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Empathy, values, personality, and mindfulness as psychosocial correlates of early STEM academic achievement: a cross-sectional exploration in Indian university students

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Introduction: Traditional models of academic achievement in STEM fields predominantly emphasize cognitive ability, overlooking the influence of psychosocial factors. Recent research in holistic and social-emotional learning has found that attributes such as empathy, mindfulness, personal values, and personality traits may contribute to learning and performance outcomes. This study examines the associative value of these psychosocial factors toward early STEM proficiency in Indian university students.

Methods: A cross-sectional design was employed with two samples. Sample 1 ($n = 580$) completed self-report measures assessing trait empathy (IRI), personal values (PVQ-RR), personality (IPIP-BFM-50), and trait mindfulness (FFMQ-39), along with self-reported high school STEM academic scores in mathematics and science. A smaller subset, Sample 2 ($n = 97$), participated in a 50-min Ānāpānasati-derived breath-based meditation induction followed by the Amsterdam Resting-State Questionnaire (ARSQ) self-report administration to assess state mindfulness. Correlations were followed by hierarchical regression analyses, controlling for gender, university STEM status, and their interactions, to determine the incremental predictive value of the psychosocial variables.

Results: Findings revealed that cognitive empathy (especially, perspective-taking) and self-direction values were modest yet significantly associated with academic performance, particularly in science. Additionally, openness to experience emerged as a positive correlate, while state mindfulness—specifically the planning dimension—showed robust associations with higher academic scores. Hierarchical models confirmed that these variables contributed incremental variance beyond traditional demographic controls.

Discussion: The findings support a multidimensional understanding of early STEM proficiency, wherein psychosocial facets complement cognitive ability in shaping academic outcomes. These results have implications for educational interventions, emphasizing the integration of socio-emotional learning and mindfulness training in STEM curricula.

KEYWORDS

early STEM proficiency, psychosocial predictors, empathy, values, personality, mindfulness, holistic education

1 Introduction

In today's dynamic educational landscape, early proficiency in mathematics and science is recognized not merely as a marker of cognitive ability but as a vital foundation for lifelong learning and economic prosperity. The acquisition of core numeracy and literacy skills is central to individual success and contributes significantly to societal well-being and national growth (Powers, 2008; Shareef et al., 2015; OECD, 2016; Qi et al., 2020). Early STEM (Science, Technology, Engineering, Mathematics) proficiency should be viewed as a composite construct that not only reflects mastery of mathematical and scientific concepts but also underpins a suite of transferable core competencies. These include problem-solving, critical thinking, and adaptability—abilities that are essential for success both within STEM fields and in broader professional and personal contexts (Black et al., 2021; Kazu and Yalçın, 2021; Chitra, 2024; Doly, 2024; Nhat et al., 2024). Additionally, recent projections indicate that STEM occupations are set to grow at significantly faster rates than non-STEM roles, reflecting an increasing global demand for STEM talent, underscoring their critical role in driving innovation and economic competitiveness on a global scale (National Science Board, 2023; OECD, 2023; U.S. Bureau of Labor Statistics, 2024).

Traditionally, academic performance in STEM subjects has been attributed largely to intelligence and analytical capacity. However, contemporary research increasingly supports the integration of holistic and social-emotional dimensions into academic outcomes (Greenberg et al., 2003; Osher et al., 2016; Brahmi et al., 2025b). Specifically, empathy, mindfulness, critical inquiry, and compassionate-values have emerged as foundational elements within globally and culturally validated Social Emotional Learning (SEL) frameworks such as CASEL and the India-based LIBRE/EMC² model (Chatterjee et al., 2020; Brush et al., 2022). These attributes are central to whole-brain and whole-person development (Immordino-Yang and Gotlieb, 2017; Di and Biswal, 2019). The present study, therefore, focuses on STEM academic achievement from the perspective of the LIBRE/EMC²'s psychosocial dimensions—empathy, mindfulness, and compassion, along with personality, not only due to their theoretical and neurocognitive grounding, but also because of their policy relevance to contemporary holistic educational initiatives like India's National Education Policy (NEP 2020) and UN Sustainable Development Goal 4.7 (United Nations Educational, Scientific and Cultural Organization, 2016; Ministry of Human Resource Development, 2018; Chatterjee et al., 2020). Overall, situated in its salience toward the culturally grounded holistic educational framework LIBRE/EMC², the present study questions the associative values of empathy, compassion, mindfulness, and personality toward early STEM academic achievement in the Indian higher education context. Notably, compassion was operationalized through Schwartz's self-transcendence values (universalism, benevolence), which are strongly associated with empathetic concern and prosocial behavior (Persson and Kajonius, 2016; Cha et al., 2023; Brahmi et al., 2024b). This framing not only captures compassion as a value-driven

behavior, but also accounts for values that may counteract it (e.g., power, achievement).

1.1 Empathy and its association with STEM academic performance

Trait empathy, the ability to understand and share another person's emotions, is increasingly recognized as a critical factor in learning and social interactions (Lockwood et al., 2016; Immordino-Yang and Gotlieb, 2017; Bacq and Alt, 2018). The Interpersonal Reactivity Index (IRI) categorizes empathy into cognitive empathy (i.e., the ability to understand others' viewpoints, measured by perspective-taking, fantasy) and affective empathy (i.e., the ability to emotionally respond to others' experiences, measured by empathic concern, personal distress) (Davis, 1980; Brahmi et al., 2025a). Prior studies indicate that students with higher cognitive empathy may exhibit greater academic engagement, cooperative learning behaviors, and intrinsic motivation (Gupta et al., 2022); while excessive affective empathy may hinder academic performance by increasing emotional burden (Dvash and Shamay-Tsoory, 2014). Tikkanen et al. (2022) reported a more complicated relationship, concluding that cognitive empathy improved study wellbeing via affective empathy. However, it is difficult to generalize these findings due to mixed and divergent results (Onwubiko, 2020; Javaeed et al., 2022; Kim, 2024).

While much of the existing literature has linked empathy to broad academic achievement, recent research has begun to examine its role in STEM-specific learning outcomes by suggesting it may enhance creative thinking and problem-solving skills, although this impact may vary by gender and age. Ghazy et al. (2019) found that while empathy has been linked to lower math performance in childhood, particularly among girls (Escovar et al., 2016), it becomes a protective factor in higher education. Their study revealed that women with higher empathy scores performed better in mathematics, suggesting that as students progress through their STEM education, empathy may play a more supportive role in engagement and persistence. Additional research has demonstrated that increasing empathy at the middle school level boosts a desire to help others and creatively solve problems, leading to higher motivation for STEM subjects and careers (Maiorca et al., 2021; Nalipay et al., 2023). These findings point to the importance of integrating prosocial and creative elements into STEM education to support student engagement (Demetriou and Nicholl, 2022).

At a broader level, Pink (2018) argues that an overemphasis on performance and testing in STEM education, particularly in mathematics, has created an empathy deficit, hindering students' development of a theory of mind, limiting their ability to engage in flexible, perspective-driven problem-solving. This perspective aligns with the argument that STEM proficiency is not solely a function of intelligence or analytical reasoning but also of social-cognitive skills that enable students to approach problems from multiple perspectives. Taken together, these findings suggest that empathy may serve as an important, though understudied, predictor of STEM proficiency.

1.2 The role of personal values in learning and achievement

Values shape individuals' motivations, decision-making, and learning behaviors, making them relevant to academic achievement (Hofer et al., 2011; Tarabashkina and Lietz, 2011; Gamage et al., 2021; Vecchione and Schwartz, 2022). Schwartz's value framework offers a systematic model for understanding human values by organizing them into a coherent motivational structure (Schwartz, 1992, 2012). Central to this theory is the notion that values are not isolated but exist within a circular continuum, reflecting both congruities and conflicts among them. Schwartz identifies four core dimensions—self-transcendence vs. self-enhancement and openness to change vs. conservation—that encapsulate the motivational goals underlying diverse behaviors.

While theoretical value frameworks suggest a link between values and broad academic success, empirical findings remain limited, for STEM-specific outcomes, even less so. Self-direction has been one of the most consistent predictors of better academic performance, particularly in subjects requiring analytical reasoning, such as mathematics (Liem et al., 2011; Vecchione and Schwartz, 2022). Students who endorse self-direction are more likely to adopt deep learning and achievement-oriented learning approaches, both of which are associated with higher academic success. In contrast, values linked to conformity—which prioritize adherence to rules and external expectations—appear to encourage surface learning strategies, potentially hindering long-term academic success (Watkins, 2001; Tarabashkina and Lietz, 2011; Beyaztaş and Senemoglu, 2015).

This ability to engage in self-regulated learning has been found to be specifically valid in STEM proficiency alongside self-efficacy and self-concept (Petersen and Hyde, 2017; Zhang et al., 2022). In primary and secondary classrooms where students internalized self-regulated learning strategies, STEM achievement improved (Dignath and Büttner, 2018). This was echoed in high school samples where students with high self-regulated learning skills, grit, and expectancy-value toward STEM had better mathematics performance (Sebial and Mirasol, 2023). In a longitudinal study, Kuyper et al. (2000) found that motivation, metacognition, and self-regulation significantly predicted long-term educational attainment in secondary education, reinforcing the importance of personal values and self-directed learning approaches.

Few studies have explored the direct relationship between values and academic achievement. However, findings indicate that self-direction is positively correlated with achievement, while stimulation and hedonism exhibit negative correlations (Liem et al., 2011; Vecchione and Schwartz, 2022). Interestingly, the same study found that conformity, specifically conformity to rules, unexpectedly positively correlated with school grades, suggesting that structured environments may benefit some students but highlighting the need for more direct research (Vecchione and Schwartz, 2022).

Results on hedonism and stimulation-seeking having negative associations are consistent, likely reflecting the conflict between short-term gratification and sustained academic effort (Hofer et al., 2011; Tarabashkina and Lietz, 2011; Vecchione and Schwartz, 2022). Other values appear to exert more complex or inconsistent

effects. Achievement, defined as striving for personal success within socially defined standards, has shown weak but significant positive correlations with exam grades (Parks and Guay, 2012). These findings align with broader research suggesting that conservation values—particularly tradition, security, and conformity—exhibit negative correlations with intelligence (Anglim and Marty, 2025), whereas values like universalism and benevolence, which emphasize broader societal well-being, show small but positive associations with cognitive ability.

1.3 Personality traits as predictors of academic performance

The Big Five personality traits—openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism—are well-established correlates of academic performance (Costa and Jr McCrae, 1992; Goldberg, 1992). Several meta-analyses have confirmed that conscientiousness explains a significant portion of the variance in academic performance, even when controlling for cognitive ability (Poropat, 2009; Mammadov, 2022). Furthermore, De Feyter et al. (2012) demonstrated that academic motivation mediates the relationship between conscientiousness and performance, reinforcing its role as a key determinant of academic success. Openness to experience has been linked to academic achievement due to traits such as curiosity, open-mindedness, and intellectual engagement. However, its overall impact remains inconsistent and weak (Poropat, 2009; Caprara et al., 2011; McAbee and Oswald, 2013; Gatzka and Hell, 2018; Gerbino et al., 2018). Studies suggest that openness may be beneficial in certain contexts, such as fostering autonomous motivation and critical thinking (Bidjerano and Dai, 2007; Mammadov et al., 2021). However, some research suggests that excessive divergent thinking may hinder performance in structured, rote-based academic settings (Chamorro-Premuzic and Furnham, 2003). The influence of extraversion and agreeableness on academic performance is less clear. Extraversion is often associated with high energy levels and social engagement, which may promote positive attitudes toward learning (De Raad and Schouwenburg, 1996). However, extraverted students may also prioritize social activities over academic work, leading to mixed findings (Chamorro-Premuzic and Furnham, 2008). Meta-analyses suggest that extraversion's effect on academic achievement decreases with educational level (Poropat, 2009; Mammadov, 2022). Agreeableness has also shown weak but significant positive correlations with academic performance (De Feyter et al., 2012; Richardson et al., 2012). While agreeableness may enhance group-based learning and collaborative projects, its direct impact on individual academic achievement remains limited (Farsides and Woodfield, 2003).

These inconsistencies may be explained by evidence suggesting that associations of personality traits can vary across school subjects (Meyer et al., 2019; Brandt et al., 2020; Coenen et al., 2021). According to a number of studies, conscientiousness and emotional stability should improve performance more in maths than in languages (Beaujean et al., 2011; Heaven and Ciarrochi, 2012;

Meyer et al., 2019). This may be due to high conscientiousness being related to higher self-discipline, organization, and goal-orientation; attributes that facilitate effective study habits and higher performance (McCrae and John, 1992). Since languages demand and reward innovative and elaborate learning processes, openness to experience and extraversion, on the other hand, exhibit larger relationships with success in languages than in maths (Meyer et al., 2019; Brandt et al., 2020). However, there are no strong theoretical arguments or empirical data to support the idea that the (weak) correlations between agreeableness and performance would change depending on the subject of study (Brandt et al., 2020).

Similarly, when it comes to neuroticism and academic performance, the evidence is scarce and unspecific. Traditionally, high neuroticism is associated with poor academic outcomes due to increased stress, test anxiety, and emotional instability (Chamorro-Premuzic and Furnham, 2003). However, some positive effects have also been reported, particularly when students channel anxiety into increased effort (Lounsbury et al., 2005; De Feyter et al., 2012; Steele-Johnson and Leas, 2013).

1.4 State and trait mindfulness in STEM academic performance

Mindfulness refers to a cognitive and emotional state characterized by focused attention on present experiences, nonjudgmental awareness, and self-regulation of thoughts and emotions (Kabat-Zinn, 1994; Baer et al., 2006). It is commonly classified into two forms: trait mindfulness, a dispositional tendency to be mindful in daily life, and state mindfulness, a temporary and situation-dependent experience of heightened awareness (Indriaswuri et al., 2023). Trait mindfulness is often measured using self-report instruments such as the Five Facet Mindfulness Questionnaire (FFMQ), which assesses key components such as observing, describing, acting with awareness, non-judging, and nonreactivity (Alomari, 2023). In contrast, state mindfulness is typically evaluated through experimental paradigms, including guided mindfulness exercises and post-mindfulness induction assessments of attentional control (Butzer et al., 2015; Brahmi et al., 2025g).

Mindfulness has been extensively studied in relation to academic performance, with findings suggesting its indirect beneficial impact on cognitive flexibility, emotional regulation, and executive functioning (Mrazek et al., 2013; Geronimi et al., 2020). Empirical research has consistently linked higher levels of mindfulness—particularly acting with awareness and nonreactivity—to better academic outcomes (Alomari, 2023). The theoretical foundation for this association is rooted in cognitive theories of attention and metacognition, which propose that mindfulness enhances working memory capacity, reduces mind-wandering, and improves self-regulation, all of which contribute to effective learning and academic success (Moore and Malinowski, 2009; Mrazek et al., 2013; Koncz et al., 2021; Li et al., 2021). Studies have demonstrated that mindfulness training can significantly enhance executive functions, such as attentional control and cognitive flexibility, which are essential for academic achievement

(Mrazek et al., 2013; Caballero et al., 2019; Parsons et al., 2020; Miralles-Armenteros et al., 2021; Xu et al., 2022).

A modicum of research has explored the impact of mindfulness abilities on specific academic subjects, with an RCT by Bakosh et al. (2018) reporting a general improvement in academic attainment, with math scores showing the most substantial gains, followed by social science. However, the intervention did not significantly impact science, reading, or writing performance. Several studies have echoed improvements in mathematical ability across ages and measurement types, concluding that mindfulness practice indirectly improves mathematical proficiency by mitigating test anxiety, enhancing problem-solving ability, increasing self-efficacy, heightening emotional regulation, and improving cognitive resource allocation (Bellinger et al., 2015; Duraku et al., 2023; Zuo and Wang, 2023).

However, the relationship between mindfulness and academic success is not uniformly strong across all studies (Alomari, 2023; Verhaeghen, 2023). This discrepancy suggests that mindfulness alone may not be a direct predictor of achievement but rather a facilitator of cognitive and emotional processes that support learning. Additionally, individual differences in personality, motivation, and study habits may moderate the impact of mindfulness on academic outcomes (Sisk et al., 2018; Alzahrani et al., 2020; Lee and Park, 2022).

2 Materials and methods

2.1 Participants

Two samples were recruited in this study: sample 1 ($n = 580$) completed a series of self-report psychometric tests asynchronously online via Google Forms, while a smaller subset i.e., sample 2 ($n = 97$), participated in an in-person assessment in the laboratory at the Indian Institute of Technology, Delhi. Participants from both samples who completed the study received food coupons as a form of appreciation for their time and effort.

2.1.1 Sample 1

A total of 580 participants (291 females, 289 males) were recruited using purposive and snowball sampling techniques through the researchers' own university networks. They completed a total of four trait-based psycho-social self-report assessments, namely the Interpersonal Reactivity Index (IRI), Revised Portrait Values Questionnaire (PVQ-RR), Five Facet Mindfulness Questionnaire (FFMQ-39), and International Personality Item Pool Big-Five Factor Markers-50 (IPIP-BFM-50); in addition to providing high school STEM academic scores and their field of study at the university level (Table 1). Eligibility criteria required participants (mean age = 22.52 years; $SD = 4.45$ years) to be affiliated with any Indian university at various academic levels (bachelor's, master's, doctoral, post-doctoral) and self-disclose as proficient in English reading and comprehension since that was the medium of instruction throughout the study.

TABLE 1 Demographic breakdown of sample 1 with a detailed distribution of gender and academic choices among participants ($n = 580$), highlighting STEM and non-STEM backgrounds across high school and university education.

Groups		Counts	
		Male	Female
University academic choices	STEM	175	98
	Non-STEM	114	193
School academic choices	Science in 12th	232	164
	No science in 12th	57	127
School academic choices	Math in 12th	233	144
	No math in 12th	56	147

“University Academic Choices” refers to the student’s enrolled degree program at the time of the study. “School Academic Choices” refers to subjects completed in the Indian Grade 12 examinations. Counts represent the number of participants within each category, disaggregated by gender. Grade 10 subject choices are not listed, as under the Indian school system, all students complete both Mathematics and Science at this level (total: 291 females, 289 males).

2.1.2 Sample 2

A secondary sample of 97 participants were recruited from sample 1 who were available to participate in an in-person assessment and disclosed they had little-to-no prior familiarity with meditation practice (Brahmi et al., 2025f). Individually, each participant completed a 50-min novel breath-awareness meditation inspired by the established Ānāpānasati protocol, followed by the Amsterdam Resting-State Questionnaire (ARSQ-28) as a measure of state mindfulness (Brahmi et al., 2025c,d,f,g). The sample’s mean age was 24.59 years ($SD = 5.18$ years) and the sample was 64.94% from a STEM background. However, due to participant availability, this sample was predominantly male (90 males).

2.2 Measures

2.2.1 Early STEM academic proficiency

Participants were asked to self-disclose their final marks out of 100 for mathematics and science in grade 10 and, if applicable, mathematics, physics, and chemistry in grade 12 (Table 2). To assess the integrity of this data informing the respondent’s early STEM proficiency, reliability was analyzed via intra-academic score correlations, which were deemed sufficiently reliable with an average correlation strength (r_{mean}) of 0.638 for the 10 highly significant correlations ($p < 0.001$ for all). Internal consistency was also high (Cronbach’s $\alpha = 0.889$, McDonald’s $\omega = 0.892$), further reinforcing the integrity of self-reported academic scores, which showed strong intercorrelations (Brahmi et al., 2025f).

2.2.2 Empathy: interpersonal reactivity index

The Interpersonal Reactivity Index (IRI), developed by Davis (1980), is a widely used self-report measure of empathy comprising 28 items divided equally across four dimensions: Fantasy (FS), Perspective Taking (PT), Empathic Concern (EC), and Personal Distress (PD). Cognitive empathy (CE) is often represented by FS and PT, while affective empathy (AE) encompasses EC and PD

TABLE 2 Counts of self-reported high school scores in mathematics and science subjects segmented by gender and STEM/non-STEM university paths.

Highschool subject	University academic choice	Counts ($N = 580$)	
		Male	Female
10th science	STEM	175	98
	Non-STEM	114	193
10th math	STEM	175	98
	Non-STEM	114	193
12th math	STEM	162	79
	Non-STEM	71	66
12th physics	STEM	172	96
	Non-STEM	60	68
12th chemistry	STEM	172	96
	Non-STEM	60	68

Counts represent the number of participants reporting high school scores in the listed subjects, disaggregated by gender and university academic path. “STEM” refers to students enrolled in Science, Technology, Engineering, and Mathematics programs at the university level; “Non-STEM” refers to all other degree programs. Totals within rows are not intended to sum to $N = 580$, as counts are presented separately by subject and category.

(Dvash and Shamay-Tsoory, 2014; Brahmi et al., 2025a). Each item is rated on a five-point Likert scale ranging from “Does not describe me well” to “Describes me very well,” with subscale scores ranging from 0 to 28.

The IRI has demonstrated strong psychometric properties with its four-factor structure having been consistently employed across diverse populations, including in India (Gilet et al., 2013; Garcia-Barrera et al., 2017; Chan et al., 2021; Zhao et al., 2021; Gupta et al., 2022; Brahmi et al., 2024b, 2025e) with a test-retest reliability between 0.62 and 0.71 (Davis, 1980). Construct and content validity have been supported through significant correlations with other empathy measures and repeated expert reviews (Péloquin and Lafontaine, 2010). Its internal consistency is reportedly strong (Cronbach’s α typically ≥ 0.70 , often in the 0.80s) (Davis, 1983; Péloquin and Lafontaine, 2010), which has been echoed in the present sample (average Cronbach’s $\alpha = 0.685$, McDonald’s $\omega = 0.70$).

2.2.3 Values: portrait values questionnaire-revised

The Portrait Values Questionnaire-Revised (PVQ-RR) includes 57 items assessing 19 values based on Schwartz’s theory (Schwartz et al., 2012). Each value is measured by three items, rated on a 6-point scale from 1 (*not like me at all*) to 6 (*very much like me*). The scale has been adapted to include male and female versions to account for gender-specific language. The asymmetry of the response scale accounts for social desirability bias (Schwartz and Cieciuch, 2016; Brahmi et al., 2025a). Further, as a corrective centering measure, the computation of Schwartz’s values’ composite score involved subtracting each participant’s mean response from every rating to mitigate potential response bias.

The PVQ-RR shows strong reliability, with Cronbach's α exceeding 0.70 for the four higher-order values and an average of 0.76 for 10 basic values across 49 cultural groups (Schwartz and Cieciuch, 2022; Brahmi et al., 2024b). Similar strength was seen in the present study, with average Cronbach's α for the ten basic values being 0.721 and for the four highest values being 0.834 (McDonald's $\omega = 0.736$ and 0.837 , respectively). Structural equation modeling confirms its validity, with 18 of 19 values positively correlating with behaviors aligned to them (Schwartz and Butenko, 2014).

2.2.4 Personality: International Personality Item Pool Big-Five Factor Markers-50

The International Personality Item Pool Big-Five Factor Markers-50 (IPIP-BFM-50) is a widely utilized instrument designed to assess the Big Five personality dimensions: Extraversion, Agreeableness, Conscientiousness, Emotional Stability, and Openness to Experience (Goldberg, 1992; Brahmi et al., 2025a). This self-report questionnaire comprises 50 items, with 10 items dedicated to each personality trait. Respondents rate each item on a 5-point Likert scale, ranging from 1 (*disagree*) to 5 (*agree*), reflecting the degree to which each statement describes them.

The IPIP-BFM-50 has demonstrated robust psychometric properties across various cultural contexts. Construct and content validity have been demonstrated through significant correlations with comparable measures such as the NEO-FFI, NEO-PI-R, and BFI/BFI-2, as well as through expert ratings (Strus et al., 2014; Akhtar and Azwar, 2019; Hřebíčková et al., 2023). Test-retest reliability was reported between 0.78 to 0.87 (Hřebíčková et al., 2023). The internal consistency ranged from Cronbach's alpha 0.76 to 0.87 between multiple studies in different cultural contexts (Goldberg et al., 2006; Strus et al., 2014; Ypofanti et al., 2015; Akhtar and Azwar, 2019; Brahmi et al., 2025e). In the present study, the average Cronbach's $\alpha = 0.743$ and McDonald's $\omega = 0.755$, indicating acceptable internal consistency within the sample.

2.2.5 Trait mindfulness: five facet mindfulness questionnaire

The Five Facet Mindfulness Questionnaire (FFMQ-39) (Baer et al., 2006) assesses trait mindfulness across five facets: observing, describing, acting with awareness, non-judging, and nonreactivity. Items are rated on a 5-point Likert scale from 1 (*never or very rarely true*) to 5 (*very often or always true*).

The FFMQ-39 demonstrates strong psychometric properties, with Cronbach's α values ranging from 0.69 to 0.9 across subscales and test-retest reliability (ICCs = 0.61–0.84) (Veehof et al., 2011). Its construct validity is supported by correlations with psychological symptoms, well-being, and personality factors like neuroticism and openness to experience (Bohlmeijer et al., 2011; Veehof et al., 2011). Cross-cultural studies confirm its reliability, with Cronbach's α consistently exceeding 0.78 (Schmidt and Vinet, 2015; Khanjani et al., 2022; Brahmi et al., 2023). Widely used in clinical and research contexts, the FFMQ-39 is sensitive to changes in mindfulness, making it suitable for evaluating mindfulness-based interventions (Bohlmeijer et al., 2011). Its psychometric strength was also evidenced in the present sample with average Cronbach's α per dimension = 0.793 and McDonald's $\omega = 0.796$.

2.2.6 State mindfulness: Amsterdam resting-state questionnaire

The Amsterdam Resting-State Questionnaire (ARSQ) is a self-report instrument developed to assess individuals' mental experiences during periods of rest (Diaz et al., 2013; Brahmi et al., 2025a). The 28-items evaluate seven dimensions of resting-state cognition: Discontinuity of Mind, Theory of Mind, Self, Planning, Sleepiness, Comfort, and Somatic Awareness (Diaz et al., 2014; Brahmi et al., 2025a). Participants rate their agreement with each statement on a 5-point Likert scale, reflecting their thoughts and feelings during rest.

The internal consistency of the subscales is generally high, with Cronbach's alpha coefficients exceeding 0.75 for most factors, indicating good reliability. Test-retest correlations have also been reported as high both on short and long-term retesting (Diaz et al., 2013). Further validation studies have supported the ARSQ's factor structure and its applicability across different populations (Marchetti et al., 2015; Wang et al., 2022; Brahmi et al., 2025d). The current dataset maintained high reliability with average Cronbach's $\alpha = 0.704$ and McDonald's $\omega = 0.724$.

2.3 Procedure

The IRI, PVQ-RR, IPIP-BFM-50, and FFMQ were administered to sample 1 ($n = 580$). These measures were completed asynchronously online via a Google Form. Although no time limit was imposed, participants were instructed to complete the questionnaires in a single sitting without prolonged interruptions. To measure state mindfulness via the ARSQ, sample 2 ($n = 97$) underwent a breath-based meditation session in a silent and undisturbed laboratory setting. To begin in a stage of stress and cognitive workload, participants solved arithmetic problems for 30 min. The meditation paradigm involved three stages subsequently: a 5-min eye-closed resting state, followed by a 5-min breath counting period, and ending with an 8–10-min silent breath focus phase (Brahmi et al., 2024a, 2025g). After completion of the session, participants were immediately administered the ARSQ. Strict protocols were adhered to in order to maintain participant privacy and confidentiality, with informed consent obtained prior to participation. Ethical approval for the study was granted by the Institute Ethics Committee of the Indian Institute of Technology, Delhi (Proposal No. P021/P0101), in compliance with the ethical guidelines outlined by the Indian Council of Medical Research for research involving human participants.

2.4 Data analyses

To investigate the relationships between variables, a preliminary correlational analysis was conducted using Pearson's correlation. This analysis included academic scores across STEM subjects (i.e., 10th-grade and 12th-grade scores in math, science, physics, and chemistry) and the chosen psycho-social variables (i.e., empathy dimensions, values, mindfulness, and personality traits). Bonferroni corrections were applied to control for multiple comparisons, lowering the significance threshold to mitigate the

risk of Type I errors. Thereupon, hierarchical regression modeling was utilized following the identification of significantly correlated pairs of academic scores and psycho-social variables. Hierarchical regression was used to evaluate the incremental contribution of each variable to academic performance while controlling for potential confounders such as gender, STEM choice at the university level, and their interactions. The analysis followed a stepwise approach:

- Step 1: Control variables (gender, university STEM choice, and their interaction) were entered.
- Step 2: The same control variables as Step 1 and predictors of interest (e.g., empathy dimensions, values, mindfulness measures, personality) were added.

The unique contribution of each predictor was assessed using the change in R^2 , which quantified the additional variance explained by the predictors added in Step 2 in the following way:

$\Delta R^2 \% = (\text{Step 2: Variance in academic scores explained by gender, university STEM choice, gender-university STEM choice interaction, and preliminary correlation significant trait}) - (\text{Step 1: Variance in academic scores explained by gender, university STEM choice, and gender-university STEM choice interaction})$

Lastly, standardized beta coefficients (β) were used to interpret the strength and direction of relationships.

3 Results

3.1 Trait empathy and early STEM proficiency

The exploration of empathy's role in early STEM proficiency began with a preliminary correlational analysis to identify significant relationships between empathy dimensions and STEM subjects. After applying Bonferroni corrections to adjust for multiple comparisons, the significance threshold was reduced to 0.0056. This rigorous adjustment ensured that only robust correlations were considered for further investigation. Among the empathy facets, Perspective-Taking (PT), Total Empathy (TE), Other-Focused Empathy (OE), and Cognitive Empathy (CE) emerged as significantly correlated with 10th-grade science scores. Specifically, PT ($r = 0.146$), TE ($r = 0.145$), OE ($r = 0.158$), and CE ($r = 0.138$) showed modest yet meaningful relationships with science proficiency. While Empathic Concern (EC) demonstrated a weak correlation, it did not remain significant after corrections, but was combined with PT for further analysis.

Building on the correlational findings, hierarchical regression analyses were conducted to assess the independent predictive value of empathy dimensions on early STEM proficiency while controlling for gender, university STEM choice, and their interactions. This stepwise approach allowed for a clear evaluation of the variance explained by empathy dimensions beyond the baseline effects of contextual factors. Across the models, the hierarchical regression analyses demonstrated that selected empathy dimensions contributed small but significant amounts of variance to 10th-grade science scores. These findings highlight

the modest yet meaningful role of cognitive and other-focused empathy in early STEM proficiency, even after accounting for the strong influences of university STEM choice and the interaction between gender and STEM. The analyses collectively suggest that empathy provides some incremental value in understanding early STEM proficiency, particularly in science-focused contexts (Table 3).

3.2 Values and early STEM proficiency

The investigation into the role of values in early STEM proficiency utilized Schwartz's values framework, with an initial focus on correlations to determine significant relationships. The analysis covered higher-order quadrants, basic values, and narrowly defined values to provide a nuanced understanding of how values influence early STEM proficiency. Bonferroni corrections were applied to account for multiple comparisons, setting more stringent thresholds for significance depending on the level of analysis (0.0125 for quadrants, 0.005 for basic values, and 0.003 for narrowly defined values). This approach ensured that only the most robust correlations were considered.

At the quadrant level, Openness to Change (OP2C) demonstrated a small but significant positive correlation with 10th-grade science scores ($r = 0.124$). Within the basic values, Self-Direction (SD) showed significant positive correlations with both 10th-grade science ($r = 0.162$) and 12th-grade physics scores ($r = 0.154$). At the narrowly defined level, Self-Direction Thought (SDT) exhibited significant positive relationships with 10th-grade science scores ($r = 0.171$), and Self-Direction Action (SDA) exhibited significant positive relationships with 12th-grade physics scores ($r = 0.163$), while Power-Resources (POR) showed a small negative correlation with 10th-grade math scores ($r = -0.146$). Further, across the hierarchical regression models, values such as SD and SDT consistently showed a modest yet significant positive variance in science-based academic performance, explaining small but meaningful proportions of variance. These results underscore the importance of values that emphasize autonomy and intellectual exploration in fostering academic success. Conversely, values linked to power and resource acquisition (POR) appeared to have a negative impact on performance, particularly in math-focused subjects (Table 4).

3.3 Personality traits and early STEM proficiency

The relationship between personality traits and early STEM proficiency was analyzed to understand how individual differences contribute to achievement in various subjects. Preliminary correlations highlighted a significant positive relationship between Openness to Experience (OC) and 10th-grade science scores. After applying Bonferroni corrections, this finding remained robust ($r = 0.179, p < 0.01$).

Hierarchical regression analyses to determine the unique variance explained by OC while controlling for gender, university STEM choice, and their interactions found that

TABLE 3 Incremental variance explained by empathy dimensions in predicting academic performance, controlling for gender, and university STEM status.

Model	Standardized beta coefficient (β)						
	Step 1 R ² (%)	Step 2 R ² (%)	Δ R ² (%)	Empathy facet	Gender	STEM	Gender X STEM
10th-grade science academic scores							
EC+PT	11.3***	13.7***	2.38***	0.0761, 0.1045*	0.0111	−0.8398***	0.346*
OE	11.3***	13.7***	2.38***	0.1568***	0.00706	−0.83987***	0.34466*
CE	11.3***	12.6***	1.28**	0.1145**	0.0199	−0.8321***	0.366*
TE	11.3***	12.7***	1.42**	0.12366**	0.00322	−0.82338***	0.34379*

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
 Δ R² % = (Step 2: Variance in 10th-Grade Science academic scores explained by gender, university STEM choice, gender-university STEM choice interaction, and empathy dimension) - (Step 1: Variance in 10th-Grade Science academic scores explained by gender, university STEM choice, and gender-university STEM choice interaction). (GENDER and STEM variables imply “Males minus Females” and “Non-STEM minus STEM”, respectively).
EC, Empathic Concern; PT, Perspective-Taking; TE, Total Empathy; OE, Other-Focused Empathy; CE, Cognitive Empathy.

TABLE 4 Incremental variance explained by value dimensions in predicting academic performance, controlling for gender, and university STEM status.

Model	Standardized beta coefficient (β)						
	Step 1 R ² (%)	Step 2 R ² (%)	Δ R ² (%)	Value	Gender	STEM	Gender X STEM
10th-grade science academic scores							
OP2C	11.3***	12.8***	1.47**	0.1225**	0.0057	−0.8589***	0.3943*
SD	11.3***	14.8***	3.49***	0.1899***	0.0115	−0.8802***	0.396*
SDT	11.3***	15.1***	3.81***	0.1975***	0.0172	−0.8833***	0.3699*
SDA	11.3***	13***	1.67***	0.1302***	0.0217	−0.8676***	0.38*
10th-grade math academic scores							
POR	11.3***	12.2***	0.982*	−0.101*	−0.117	−0.798***	0.334*
12th-grade physics academic scores							
SD	8.76***	11.35***	3.49***	0.1886***	−0.0968	−0.7986***	0.2941
SDA	8.76***	11.81***	3.04***	0.1751***	−0.0912	−0.7703***	0.2946

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
 Δ R² % = (Step 2: Variance in 10th-Grade Science/10th-Grade Math/12th-Grade Physics academic scores explained by gender, university STEM choice, gender-university STEM choice interaction, and value dimension) - (Step 1: Variance in 10th-Grade Science/10th-Grade Math/12th-Grade Physics academic scores explained by gender, university STEM choice, and gender-university STEM choice interaction). (GENDER and STEM variables imply “Males minus Females” and “Non-STEM minus STEM”, respectively).
OP2C, Openness to Change; SD, Self-Direction; SDT, Self-Direction Thought; SDA, Self-Direction Action; POR, Power-Resources.

OC had a small but significant predictive value on 10th-grade science scores, accounting for an additional proportion of variance beyond the baseline effects of contextual factors (Table 5).

3.4 Mindfulness and early STEM proficiency

The examination of mindfulness in early STEM proficiency focused on both trait and state mindfulness dimensions, as measured distinctly in samples one and two, respectively. Correlations were examined to uncover significant relationships with Bonferroni corrections applied to account for multiple comparisons, setting thresholds at 0.008 for trait mindfulness and 0.006 for state mindfulness. These adjustments ensured robust findings. Only state

mindfulness, specifically the Planning (PLN) dimension, exhibited significant positive correlations with 12th-grade physics ($r = 0.344$), chemistry ($r = 0.340$), and math scores ($r = 0.416$).

Building on these correlations, hierarchical regression analyses demonstrated that PLN contributed significantly to variance in 12th-grade STEM academic scores, even after accounting for gender, university STEM choice, and their interactions. Across the models, PLN consistently emerged as a significant predictor, explaining a meaningful proportion of variance in physics, chemistry, and math scores (Table 6). The findings indicate that an over-dependence on planning abilities may impede optimal state mindfulness, subsequently affecting the cultivation of improved trait mindfulness among individuals proficient in STEM subjects. Thus, mindfulness sessions aimed at improving situational focus may enhance

TABLE 5 Incremental variance explained by personality traits in predicting academic performance, controlling for gender, and university STEM status.

Model	Standardized beta coefficient (β)						
	Step 1 R ² (%)	Step 2 R ² (%)	Δ R ² (%)	OC	Gender	STEM	Gender X STEM
10th-grade science academic scores							
OC	11.3***	14.8***	3.47***	0.1866***	0.195	−0.8702***	0.3989*

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
 Δ R² % = (Step 2: Variance in 10th-Grade Science academic scores explained by gender, university STEM choice, gender-university STEM choice interaction, and personality trait-openness to experience) - (Step 1: Variance in 10th-Grade Science academic scores explained by gender, university STEM choice, and gender-university STEM choice interaction). (GENDER and STEM variables imply “Males minus Females” and “Non-STEM minus STEM”, respectively).
OC, Openness to Experience.

TABLE 6 Incremental variance explained by state mindfulness in predicting academic performance, controlling for gender, and university STEM status.

Model	Standardized beta coefficient (β)						
	Step 1 R ² (%)	Step 2 R ² (%)	Δ R ² (%)	PLN-AVG	Gender	STEM	Gender X STEM
12th-grade physics academic scores							
PLN	15**	26***	11***	0.333***	0.247	−0.864***	1.058
12th-grade chemistry academic scores							
PLN	15.3**	26***	10.7***	0.3287***	0.0769	−0.8827***	1.3167
12th-grade math academic scores							
PLN	22.4***	38.7***	16.3***	0.405***	0.36	−1.052***	0.314
12th-grade physics-chemistry-math combined average academic scores							
PLN	16.9**	31.6***	14.6***	0.384***	0.239	−0.938***	0.888

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
 Δ R² % = (Step 2: Variance in 12th-Grade Physics/12th-Grade Chemistry/12th-Grade Math/12th-Grade Physics-Chemistry-Math Combined Average academic scores explained by gender, university STEM choice, gender-university STEM choice interaction, and state mindfulness dimension-planning) - (Step 1: Variance in 12th-Grade Physics/12th-Grade Chemistry/12th-Grade Math/12th-Grade Physics-Chemistry-Math Combined Average academic scores explained by gender, university STEM choice, and gender-university STEM choice interaction). (GENDER and STEM variables imply “Males minus Females” and “Non-STEM minus STEM”, respectively).
PLN, Planning.

meditation performance among students skilled in cognitively demanding STEM disciplines.

complexity of early STEM proficiency as a multidimensional construct influenced by both psychosocial dispositions and contextual dynamics.

4 Discussion

This study examined the role of psychosocial factors—trait empathy, personal values, mindfulness, and personality—in predicting early STEM proficiency, operationalized through high school science and mathematics performance. Emerging research has suggested that psychosocial attributes collectively influence STEM domains by impacting critical learning processes such as self-regulation, motivation, and problem-solving (Black et al., 2021; Kazu and Yalçın, 2021; Chitra, 2024; Doly, 2024; Nhat et al., 2024). Anchored in contemporary holistic educational frameworks that emphasize social-emotional learning and whole-person development, our approach sought to examine whether these aforementioned psychosocial dispositions contribute meaningfully to academic outcomes (Brahmi et al., 2025b; Chatterjee et al., 2020; Brush et al., 2022). While our results revealed nuanced and modest relationships across these psychosocial factors; collectively, they underscore the

4.1 Empathy’s role in early STEM performance

The relationship between empathy and early STEM proficiency emerged as multifaceted, reflecting the multidimensional nature of trait empathy. Cognitive empathy, particularly Perspective-Taking (PT), demonstrated a modest positive relationship with 10th-grade science scores. This suggests that the ability to adopt others’ viewpoints may facilitate academic engagement and collaborative learning, especially in subjects requiring critical thinking and problem-solving (Maiorca et al., 2021; Nalipay et al., 2023). Interestingly, Other-Focused Empathy (OE) and Total Empathy (TE) also showed positive associations with academic outcomes, indicating that empathetic students may benefit from enhanced peer interactions and cooperative learning environments (Onwubiko, 2020). However, these findings contrast

with studies like Kim (2024), which reported negative correlations between affective empathy and academic performance, indicating potential cultural and contextual differences in how empathy manifests in academic settings. Lastly, empathic traits contributed only a modest incremental variance to STEM-focused academic performance beyond gender and university STEM choice. The mixed results in the literature thus underscore the need for future studies to consider potential moderating variables, such as emotional regulation skills, which may influence the adaptive or maladaptive effects of empathy on STEM-focused academic outcomes.

4.2 Associative power of values with early STEM proficiency

The role of personal values in early STEM proficiency, explored through Schwartz's value framework, highlighted the significance of self-direction and openness to change as facilitators of STEM-based academic success (Schwartz, 1992, 2012). Self-Direction Thought (SDT) and Self-Direction Action (SDA) emerged as mild positive correlates, particularly with science-based subjects, supporting previous findings that link autonomous learning and intellectual curiosity to higher academic achievement (Liem et al., 2011; Petersen and Hyde, 2017; Vecchione and Schwartz, 2022; Zhang et al., 2022). Additionally, the weak association between the Openness to Change quadrant and academic scores might further reinforce the notion that flexibility and a willingness to explore new ideas enhance learning outcomes (Hofer et al., 2011; Tarabashkina and Lietz, 2011). Conversely, Power-Resources (POR) showed a small negative association with 10th-grade math scores, suggesting that values centered on control and resource acquisition may detract from sustained academic effort, potentially due to a focus on extrinsic rather than intrinsic motivations (Hofer et al., 2011; Tarabashkina and Lietz, 2011).

The nuanced effects of values on early STEM proficiency underscore the importance of value congruence within educational environments. For instance, structured academic settings may favor students who endorse conformity values, while inquiry-based learning may benefit those aligned with self-direction (Beyaztaş and Senemoglu, 2015; Dignath and Büttner, 2018; Sebial and Mirasol, 2023). These findings offer valuable insights for educators aiming to foster value-aligned pedagogical strategies that support diverse student motivations.

4.3 Personality traits' impact on early STEM-based academic outcomes

The associative power of Openness to Experience (OC) on early STEM proficiency aligns with prior meta-analytic findings highlighting its role in fostering intellectual engagement and curiosity (Bidjerano and Dai, 2007; Caprara et al., 2011; McAbee and Oswald, 2013). The absence of significant findings for traits like neuroticism and agreeableness mirrors previous research indicating that their influence on academic outcomes is often context-dependent (De Feyter et al., 2012; Richardson et al., 2012).

Additionally, these findings, being science-specific, lend to the evidence that associations may be subject-specific and OC may have less predictive value on purely arithmetic subjects (Brandt et al., 2020; Meyer et al., 2019).

These results contribute to the broader discourse on personality-STEM performance linkages by reaffirming the importance of openness while also highlighting the need for future studies to explore potential interaction effects among personality traits. For instance, the combination of high openness and conscientiousness may yield synergistic benefits for academic success, a hypothesis supported by dual-trait models of academic achievement (Chamorro-Premuzic and Furnham, 2008). Additionally, cross-cultural findings suggest that personality-academic performance relationships may be moderated by cultural factors, with Asian samples demonstrating stronger correlations than their North American and Western European counterparts (Mammadov et al., 2021). However, given the small proportion of Asian samples in prior meta-analyses, further research is needed to disentangle potential cultural influences.

4.4 Mindfulness's role in early STEM performance

The findings related to mindfulness, particularly state mindfulness as measured by the Planning (PLN) dimension of the ARSQ, revealed significant positive associations with 12th-grade scores in physics, chemistry, and mathematics. Considering that STEM disciplines require sustained cognitive effort and complex problem-solving, these results suggest that care must be taken toward STEM students' distinct analytical and focused cognitive demands. The holistic mindfulness interventions for these students, therefore, must be tailored for attenuation of 'analysis-paralysis' ridden overemphasized planning faculty (Talbert, 2017) in the science-proficient, especially, whilst ensuring to safeguard their curious inquisitiveness (Carsley et al., 2017). The absence of significant findings for trait mindfulness highlights the complex nature of its influence on academic performance. While certain facets, such as acting with awareness and nonreactivity, have shown positive associations with academic outcomes (Alomari, 2023), the overall impact appears modest (Verhaeghen, 2023). This discrepancy suggests that situational mindfulness, rather than dispositional tendencies, may exert a more direct effect on performance, particularly in task-specific contexts.

5 Conclusion

This study provides an empirical picture of the associative role of holistic educational psychosocial factors toward early STEM academic achievement. While traditional models have emphasized cognitive determinants, our findings highlight the incremental contributions of empathy, values, personality, and mindfulness to early STEM proficiency. Cognitive empathy was positively associated with STEM success, suggesting that perspective-taking skills might enhance collaborative learning and problem-solving. This aligns with research on social cognition's role in STEM engagement, though mixed findings on affective empathy

warrant further study. Similarly, self-direction and openness to change associated with academic success, highlighting the role of intrinsic motivation. In contrast, power-related values negatively correlated with math performance, suggesting that extrinsic motivation linked to dominance may hinder sustained academic effort. These findings support the importance of self-regulated learning and self-efficacy in STEM achievement. When it came to personality, openness to experience was significantly associated with science performance, emphasizing its role in intellectual engagement. Finally, mindfulness related to planning was significantly linked to STEM achievement, highlighting the necessity for specific mindfulness interventions to reduce unnecessary cognitive resource allocation to forethought in meditative contexts.

While the observed associations between psychosocial traits and STEM achievement were modest, they align with contemporary Social and Emotional Learning (SEL) frameworks that view learning as a multidimensional process shaped by emotional, ethical, and dispositional capacities (Chatterjee et al., 2020; Brush et al., 2022). In this context, even subtle trait–academic links are meaningful, particularly for informing holistic education policies such as India's National Education Policy (NEP 2020) and global initiatives like UN Sustainable Development Goal 4.7, which emphasize emotional development, character education, and inclusive growth (United Nations Educational, Scientific and Cultural Organization, 2016; Ministry of Human Resource Development, 2018). These results add to the growing body of evidence supporting an integrative model of academic development that extends beyond cognitive ability alone.

These findings have potential implications for education policy and curriculum development, as well as extend to mental health professionals and educators. Fostering adaptive traits, such as balanced cognitive empathy and self-direction, may not only enhance learning but also mitigate stress and anxiety among students—a crucial consideration for stakeholders of student mental health care. Furthermore, the observed associations suggest that targeted interventions, such as mindfulness-based programs and resilience training (Goswami et al., 2024), could serve as dual-purpose strategies, improving both academic outcomes and psychological well-being. By fostering a balanced development of cognitive and non-cognitive skills, educators can better prepare students for the complexities of an increasingly technology-driven world that requires a more holistic education.

5.1 Limitations and future directions

The reliance on self-reported academic data and a cross-sectional design warrants a cautious interpretation of causality, emphasizing the need for longitudinal research and the incorporation of objective academic metrics. Additionally, cultural nuances and individual differences in coping and emotional regulation suggest that future investigations should explore these dynamics across diverse populations and educational contexts. Future studies may also benefit from incorporating formal assessments of variables such as socioeconomic status, mental health, and language proficiency to enhance generalizability.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Institutional Ethics Committee of the Indian Institute of Technology, Delhi (IEC-IITD; Proposal No. P021/P0101). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. DS: Conceptualization, Data curation, Resources, Writing – review & editing. HJ: Validation, Writing – original draft, Writing – review & editing. JK: Resources, Supervision, Writing – review & editing.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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