Responses associated with the Vicarious Experience source were typically centred on Parents and Peers (See Table 8). Collaborative University based learning experiences were frequently highlighted as opportunities to observe peers and to be guided by their actions. When mapped considerable cross links between the Social Persuasions and Vicarious Experiences were observed (See Figure 7).

These findings are particularly interesting as Vicarious Experience reports in quantitative studies frequently demonstrate poor reliability. Self-efficacy researchers have suggested that this could be due to the sheer volume of social interactions that a typical student experiences per day, and that many internalised interactions likely happened in the distant past reducing recall (Anderson and Betz 2001; Britner and Pajares 2006; Usher and Pajares 2008).

Results summary

In summary, the qualitative data highlights a difference in the nature of mastery experiences and associated social persuasions at differing points of experience. A common focus on the value of enactive mastery experiences was evident, but the nature of these activities differed substantially. Although both groups reported that experiences of applied problem solving in collaborative settings were especially valuable, final year students focused on professional placement experiences, while first year students focused on PBL style modules. The quantitative data showed no statistically significant differences between first and final year overall reports of self-efficacy. However, differences were observed in the value of design, experimental and tinkering activities in the formation of self-efficacy beliefs.

Discussion

Enactive Mastery experiences were reported by first year and final year students as particularly important when forming self-efficacy beliefs. The dominance of the mastery source in the formation of self-efficacy is consistent across the evidence base (Blackmore et al. 2021; Honicke and Broadbent 2016; Sheu et al. 2018; Talsma et al. 2018). In contrast to existing research, overall levels of self-efficacy demonstrated no statistically significant differences between first and final year students (Concannon and Barrow 2009). The types of enactive experiences reported by first and final year students that support self-efficacy development were substantially disparate and the associated social persuasions characterisations were also notably different. As considered by Honicke and Broadbent (2016) this is potentially due to 'Students lacking experience within university environments have limited exposure in which to experience mastery in learning within such environments and have not been afforded the opportunity to develop efficacious beliefs of performance abilities' (80).

First Year students focused on experiences that broadly relate to the 'tinkering' subscale. With frequent links to PBL modules in university, STEM subjects in second level (high school) and personal activities such as working with a family member on a project at home. Christensen, Knezek, and Tyler-Wood (2014) highlight the value of applied activities in the development of beliefs associated with STEM. Social persuasions were aligned with the nature of these activities and centred on parental/familial and second level educator encouragement. Research suggests that practical activities that the individual associates with the engineering profession are a valuable early source of engineering self-efficacy (Cheryan et al. 2017; Power, Tanner, and Buckley 2024). However, individuals outside the profession frequently hold inaccurate views of what engineering is (Christensen, Knezek, and Tyler-Wood 2014; Hammack et al. 2015). As such the self-efficacy enhancing value of these activities should not be conflated with direct value to the student acting within the engineering profession and need to be carefully considered from a critical perspective where program level changes are being considered.

In contrast to First Year students, Final Year students focused heavily on professional placement experiences. These placements, colloquially referred to as Co-op by many participants, require the student to work within an engineering setting for an 8 month period in the later stage of their 3rd year. Participants reported that a chance to apply their engineering skills and knowledge to solve complex industry based problems was an exceptionally valuable experience. Descriptions again focused on enactive mastery experiences, but specifically activities that aligned with design and experimental roles as opposed to the tinkering type experiences that were the primary focus of the first year participants. Reports of social persuasions from the Final Year students tended to focus on colleagues and managers within these industry settings. Reports of negative social persuasions based on social interactions with peers was evident. This is especially concerning given the under representation of women in engineering, but also due to existing research that identified a drop in self-efficacy beliefs in female engineering students with a direct focus on social persuasions (Marra et al. 2009). This is linked to collaborative problem solving activities that are broadly referencing as key to self-efficacy development by participants and highlights the need for educators to carefully consider negative interactions based on gender when selecting collaborative pedagogical strategies.

Differences between first and final year reports of self-efficacy enhancing experiences are potentially related to how the individual perceives themselves relative to the profession. Many entrants to engineering degree programs hold inaccurate beliefs about the profession (Winters et al. 2013). Research suggests 'professional practice' experiences heavily influence the development of a professional identity, more so than academic experiences (Choe et al. 2019). Sheppard et al. (2010) also considers engineering professional placement experiences as they relate to identity and concludes that they enhance motivation. While motivation is a distinct construct to self-efficacy, it is a commonly reported correlate and has been repeatedly theoretically linked (Bandura 2006, 2012; Schunk 1991; Sheu et al. 2018). It is possible that 4th year students have begun to focus on sources that are more aligned with this developed perspective. This is supported by a shift in SEM model structure with a lower value for tinkering activities, but a stronger relationship between experimental and design activities within the overall model. Further research examining the potential role of professional identity as it relates to engineering self-efficacy development has the potential to refine the prescribed professional placement models commonly used within undergraduate engineering programs.

Implications for policy

The findings of this study provide critical insights into the evolution of engineering self-efficacy among undergraduate students, highlighting key areas for improvement in both policy and educational practice. These insights can inform strategies for enhancing engineering education to better support student retention, engagement, and professional preparedness.

The study identifies professional placements as a cornerstone for developing late-stage engineering self-efficacy. Authentic and well designed placement experiences have been shown to enhance self-efficacy across a range of disciplines (Lucas et al. 2009; Ngonda, Shaw, and Kloot 2020). Policymakers and institutional leaders should prioritise partnerships with industry to create structured and meaningful placement opportunities. These placements should be accessible to all students, with additional support for underrepresented groups, including women and students from socioeconomically disadvantaged backgrounds, to mitigate inequities in workplace experiences and outcomes.

A clear discrepancy between first-year and final-year self-efficacy sources was observed, with first-year students emphasising tinkering and applied problem-solving, while final-year students valued real-world design and experimental tasks. Policymakers should advocate for curricular designs that scaffold these experiences progressively. This includes embedding project-based learning (PBL) in early years (O'Connor et al. 2024) and expanding experiential learning opportunities, such as capstone projects and research-based internships, in later years.

Reports of negative peer interactions, particularly among women, underscore the need for institutional policies that promote gender equity. Policies should include mandatory training for faculty and students on bias and inclusivity, the establishment of mentorship programs for underrepresented groups, and the development of peer evaluation systems that minimise bias in group settings.

Implications for practice

Social persuasions, such as positive feedback and mentorship, emerged as significant contributors to self-efficacy. Educators should implement structured feedback systems that emphasise constructive and affirming comments. Additionally, mentorship programs that connect students with faculty, alumni, and industry professionals can offer role models and guidance that reinforce self-efficacy. However, the design and delivery of collaborative learning must be carefully considered in light of research highlighted variances in experiences and achievement across groups (Stump et al. 2011).

First-year students benefit from activities that simulate engineering practices, such as tinkering and collaborative PBL modules. Faculty should design early coursework to include hands-on, exploratory projects that mirror real-world engineering tasks (Power, Tanner, and Buckley 2024). For final-year students, educators should focus on integrating complex, industry-relevant challenges into the curriculum to reinforce design and experimental self-efficacy.

Physiological and emotional states, such as stress and anxiety, were cited as barriers to self-efficacy, particularly among first-year students. Universities should offer support services, such as stress management workshops, counselling, and time management training. Faculty can also adopt flexible teaching approaches, such as incremental deadlines and formative assessments, to reduce academic pressure. The purpose and nature of assessment should also be clearly communicated to students to mitigate negative emotional reactions. Assessment outcomes should be framed as opportunities for further development. This approach has been shown to be particularly beneficial for underrepresented groups (Chen et al. 2023; Godwin et al. 2018).

By implementing these policy and practice changes, institutions can cultivate a learning environment that not only enhances engineering self-efficacy, but also prepares students for successful and equitable participation in the engineering profession.

Conclusions

Professional placement experiences are identified as the primary factor in late-stage engineering student self-efficacy development. They act as a potent formative experience that is centred on the mastery and social persuasions sources of self-efficacy. Reports regarding the value of these professional placements concentrated on enactive mastery experiences with associated professional recognition from esteemed colleagues. Similarly, PBL experiences that sought to emulate the challenges of a professional engineering environment were reported as the primary source of self-efficacy for first year engineering students. The value placed on these two disparate settings suggest that commonalities including the challenge of complex real-world tasks, autonomy and collaboration, are especially valuable for engineering self-efficacy development. These findings provide valuable new insights that have the potential to further refine existing project-based learning approaches and professional placement systems for enhanced engineering self-efficacy development. The findings of this study directly address the dearth of research examining the evolution of self-efficacy within a third level learning environment identified by Honicke and Broadbent (2016), and provides a novel perspective of engineering self-efficacy development.

Limitations and recommendations for future research

Cross sectional comparisons have practical and logistical advantages, but conclusions must be tempered due to possible variations in baseline beliefs and related experiences. Future longitudinal studies using comparable methods have the potential to provide further insight regarding the development of engineering self-efficacy. However, this will pose considerable challenges relating to participant retention, which will in turn compound existing statistical power limitations that are common within the field. Improved data sharing and greater collaboration across institutions could further enhance the value of future research efforts in this area (Buckley et al. 2023; Power 2021a).

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No potential conflict of interest was reported by the author(s).

Authors' contributions

The first author created the initial draft, developed the methodology, qualitative data analysis, completed final editing and prepared the document for submission. The second, and fourth authors contributed to the conceptualisation of the project and revised each version of the paper. The third author was responsible for data collection and contributed to the conceptualisation of the paper. The final author was responsible for data curation, data analysis, and reporting.

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Data availability and materials statement

A full anonymised data set is linked within the manuscript and hosted on the Open Science Framework. This includes a codebook, syntax and supplementary statistics: https://osf.io/nd245/?view_only = 0801a61fbc1c455094c0a8d45d15c20c.

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