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Creative Self-Efficacy: Why It Matters for the Future of STEM Education

Maria Vieira, JohnPaul Kennedy, Simon N. Leonard, and David Cropley

University of South Australia

ABSTRACT
In preparation for the future of work, developed economies face two critical challenges related to their STEM workforces. The first is the need to increase female participation, as women remain underrepresented in these disciplines. The second is the need, in a rapidly digitalizing world, to equip workers with abilities that cannot be easily replaced by artificial intelligence and automation. Could creativity be the solution to both challenges? Building on existing scholarship, this study proposes Creative Self-Efficacy (CSE) as being an essential component of STEM education, necessary to support both increased female participation and proper preparation for the demands of the future of work. A quantitative study was conducted with 2,123 Australian students, across Years 6 to 12, to examine the role of CSE in STEM subjects. The analyses compare the CSE levels between STEM and non-STEM disciplines, between genders and examine the differences in the correlation between CSE and intention for further study between the different year groups. The most relevant finding of this paper is that CSE correlates with the decision to continue studying STEM and non-STEM subjects, both for female and male students. Further implications and practical methodologies to stimulate this construct in STEM classrooms are proposed.

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Introduction

With the transition of advanced economies to a new industrial revolution, the so-called Industry 4.0, the nature of work is changing. On the one hand, this transition emphasizes the role of Science, Technology, Engineering, and Mathematics (STEM) as core disciplines to foster innovation (Vincent-Lancrin et al., 2019). On the other hand, there is the understanding that the essential capabilities of the 21st century are shifting to favor the capabilities that computers, automation, and Artificial Intelligence (AI) cannot deliver (Leopold, Ratcheva, & Zahidi, 2016). The capability to find new and effective solutions to open-ended problems, known as creativity, is increasingly emphasized in consideration of future workforce needs (Cropley & Cropley, 2021; OECD, 2022b). In short, STEM skills will be essential to future workers with a significant focus being placed on complex, creative problem-solving (Cropley, 2020). However, developed countries face two issues in the transition to Industry 4.0. Firstly, there is a STEM skills shortage, driven largely by the underrepresentation of females in this field (Australian Academy of Science, 2018; Jaremus, Gore, Fray, & Prieto-Rodriguez, 2019; UNESCO, 2017). Secondly, the development of skills in creativity has been misinterpreted and neglected in school and university curricula (OECD, 2022b; Patston, Kaufman, & Cropley, 2022).

Although the lack of women in STEM industries is a widely recognized issue worldwide, it remains a significant problem in many developed countries. The educational-gender-equality paradox (Stoet & Geary, 2018) suggests that developed countries with high levels of gender equality – such as Finland, Norway and Sweden – have higher gaps in STEM education at the secondary and tertiary levels. As an example, in the UK, females form only 9% of the workforce in engineering, compared to 52% of the overall workforce (British Science Association, 2020). Also, in Australia, women comprise around 48% of the paid labor force (Workplace Gender Equality Agency, 2022) and 38% of university STEM completions, yet make up only 15% of the employed STEM-qualified workforce (Australian Government Department of Industry, Science and Research, 2022).

In response to the gender gap in STEM fields, both public and private sectors have been addressing gender inequalities with several initiatives across the globe. The recent Equity and Inclusion in Education report (OECD, 2023) outlines some specific examples of programs aiming to tackle the issue being established in

CONTACT Maria Vieira maria.vieira@unisa.edu.au University of South Australia, Room M2-28, Mawson Centre, University of South Australia - Mawson Lakes Campus, Adelaide, SA 5095, Australia

Canada, Germany and New Zealand. Furthermore, Australia has seen at least 337 gender equity in STEM programs being delivered across the country in the past years, the majority of them focused on tertiary education (McKinnon, 2020).

However, it is known that the gender barriers to female participation in this field start at a very early age, when females start to become less confident in their abilities in STEM subjects (Alexander, Johnson, & Kelley, 2012; Bian, Leslie, & Cimpian, 2017; Kerkhoven et al., 2016; Kerr, 2016). In Australia, this gap becomes more evident in the middle years of school, when the proportion of females in STEM classrooms reduces drastically (Australian Academy of Science, 2018; Kennedy, Lyons, & Quinn, 2014; Kennedy, Quinn, & Lyons, 2017; Watt, Eccles, Durik, & Wynarczyk, 2006). Females' confidence in STEM tends to drop as they get older – from 12% considering engineering when they are 12 or 13-year-olds to only 8% when they are between 14 to 17-years-old (Australian Government Department of Industry, Science and Research, 2022). A large number of factors have been put forward to explain this phenomenon, including the impact of stereotypes (Bell, 2010; Dasgupta & Stout, 2014; Gleeson, Walsh, Gallo Cordoba, Waite, & Cutler, 2022; Kennedy, Quinn, & Lyons, 2017; Roberts, Hughes, & Kertbo, 2014), the large number of subjects being offered as elective units to students (Kennedy, Lyons, & Quinn, 2014; Panizzon, Corrigan, Forgasz, & Hopkins, 2015), and the pressure to achieve a high score in the Australian Tertiary Admission Rank (ATAR) (Lyons & Quinn, 2010; Panizzon, Corrigan, Forgasz, & Hopkins, 2015). As a result, Australian female students are around half as likely to aspire to a profession in STEM when compared to male students (Australian Government Department of Industry, Science and Research, 2022).

Recent research (Cooper & Heaverlo, 2013; Kennedy, Thompson, Fowler, & Leonard, 2021; Kijima & Sun, 2021) suggests the use of creativity as a possible pedagogic approach to increase female participation in STEM. Higher levels of creativity have been shown to be associated with a reduction in negative attitudes – such as anxiety and perception of difficulty – as well as increasing enjoyability, perceptions of relevance, and self-efficacy. Creativity is conventionally defined as the ability to discover new and original solutions to problems (Sternberg & Karami, 2021), and has been gaining attention in education circles in recent years as a teachable and learnable competency that can translate between situations and domains (Patston, Kaufman, & Cropley, 2022; Patston, Kaufman, Cropley, & Marrone, 2021). Consequently, the number of nations adding creativity as a competency to their curriculum has grown in the recent years (Patston, Kaufman, & Cropley, 2022; Patston, Kaufman, Cropley, & Marrone, 2021). On a global scale, the OECD Program for International Student Assessment (PISA) has also added specific items to measure creative thinking (OECD, 2022b).

Despite this, simply incorporating creativity into the curriculum appears to be insufficient to comprehensively tackle the gender inequalities in STEM, especially given that creativity hinges not only on cognitive abilities but also on the confidence to perform creative actions (Beghetto, 2021; Karwowski, Lebuda, & Beghetto, 2019; Zielińska, Lebuda, & Karwowski, 2022). Although the literature has not found compelling differences in the levels of creativity in male and female students (Kaufman, 2006), other researchers have reported that females tend to be more uncertain about their creative aptitudes and less incentivized to develop their creative skills (Esslinger, 2011). According to the OECD (2022a), girls are prone to exhibiting reduced levels of confidence and experience less-positive emotions in terms of acquiring and imparting knowledge related to creativity. Additionally, they tend to underestimate their creative abilities and face obstacles that stem from a culture dominated by males, while their male classmates frequently overestimate their own creative potential (Karwowski, 2011). It appears logical to infer that endeavors to integrate creativity into education must extend beyond simple activities and should progress toward incorporating the non-cognitive facets of creativity as integral components of a comprehensive approach.

When discussing the role of creativity in education, it also important to recognize its domain-specific aspects (Kaufman, 2006). That is, considering the specific context or domain in which the learning is taking place is critical when nurturing creative competencies. The present focus on the integration of digitalization into Industry 4.0, and the emphasis on vital skills as a component of the future of work all offer a justification for directing attention toward the individual domains that make up STEM (van Broekhoven, Cropley, & Seegers, 2020). However, despite the known benefits of STEM education in promoting creativity and innovation in learning, there is a lack of research on the specific application of creativity learning within the STEM field (Unal & Taşar, 2021).

Understanding that non-cognitive and domain-specific aspects of creativity are critical for the advancement of research in this field, it seems reasonable to investigate the concept of creative self-efficacy (CSE), a term coined by Tierney and Farmer (2002), to describe one's belief in one's own ability to be creative. Since researchers (Kennedy, Quinn, & Lyons, 2017; Nguyen, Russo-Tait, Riegle-Crumb, & Doerr, 2022) have suggested that career choices might be strongly influenced by stereotypes, then exploring ideas of self-concept and in particular self-efficacy would appear fruitful. Self-efficacy has been acknowledged as an important construct in supporting women to make adjustments to overcome internal obstacles and also positively influences their management of the external barriers that they face in the STEM fields (Deemer, Thoman, Chase, & Smith, 2014; Hackett & Betz, 1981). Hence this paper asks the question: If stimulated within the classroom, might CSE lead to transformative changes in the STEM workforce by contributing to both gender equality and the development of a more skilled workforce in this field?

Background

Exploring affective factors: self-efficacy

Prior to delving into the specifics of this investigation, it is imperative to examine self-efficacy more closely to comprehend its significance and how it can aid in resolving the identified issue. First coined by Bandura (1977), self-efficacy is defined as the belief in one's capability to act in order to achieve a specific goal. People who hold a strong sense of self-efficacy are more inclined to engage and persist in a task, even when facing adverse situations. Bandura (1997) outlined four key influences on the development of self-efficacy: mastery experiences, defined as the feeling of success after completing a task or overcoming a challenging situation; vicarious experiences, which relates to the feeling of learning from other peoples' experiences; verbal persuasion, associated with encouragement and feedback to individuals achieve their goals; and finally physiological and affective states, connected to positive and negative emotions people experience.

The relevance of self-efficacy theory in understanding gender based actions and phenomena has long been recognized. Hackett and Betz (1981) suggested that higher levels of self-efficacy might support the management of both the internal and external barriers that women face in the workplace. Of particular concern is the body of research that has analyzed self-efficacy with a focus on gender differences and identified that females exhibit considerably lower levels of self-efficacy when compared to their male peers (Almukhambetova, Torrano, & Nam, 2021; Mau & Li, 2018; Sterling et al., 2020). The obstacles women face in following a STEM career include negative stereotypes, sexual harassment and lack of appropriate role models among many others (Australian Academy of Science, 2018). These challenges contribute to a phenomenon often referred to as a "leaky pipeline" (Bell, 2010; Berryman, 1983; Clark Blickenstaff, 2005). Women "leak" from the STEM pipeline more than men due to the cumulative effect of the series of individual and contextual barriers they face from primary school to senior-level careers. Building on the work of Hackett and Betz (1981), we suggest that efforts to develop self-efficacy in female students will empower them to expand their career options – including to traditionally "non-female" areas – and also increase their career satisfaction, thus decreasing their likelihood of leaking from the STEM pipeline.

A number of studies have sought to better understand the development of self-efficacy in the context of education (Unal & Taşar, 2021). However, Kaufman (2006) cautions that an individual's self-efficacy depends on the specific learning context and attempts to analyze it from a general perspective should be avoided. Essentially, Kaufman is suggesting that although a student may report high levels of self-efficacy toward Science, this positive attitudinal position may not be assumed for other subject domains such as Mathematics or English (see also Kennedy, Quinn, & Lyons, 2020; Patston, Kennedy, et al., 2021). Therefore, understanding the patterns of self-efficacy within the STEM fields can be seen as a first step toward informing solutions that better address the gender gap in this area (Kiran & Sungur, 2012).

Although some efforts have been made to investigate gender differences in self-efficacy, specifically in STEM areas, findings remain inconclusive. While some studies suggest that middle school female students exhibit higher levels of science self-efficacy than their male peers (Britner & Pajares, 2006), others report that female self-efficacy toward science in the first year of high school (Year 7) is significantly lower than male students (Kennedy, Quinn, & Lyons, 2020), while others still found no relationship between student gender and science self-efficacy (Kiran & Sungur, 2012). However, both Britner and Pajares (2006) and Kiran and Sungur (2012) show consensus in reporting that female students self-report higher levels of anxiety and emotional stress in science subjects both in middle and high school.

Lyons and Quinn (2010) suggest that female students are more susceptible to the perception of difficulty and finding it more challenging to envision themselves as future scientists. This would lead to fewer positive mastery experiences and greater negative self-talk or verbal persuasion leading to lower levels of self-efficacy. The theoretical model developed by Eccles (2011) also suggests that experiences of negative stereotypes associated with gender might amount to negative vicarious experiences and unhelpful verbal persuasion thus leading to gender-based differences in self-efficacy and thence to negative impacts on female students' career decisions. Consequently, investigating possible interventions associated with improving female students' self-efficacy is critical to providing supports that help them to learn to self-regulate the internal and external obstacles they encounter and to close the gender gap in the STEM fields.

Examining the depths of creativity

Creativity, as defined by Stein (1953), centers around work that is both novel and useful to a group of individuals. The development of creative competency has been gaining attention in the school curriculum as a teachable and learnable competency (Cropley & Cropley, 2010; Rhodes, 1961; Scott, Leritz, & Mumford, 2004) that must be integrated into STEM curricula (Patston, Kaufman, Cropley, & Marrone, 2021; Wingard, Kijima, Yang-Yoshihara, & Sun, 2022). The pedagogical reasons to do so are many but include the research findings that creativity may have the potential to positively impact non-cognitive capabilities such as motivation and teamwork (Cropley, 2020), and to shape students' affective states, reducing negative attitudes such as anxiety and perception of difficulty as well as increasing enjoyability, relevance and self-efficacy (Patston, Kennedy, Thompson, Fowler, & Leonard, 2021).

Australia is one of an increasing number of nations to incorporate creative thinking into its national curriculum (Patston, Kaufman, Cropley, & Marrone, 2021). The Australian Curriculum General Capabilities defines creative thinking as "[. . .] learning to generate and apply new ideas in specific contexts, seeing existing situations in a new way, identifying alternative explanations, and seeing or making new links that generate a positive outcome [. . .]" (Australian Curriculum Assessment and Reporting Authority ACARA, 2021). This clearly aligns with recent trends in the field of creativity (Kaufman, 2006) and emphasizes the domain-specific approach to this construct as opposed to the original, more generalist views adopted by earlier scholars. That is, the knowledge a person has in a particular field of study likely influences how capable they are of creating a novel and useful solution to a problem.

However, the paths between recognizing the importance of creativity and adapting it to the curriculum seem to be tenuous and obscure. As an example, although studies have not found consistent differences in creativity between males and females (Kaufman, 2006; Shaw, Kapnek, & Morelli, 2021), female students still tend not to demonstrate enough confidence in their creative abilities (Esslinger, 2011; Hora, Lemoine, Xu, & Shalley, 2021). Recent data from the OECD (2022a) collected across several countries also suggests that female students report lower levels of positive feelings and less confidence in the teaching and learning process of creativity and critical thinking. Therefore, a careful look at the concept of CSE could be more accurate in providing possible insights to increase female participation in STEM.

Creative self-efficacy: a closer look

Cropley and Cropley (2009) posit that, "people who are dissatisfied with gaps in what exists, but do not believe that they can do anything about it, are hardly likely to be motivated to generate effective novelty" (p. 111). Therefore, the belief that one is capable of producing original solutions, known as CSE (Tierney & Farmer, 2002), is a critical capability to be developed and must be given appropriate attention in education. The motivation for this focus goes beyond the general pre-requisite need for positive CSE in the development of creativity itself (van Broekhoven, Cropley, & Seegers, 2020), and extends to academic success. CSE correlates positively with optimistic beliefs about academic abilities, as well as intentions to attend university in the future (Beghetto, 2006).

Karwowski (2015) also defines CSE as an important aspect of the creative self-concept (a multifaceted construct that covers other characteristics such as creative personal identity, self-rated creativity, and creative metacognition). According to the author, the development of CSE begins around the age of 10, and the phase between late adolescence and early adulthood is when it presents a substantial growth. Zandi, Karwowski, Forthmann, and Holling (2022) also highlight the malleability of CSE in comparison to more enduring constructs like personality traits or academic self-concept. Because of its predictive power regarding creative efforts and actions, the significance of reinforcing and improving CSE gains particular importance, particularly within the context of school education. Therefore, stimulating creativity in the classroom is one of the most significant capabilities a teacher can foster (Cropley & Cropley, 2009). STEM disciplines, in particular, should receive emphasis, as they are often seen by students as more difficult (Lyons & Quinn, 2010) and offer less opportunities to be creative (Kaufman, 2006).

Instruments that measure creativity and self-efficacy as isolated constructs have been developed for many years (e.g., Klassen & Usher, 2010; Said-Metwaly, Noortgate, & Kyndt, 2017). However, validated instruments to measure CSE have only appeared in the literature in recent years. The availability of tools for assessing CSE specifically in children and adolescents is even more scarce (Valquaresma, Coimbra, & Costa, 2022). These instruments tend to be of the self-report survey format with items measuring concepts of creativity and self-efficacy using Likert style responses – for example, "I am good at coming up with good ideas" and "I have a lot of good ideas" (Beghetto, 2006; Shaw, Kapnek, & Morelli, 2021; Tierney & Farmer, 2002).

Among other purposes, those instruments have been utilized to analyze gender differences in CSE, presenting inconclusive results until recently. Some researchers (Beghetto, 2006; He & Wong, 2021; Karwowski, 2011) suggest that female students have significantly lower levels of CSE than male students, while other authors have found the opposite trend, or no statistical difference between genders (Du et al., 2020; Hashim, Sharipah Ruzaina Syed, & Fook, 2022; Kaufman, 2006; Shaw, Kapnek, & Morelli, 2021; Zielińska, Lebuda, & Karwowski, 2022).

Research questions

To improve the involvement of women in STEM fields, and to ensure that the upcoming STEM workforce has the necessary skills to adapt to fast-paced digitalization, several questions must be addressed. Prior research (Beghetto, 2006; Du et al., 2020; Hashim, Sharipah Ruzaina Syed, & Fook, 2022; He & Wong, 2021; Karwowski, 2011; Kaufman, 2006; Shaw, Kapnek, & Morelli, 2021; Zielińska, Lebuda, & Karwowski, 2022), as summarized earlier, presents contradicting results on gender differences in CSE between females and males, indicating the need of further investigation as CSE could have a detrimental effect on females' decisions to pursue careers in STEM. As a result, this paper explores four questions based on data collected using the School Attitudes Survey (Kennedy, Quinn, & Taylor, 2016) from Australian school students aged 10 to 18 years old. Firstly, what differences in CSE are reported by male and female students? Secondly, what variations in CSE are documented between different year groups? Thirdly, how do students' reported levels of CSE differ between STEM and non-STEM domains? Finally, does the correlation between students' CSE and their intentions to pursue STEM subjects in post-compulsory education or in their careers show differences between the different year groups?

Methods

Instruments

Due to the absence of accurate measurement tools for Creative Self-Efficacy (CSE) within STEM fields, we opted to employ a concise scale that could be conveniently utilized in educational settings. Taking inspiration from the CASES scale (Valquaresma, Coimbra, & Costa, 2022), our approach involved crafting a combined assessment of CSE that integrates both creative self-efficacy and creativity factors.

The School Attitude Survey (SAS) builds on the work of Kennedy, Quinn, and Taylor (2016) and measures students' attitudes toward each of their school subjects across nine attitudinal constructs including self-efficacy, creativity, and future enrollment intentions (hereafter simply intentions). The SAS is a concise online survey delivered through a custom platform that takes approximately 10 minutes to complete. In Australia, students typically study between four and twelve subjects per year and to thus use typical multi-item scales for each attitudinal construct would place an undue burden on participants. Instead, the SAS makes use of single item scales and presents sliders for all of a student's subjects for each attitudinal construct on one page (Figure 1) – see Kennedy, Quinn, and Taylor (2016) for further explanation. Each slider has the form of a visual analog scale running from −50 to + 50, initialized to 0. From the second data entry point onwards, each individual slider is initialized to the participant's previous rating thus both the change in rating and the difference in ratings between subjects have meaning. This level of personalization means that the SAS generates a survey that is tailored to each participant, and an exact copy cannot be provided here. However, for the sake of clarity, the phrasing of the questions utilized in this particular study can be found in Table 1. Note that the placeholder <SUBJECT> is replaced in the actual survey presented to participants with the name of the subject as it appears on their timetable.

Creativity in the SAS refers to the student's beliefs of being able to demonstrate creativity in their learning in each subject. The wording of this item was developed through an iterative process with creativity research expert, J. Kaufman (personal communication, 2020). The items related to students' enrollment intentions in the SAS are phrased differently depending on the student's stage of schooling. For students at or below Year 10, the construct reflects the student's desire to study

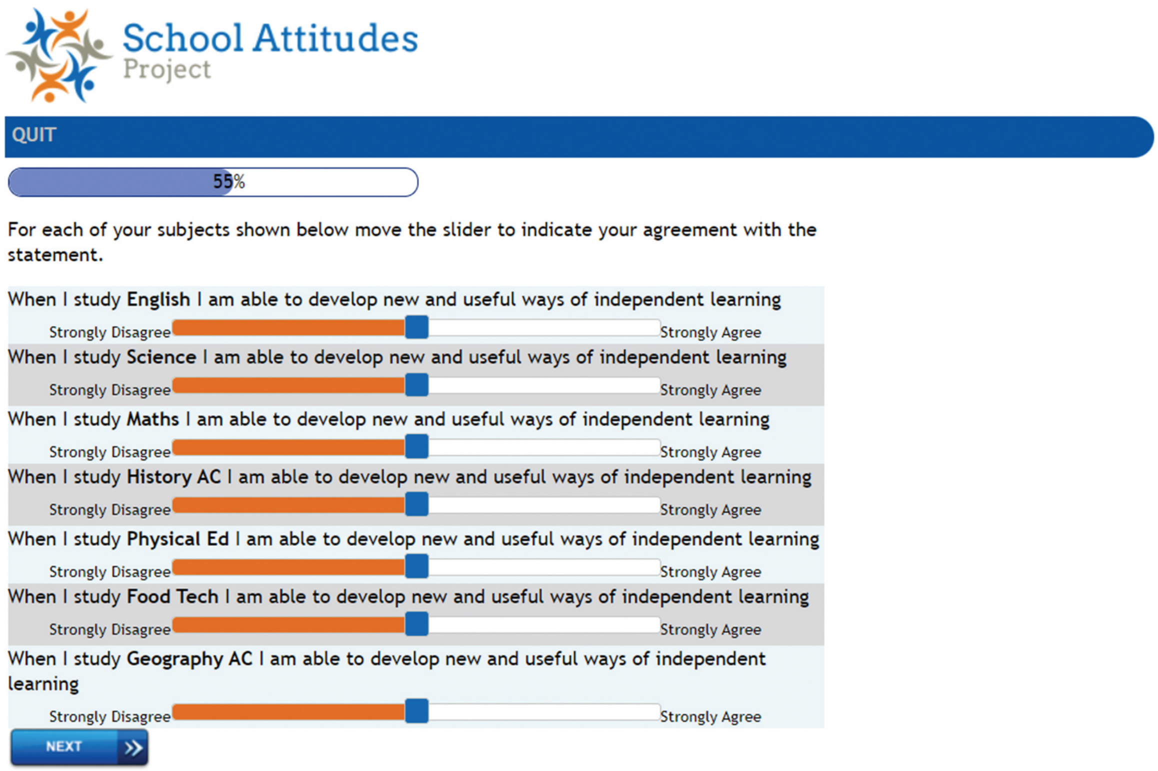

Figure 1. Screen shot of one of the data entry screens of the school attitudes system.

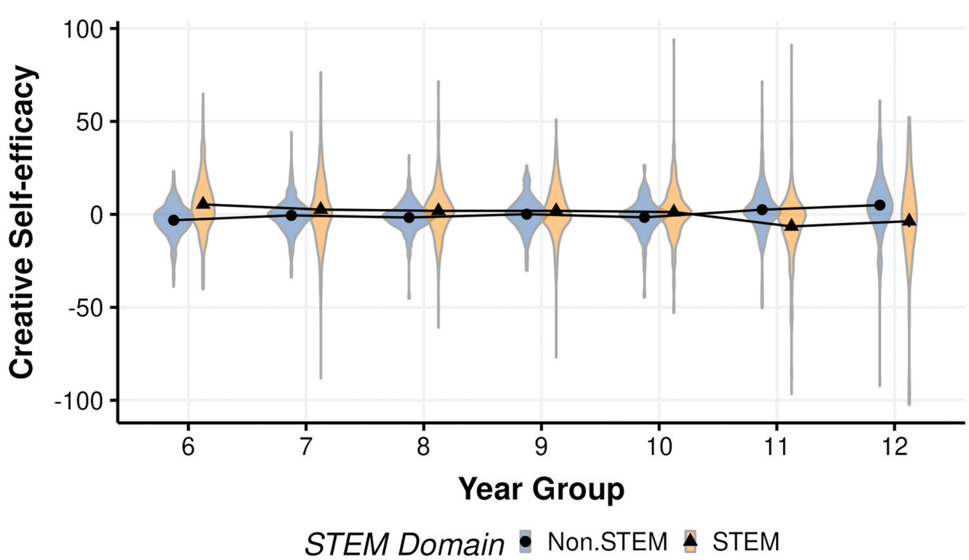

Figure 2. Creative self-efficacy as effected by student year group and STEM domain.

Table 1. Item wording for the school attitudes survey.

Attitudinal Factor	Item Wording	Left Hand Indicator	Right Hand Indicator
Creativity	When I study <SUBJECT> I am able to develop new and useful ways of independent learning	Strongly Disagree	Strongly Agree
Self-Efficacy	I think I am very good at <SUBJECT>	Strongly Disagree	Strongly Agree
Intentions	I am very likely to enroll on a <SUBJECT> course in Year 11	Strongly Disagree	Strongly Agree
	I am very likely to enroll on a <SUBJECT> course after school		

a subject in the final two years of school. For students in Years 11 or 12, the construct related to the intention to continue study in this area, or a closely related one, after school.

For each student's set of responses to each attitudinal construct across all subjects, a mean response score is calculated, known as the Composite Attitude Rating (CAR). This represents the student's average attitudinal score toward school in general; for example the self-efficacy CAR represents the student's overall average self-efficacy across all their subjects. The Subject Attitude Rating (SAR) is then calculated by subtracting the CAR from the raw response score for each subject and will have a value between −100 and + 100. A score of zero indicates that the student holds an attitude for a particular subject that is the same as their attitude toward school as a whole. In this way, the SAR represents a student's relative attitude toward a single subject area compared to their attitude about school more generally. In the analyses that follow, the SAR will be presented.

The SAS measures creativity and self-efficacy as independent, yet related, concepts. When examined across all subject areas, for all students and at all time points, the Pearson product-moment correlation coefficient between the two measures was found to be r(38609) = .53, $p < .001$.While some variation in this correlation exists between the STEM (r(14753) = .51, $p < .001$) and non-STEM (r(23624) = .54, $p < .001$) domains, the strengths of the correlations are very similar. It is reasonable therefore to hypothesize that the nature of the relationship between CSE and each of the measured constructs of creativity and self-efficacy is similar for STEM and non-STEM courses.

Exploring the nature of these relationships in the prior research we find that Shalley, Zhou, and Oldham (2004) referenced the work of Redmond, Mumford, and Teach (1993) to propose that an individual's overall self-efficacy has a positive correlation with creativity (p. 946). Meanwhile, empirical support for the connection between various combinations of self-efficacy, creative self-efficacy, and creative performance has been provided by (Tierney & Farmer, 2002), Beghetto, Kaufman, and Baxter (2011), and Tierney and Farmer (2011) across diverse contexts such as workplaces, science, and mathematics, encompassing both adults and children. In their studies, all three of these researchers observed consistent findings. They identified modest yet significant positive correlations, typically within the range of $r = .18$ to .25, between creative performance or expression and creative self-efficacy. Moreover, Tierney and Farmer (2004, 2011) found moderate and significant positive correlations, typically around $r = .40$, between self-efficacy related to one's job and creative self-efficacy. Lastly, Tierney and Farmer (2002) established a weak yet statistically significant positive correlation ($r = .13$) between job-related self-efficacy and creative performance. Hence, there are compelling grounds to consider the linear amalgamation of creativity and self-efficacy as an effective proxy-measurement for CSE.

We therefore propose that CSE can be represented as a weighted linear combination of creativity and self-efficacy and calculated for each student, for each subject, at each time point. The derivation of this relationship is shown in Appendix 1.

$$CSE = (1.17 \times Creativity) + (0.702 \times SelfEfficacy) + 0.035$$

Participants

A total of 2,123 male and female students from South Australian schools in Primary and Secondary School – Years 6 to 12 (typically aged 11 to 18 years-old) – contributed data during the 2022 school year which has been used in this analysis. Students were emailed a personalized login to the SAS instrument once per term and time was provided during the school day to complete the survey. A full breakdown of student numbers by gender and year group is shown in Table 2. This research was approved by the Human Research Ethics Committee of the University of South Australia as protocol number 202,684. The legal guardians of all participants provided written opt-in informed consent for

Table 2. Participant numbers by year group and gender.

Year	Schooling phase	Female	Male	Total
6	Primary	173	166	339
7	Lower Secondary	197	182	379
8		205	192	397
9		176	152	328
10		151	133	284
11	Upper Secondary	102	129	231
12		80	85	165
Total	-	1084	1039	2123

Table 3. Key learning areas and domain groupings.

STEM domain areas	Non-STEM domain areas	Excluded domain areas
Sciences	English	Vocational Education and Training
Mathematics	Humanities and Social Sciences	
Technology and Applied Studies	Creative and Performing Arts	
	Personal Development, Health and Physical Education	
	Languages other than English	

the study and all student participants also provided informed assent to the research study.

The Australian school system offers many courses to students within each faculty or key learning area. For the purposes of analysis, course data are aggregated at the key learning area level and further grouped as STEM or non-STEM domains. These key learning areas are shown in Table 3. Courses in the Vocational Education and Training key learning area have been excluded in this analysis as they encompass a wide range of courses that sit across the STEM and non-STEM domains that cannot be disentangled readily.

Results

Understanding creative self-efficacy

A factorial mixed ANOVA, with a critical value of $\alpha_c = 0.05$, was performed using the afex package (Singmann, Bolker, Westfall, Aust, & Ben-Shachar, 2023) in R to investigate how students' CSE was affected by gender (female vs male) and year group (Year 6 to Year 12) as between-subject independent variables and STEM domain (STEM vs non-STEM) as a within-subject variable. The estimated marginal means (EMM) and standard errors for this 2 × 7x2 design are shown in Appendix 2. Contrast analysis using the model based package (Makowski, Ben-Shachar, Patil, & Lüdecke, 2020) in R was used to carry out pairwise t-tests with a Bonferroni correction of cells, to explore any differences present in the data. Differences in CSE (Δx_{CSE}) between cells with adjusted p-values and effect sizes calculated using Cohen's d are reported where significant.

There was a statistically significant effect of student gender on CSE level, F(1,2019) = 55.14, $p < .001$, $\eta^2_G = .005$, indicating that across all year groups and both course domains, male students reported CSE levels that were 2.19 points higher (SE = 0.29) than their female peers. The main effect of year group, F(6,2019) = 7.96, $p < .001$, $\eta^2_G = .004$ – small effect size –, was also statistically significant in explaining students' CSE. Plotting the differences in EMMs between year groups, using Year 6 as a reference baseline, showed that while there is a steady decrease in EMM over time, this year-on-year trend is not significant ($x'_{CSE}(t) = 0.26$ points y-1, $R = .44$, $p = .39$). The main effect of STEM domain had no statistically significant effect. That is, no differences in CSE between STEM and non-STEM disciplines were observed.

The two way interaction effect of the between student variables gender and year group was found to be significant, F(6,2019) = 3.50, $p = .002$, $\eta^2_G = .004$. For each year group, male students reported greater levels of CSE than their year group female peers. However, contrast analysis with Bonferroni correction, revealed that these pairwise differences in overall CSE were only significant in Year 7 ($\Delta x_{CSE} = 2.45$, SE = 0.64, t(2019) = 3.84, $p = .012$, d = 0.17), and Year 12 ($\Delta x_{CSE} = 6.31$, SE = 1.15, t(2019) = 5.49, $p < .001$, d = 0.24).

The two-way interaction effects with STEM domain were both significant. The interaction effect of STEM domain and student gender, F(1,2019) = 85.60, $p < .001$, $\eta^2_G = .033$, indicated that male students reported higher levels of CSE in STEM subjects than non-STEM areas ($\Delta x_{CSE} = 5.98$, SE = 0.86, t(2019) = 6.98, $p < .001$, d = 0.31) and this difference is significant. Female students reported the opposite relationship reporting that their levels of CSE in STEM subjects was lower than in non-STEM areas ($\Delta x_{CSE} = -5.35$, SE = 0.88, t(2019) = 6.12, $p < .001$, d = 0.27). In non-STEM areas, female students reported having higher CSE than their male peers ($\Delta x_{CSE} = 3.48$, SE = 0.50, t(2019) = 6.94, $p < .001$, d = 0.31), while in the STEM areas female students reported having lower CSE than their male peers ($\Delta x_{CSE} = -7.86$, SE = 0.82, t(2019) = 9.58, $p < .001$, d = 0.43).

The interaction effect of STEM domain and year group was statistically significant, F(6,2019) = 14.16, $p < .001$, $\eta^2_G = .033$, indicating that there is a difference in CSE between STEM domains that varies by year group (Figure 2). Plotting CSE against year group for both STEM and non-STEM courses reveals that students' CSE in STEM courses is higher than their CSE in non-STEM courses for students in Years 6 to Year 10. In Years 11 and 12 this pattern is reversed.

In Year 6 the difference in CSE between STEM areas and non-STEM areas was statistically significant ($\Delta x_{CSE} = 8.52$, SE = 1.40, t(2019) = 6.06, $p < .001$, d = 0.27). Similarly this same difference was significant in Year 11 ($\Delta x_{CSE} = -9.00$ SE = 1.72, t(2019) = 5.24, $p < .001$, d = 0.23) and Year 12 ($\Delta x_{CSE} = -8.65$, SE = 2.39, t(2019) = 3.62, $p < .001$, d = 0.16). All other within year group differences were not significant. There were no significant year-to-year differences in CSE within the STEM and non-STEM domains except between Year 10 and Year 11. Year 11 students in STEM domains reported a significant lower level of CSE compared to the Year 10 students ($\Delta x_{CSE} = -7.75$, SE = 1.54, t(2019) = 5.04, $p < .001$, d = 0.22) while in the non-STEM domains, Year 11 students reported a significantly higher level of CSE compared to their Year 10 peers ($\Delta x_{CSE} = 4.13$, SE = 0.94, t(2019) = 4.39, $p = .001$, d = 0.20).

The three-way interaction effect of gender, year group and STEM domain, F(6,2019) = 2.22, $p = .039$, $\eta^2_G = .005$, was found to not be statistically significant after applying the appropriate Bonferroni correction to the critical value ($\alpha^*_c = 0.017$).

The relationship between creative self-efficacy and intentions

Examining all data-points (Figure 3) revealed a moderate positive correlation between CSE and intentions, r(38379) = .56, $p < .001$.Dividing the sample on gender reveals that the correlation between CSE and intentions for female students (r(20154) = .55, $p < .001$) is very slightly weaker than for male students (r(18223) = .57, $p < .001$) but this is statistically significant, z = 3.43, $p < .001$.Splitting the sample on STEM domain also shows a statistically significant difference in correlation between the STEM courses (r(14753) = .52, $p < .001$) and the more strongly correlated non-STEM courses (r(23624) = .58, $p < .001$), z = 8.21, $p < .001$. Examining the change in the correlation between CSE and intentions between the different year groups shows

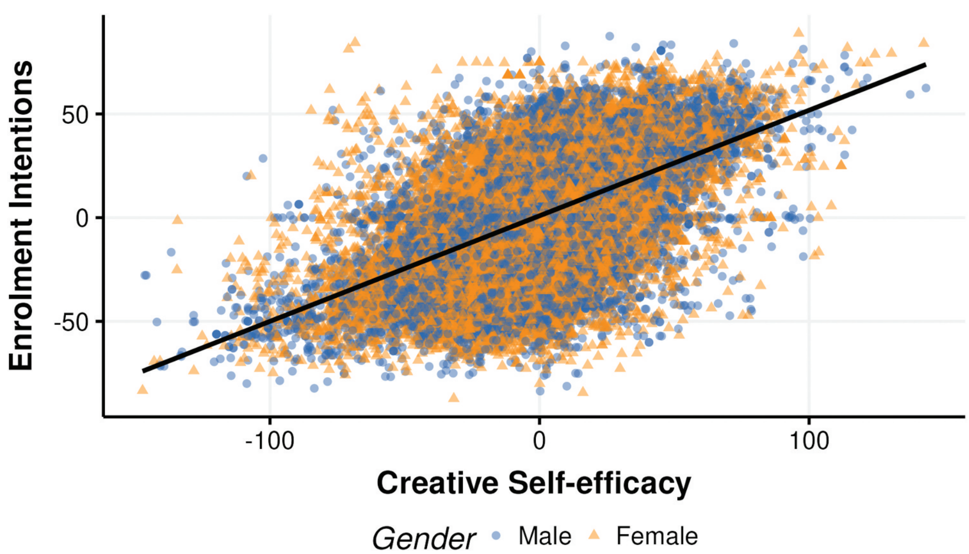

Figure 3. Correlation between creative self-efficacy and enrolment intentions.

Table 4. Correlations between CSE and intentions between year groups for non-STEM and STEM domains for both male and female students.

		Male			Female		
Domain	Year Group	df	r	p	df	r	p
Non-STEM	6	2067	.63	<.001	2302	.60	<.001
	7	2492	.62	<.001	3050	.59	<.001
	8	2639	.57	<.001	3260	.55	<.001
	9	1705	.56	<.001	1556	.61	<.001
	10	1301	.43	<.001	1588	.55	<.001
	11	596	.52	<.001	507	.57	<.001
	12	219	.45	<.001	316	.34	<.001
STEM	6	1232	.55	<.001	1350	.53	<.001
	7	1205	.55	<.001	1417	.49	<.001
	8	1636	.54	<.001	2030	.54	<.001
	9	1386	.56	<.001	1154	.53	<.001
	10	1000	.36	<.001	1115	.47	<.001
	11	518	.53	<.001	353	.50	<.001
	12	201	.34	<.001	130	.22	0.013

that there is a small decrease in correlation as the students become older. That is, the correlation between CSE and intentions is weaker for Year 9 students than for Year 6 students and this becomes weaker still when comparing Year 12 students to Year 6 students.

Table 4 shows the variation in the correlation between CSE and intentions for male and female students across both STEM and non-STEM domains by year group. It can be seen that for non-STEM courses the change in the correlation between year groups suggests that the relationship between these variables becomes gradually weaker in the older year groups. This trend is present in both male and female student data, although the correlation is slightly stronger in all year groups for male students than female. A different pattern is seen in the correlation data for STEM courses. Both male and female students in Years 6 to 9 appear to have a relatively stable correlation between CSE and intentions. However, from Year 10 upwards, this correlation becomes markedly weaker year-on-year. Again, the correlation tends to be weaker for female students than for males.

Discussion

This paper has analyzed the relationship between CSE and subject intentions for 2,123 Year 6 to 12 (11–18 year-old) Australian students. Although this total number is relatively small, some interesting patterns can be observed.

Responding to the first research question about the gender differences in CSE, the data show statistically significant differences between male and female students in their overall CSE scores with male students reporting higher levels of CSE than their female peers across each year group. This finding is in line with some previous research (Beghetto, 2006; He & Wong, 2021), although other research (Shaw, Kapnek, & Morelli, 2021; Zielińska, Lebuda, & Karwowski, 2022) reported negligible gender differences for CSE.

Karwowski (2011) has suggested that, although no differences in creative capacity between females and males exist, the way they perceive themselves is significantly different. That is, apart from misjudging their own creative abilities, females also face the challenge of thriving in a context where males often overestimate their CSE. Taking all of this into account and combined with the very small effect size of the relationship reported here ($\eta_G^2 = .004$), we have to conclude that while student gender is clearly important, it is not sufficient as a sole predictor to explain the differences in CSE we observe. Further research with more nuanced measures of CSE is clearly required.

The data also showed that there was a steady decrease in CSE between the students in the different year groups, which addresses the second question of this study. While this pattern may be due to inter-cohort student variations, the steadily declining nature of this trend suggests that it is more likely that as students' ages increase, their levels of CSE tend to decrease. While the effect of year group was a statistically significant predictor of students' CSE, the pattern in the decrease of CSE between year groups was not statistically significant. That is, the intra-cohort variations between the students within each year group were larger than the differences between the year groups. While this study cannot determine the underlying causal nature of any changes in CSE over time, it does offer intriguing insights into CSE during school-age years. The uncertainty around this observation is likely attributable to the cross-sectional nature of the analysis and a larger population would be required or a longitudinal study design adopted, to explore this further.

As a response to the third research question, this study also analyzed how females and males perceive their CSE differently in the STEM and non-STEM disciplines. Although differences in CSE against disciplines were revealed, the differences were only statistically significant in Year 6, Year 11, and Year 12. These time-points correspond to the final year of primary school, the first year of senior secondary, and the final year of school respectively. Interestingly, students presented higher CSE for STEM disciplines in Year 6, having this pattern reversed to non-STEM disciplines in Years 11 and 12. In Year 6, students have a well-defined compulsory curriculum that is generally taught by a single, generalist teacher. In Years 11 and 12, students are studying a curriculum composed almost entirely of elective subjects. There are therefore a number of possible explanations for the observed pattern. Firstly, the lower CSE in senior STEM subjects might be explained by the fact that opportunities for creativity are less evident and the content tends to be more rigid and fixed in the curriculum of advanced STEM disciplines. Alternatively, the elective nature of this curriculum phase may indicate that students who perceive themselves as creative may have begun to opt out of the STEM disciplines and hence the differences in CSE may be related more to the students than the curriculum. A similar argument might be made for the higher STEM CSE reported in Year 6. The generalist nature of the teachers' training combined with the skills-heavy, content-light nature of the curriculum, may be resulting in more open-ended STEM learning experiences that naturally bring in aspects of creativity. While the results presented here are inconclusive toward pinpointing any differences between students CSE in the STEM and non-STEM disciplines, there are many opportunities identified for more narrowly focused future studies.

Finally, the fourth research question was addressed by investigating the correlation between CSE and enrollment intentions, working from the assumption that students who hold high levels of enrollment intentions toward further study in the STEM disciplines are more likely to pursue future careers in STEM. The data revealed a moderate positive correlation between these two factors for both male and female students and for the STEM and non-STEM disciplines. In all cases, these correlations were statistically significant with female students reporting a slightly weaker correlation than their male peers and the non-STEM courses revealing a slightly stronger correlation than STEM courses. It is important here to acknowledge that the SAS (Kennedy, Quinn, & Taylor, 2016) was designed to be a light-touch tool to measure students' attitudes toward their schooling and was not designed as an explicit CSE instrument. It is also important to note the nature of the assumption linking enrollment intentions with future career pathways. Nevertheless, the data do show that it is likely that if students can increase their CSE in a specific domain then their intentions to study further in that domain are also likely to increase.

Implications for classroom teaching

Just as with creativity itself, CSE is also considered a teachable competence associated with the willingness to take risks, openness and tolerance for ambiguity (Cropley & Cropley, 2009). Therefore, providing enquiry-orientated learning experiences that can facilitate efficacy-building must become more commonplace in both formal and informal education (Britner & Pajares, 2006). These experiences additionally need to draw on multiple sources of self-efficacy (Bandura, 1997) and assist students to build the metacognitive skills needed for success.

Approaches such as Design Thinking have been gaining attention as an effective methodology to be easily applied in the context of school education to foster CSE (Jobst et al., 2012; Kelley & Kelley, 2013; Kijima & Sun, 2021; Wingard, Kijima, Yang-Yoshihara, & Sun, 2022). Defined as a human-centric methodology to problem-solving (Goldman & Kabayadondo, 2017; Kelley & Kelley, 2013), Design Thinking has its foundations in constructivist pedagogy (Kijima, Yang-Yoshihara, & Maekawa, 2021) in which teachers are invited to act more as facilitators than lecturers by guiding students through a series of steps to solve a problem creatively – understand, observe, define point of view, ideate, prototype and test (Lewrick, 2018). Jobst et al. (2012) have observed that Design Thinking, as a methodology, is capable of utilizing many of the four sources of self-efficacy posed by Bandura. Vicarious experience, or "social learning," is encouraged with multi-disciplinary team collaboration and the openness to learn from other students and teachers in an environment free from judgment. Verbal persuasion is facilitated with strong social support and encouraging paradigms such as "fail early and fail often." "Warm-up" activities allow participants to have early and risk-free success engaging with the problem, establishing positive physiological and affective responses early in the activity. Finally, mastery experience is stimulated with creative challenges that need to be solved by participants using mediated techniques to deal confidently with ambiguity and "wicked problems" (Rittel & Webber, 1973).

In short, the findings of this study emphasize the significant correlation between CSE and intentions and suggest that developing students' CSE may be fruitful in shaping their decisions to pursue STEM and non-STEM subjects, regardless of gender. This insight presents a potential solution to address two pressing challenges in STEM education: firstly, it offers a pathway to increase female representation in these fields; secondly, it equips future workers with skills that are uniquely human and thus resistant to automation. Therefore, it is imperative for principals, teachers, and parents across all educational domains to prioritize further research and explore methodologies that support the development of CSE in the school context. By doing so, we can foster a generation of innovative and adaptable individuals ready to tackle the challenges of the future.

Limitations and future research

Although the findings of this study provide important understandings for exploring the impact of student gender of creativity development, there are a number of limitations that must be considered. Firstly, it is important to note the constraints around the use of a self-report instrument. Kaufman (2006) puts emphasis on the fact that "self-perceptions of creativity are not the same thing as actual creativity" (p. 1075) and highlights that self-report measures do not always correlate strongly with performance tests. Therefore, such data needs to be interpreted with caution. Furthermore, we also recognize that internal barriers such as self-esteem and academic self-concept might shape the self-perceptions of creativity reported by the students.

We also need to be aware that some people might see opportunities for creativity in some subjects more easily than in others. For example, the arts may be more easily associated with creativity by students than science or mathematics (Kaufman, 2006). Follow-up studies using more nuanced measurements of CSE are thus necessary to further explore the results presented in this paper. Validated instruments to measure this construct (Shaw, Kapnek, & Morelli, 2021; Tierney & Farmer, 2002; Valquaresma, Coimbra, & Costa, 2022; Zielińska, Lebuda, & Karwowski, 2022) could be adapted to capture CSE differences at the domain-specific level, and so it should be possible to explain the differences between STEM and non-STEM disciplines in greater detail. Qualitative methods are also suggested for future studies to enrich the results presented in this study.

It is important to acknowledge that, due to the instrument's relative newness, the current data collected might not be robust enough to support more complex and in-depth analyses. In forthcoming studies, we also suggest enhancing the comprehension of CSE's potential to tackle gender equality by employing a multi-year longitudinal strategy to operationalize and validate the findings of this investigation. While the execution of such studies might require additional time and resources, they will yield valuable insights for addressing gender equity concerns within the realm of STEM.

Furthermore, even though the findings of this research suggest that CSE may be an important construct in understanding career choices, the implications are not limited to only a pre-university context. Considering that only 29% of Australian women who graduate in the STEM fields go on to employment in these fields (Australian Government Department of Industry, Science and Research, 2022), efforts to tackle the gender gap in STEM need to go beyond acquisition and also focus on retaining females in those areas. Therefore, expanding this research to explore the nature of CSE among undergraduate and post-graduate cohorts would also be an important contribution to advance studies in this field.

Conclusion

The study presented in this article aimed to understand the importance of CSE to the future of STEM education as a possible avenue for exploration in addressing both gender equity and the development of a STEM-qualified workforce. The results indicate statistically significant gender differences in CSE between male and female students, suggesting that CSE is impacted by gender for Australian school students. However, the results also highlight that gender alone is not sufficient to explain the observed differences. The importance of CSE within an educational context is thus a wicked problem. The data also show moderate positive correlations between CSE and enrollment intentions across both STEM and non-STEM domains. Therefore, it is imperative that activities that give opportunities to enhance students' CSE are actively incorporated into the school curriculum.

We believe that one way to achieve this might be through the implementation of Design Thinking in the classroom. This has potential to be a substantive influence on the development of students' CSE, and could therefore, contribute to increasing female participation in STEM. Additionally, enhanced CSE could lead to a more STEM-skilled workforce. However, Lykkegaard and Ulriksen (2019) remind us that career choices are complex and must be seen as an ongoing process. Therefore, Design Thinking may be best viewed as being capable of creating a critical moment of stimulation for students, particularly female students, allowing them to reflect on their future career pathways but may not be sufficient for them to make a decision toward pursuing a career in STEM.

As always, further research is required. However, future studies that seek to explore more precisely how CSE can be enhanced in an educational context and thus lead to flow on effects to STEM career pathways will likely be of great interest to stakeholders from across the sector.

Disclosure statement

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

ORCID

Maria Vieira http://orcid.org/0000-0001-8391-1667
JohnPaul Kennedy http://orcid.org/0000-0002-8126-7086
Simon N. Leonard http://orcid.org/0000-0002-7914-356X
David Cropley http://orcid.org/0000-0002-7964-6538

Data availability statement

The data that support the findings of this study are available from the authors, but some restrictions apply to the availability of these data. The data are, however, available from the authors upon reasonable request.

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Appendices

Appendix 1 - Measuring Creative Self-Efficacy

The SAS measures creativity and self-efficacy as independent, yet related, concepts. As students contributed data at multiple timepoints in the year and study between three and nine subjects, the data analyzed here equate to 7,559 data-tuples or 38,611 data-points. A data point corresponds to the column vector, x, of SAR scores where the subscripts indicate the attitudinal construct measured (C: creativity, SE: self-efficacy, I: Intentions).

$$x = \begin{pmatrix} x_C \\ x_{SE} \\ x_I \end{pmatrix}$$

A data tuple is thus represented as $\langle x \rangle$ where the numerical indices indicate each of a student's subjects.

$$\langle x \rangle = \begin{pmatrix} x_C \\ x_{SE} \\ x_I \end{pmatrix}_1, \begin{pmatrix} x_C \\ x_{SE} \\ x_I \end{pmatrix}_2, \cdots, \begin{pmatrix} x_C \\ x_{SE} \\ x_I \end{pmatrix}_n$$

Plotting creativity against self-efficacy for all data-points across all subjects shows a moderate Pearson correlation coefficient of $r(38609) = .53$, $p < .001$.The equation of the line of least-squares regression line is given by:

$$x_C = \hat{\beta} x_{SE} + b_0$$

For the data analyzed here this yields values of b_0= -0.05 and $\hat{\beta} = 0.6$. A reasonable estimation of a student's CSE (x_{CSE}) can be found by the orthogonal projection of the point defined by their creativity and self-efficacy onto this regression line using the following relationship.

$$x_{CSE} = \frac{1}{\sqrt{1 + \hat{\beta}^2}} \left(x_C + \hat{\beta}(x_{SE} - b_0) \right)$$

The process of orthogonal projection has the effect of firstly translating all points down by b_0 so that the regression line passes through the origin. Then graph is then rotated so that the regression line is horizontal. Each student's reported values of creativity and self-efficacy define a specific point on this graph. Their CSE is given by dropping a vertical line from this point to its intercept with the horizontal CSE axis.

Values for each student's CSE were calculated in R using this approach for each of their subjects for each measurement time and the data-points can therefore be rewritten as:

$$x \equiv \begin{pmatrix} x_{CSE} \\ x_I \end{pmatrix} = \begin{pmatrix} 1.17(x_C + 0.6(x_{SE} + 0.05)) \\ x_I \end{pmatrix} = \begin{pmatrix} 1.17x_C + 0.702x_{SE} + 0.035 \\ x_I \end{pmatrix}$$

Appendix 2: Table of Estimated Marginal Means and Standard Errors

Estimated marginal means and standard errors for students' creative self-efficacy by year group, subject domain and gender. All cells have 2019 degrees of freedom.

		Male Students		Female Students		All Students	
Domain	Year Group	EMM	SE	EMM	SE	EMM	SE
STEM	6	9.574	1.340	1.148	1.320	5.361	0.940
	7	6.679	1.285	−1.541	1.221	2.569	0.886
	8	4.217	1.234	−0.461	1.194	1.878	0.858
	9	3.526	1.312	0.243	1.392	1.884	0.956
	10	5.189	1.490	−2.659	1.392	1.265	1.020
	11	−3.013	1.513	−9.954	1.731	−6.483	1.150
	12	4.120	2.220	−11.469	2.299	−3.675	1.598
	All Years	4.327	0.574	−3.528	0.586	0.400	0.410
Non-STEM	6	−5.682	0.820	−0.626	0.807	−3.154	0.575
	7	−2.210	0.786	1.118	0.747	−0.546	0.542
	8	−2.105	0.755	−1.283	0.730	−1.694	0.525
	9	−0.710	0.802	0.939	0.852	0.115	0.585
	10	−4.839	0.911	1.621	0.852	−1.609	0.624
	11	0.486	0.926	4.549	1.059	2.517	0.703
	12	3.490	1.358	6.469	1.407	4.980	0.978
	All Years	−1.653	0.351	1.827	0.358	0.087	0.251
Both Domains	6	1.946	0.481	0.261	0.474	1.103	0.338
	7	2.234	0.462	−0.212	0.439	1.011	0.319
	8	1.056	0.443	−0.872	0.429	0.092	0.308
	9	1.408	0.471	0.591	0.500	0.999	0.344
	10	0.175	0.535	−0.519	0.500	−0.172	0.366
	11	−1.263	0.544	−2.703	0.622	−1.983	0.413
	12	3.805	0.798	−2.500	0.826	0.652	0.574
	All Years	1.337	0.206	−0.851	0.211	-	-