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Inventory of Mathematics Attitudes for STEM University Students: An Example of Engineering Courses

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ABSTRACT

Background: Students' attitudes toward mathematics are a fundamental factor in their academic progress and performance. In this context, it is important to rely on reliable instruments capable of capturing these attitudes, such as the Attitudes Toward Mathematics Inventory (ATMI), which consists of 49 items and is designed to measure six psychological dimensions. **Objectives**: We present an instrument developed by researchers from Brazil and the Czech Republic to identify mathematical self-efficacy and anxiety. First, we want to test the statistical validity of this instrument, based on the ATMI and adapted to the context of university education. Then, we use it to assess the mathematical attitudes of engineering students at a university in Brazil. **Design**: We adapted and validated a 20-item version of the Attitudes Toward Mathematics Inventory (ATMI), using a five-point Likert scale ranging from "strongly disagree" to "strongly agree." We conducted an Exploratory Factor Analysis (EFA) using SPSS 22 software, and obtained results regarding the self-efficacy and anxiety of the studied population. **Setting and Participants**: The study was conducted with 323 first-year undergraduate STEM students at the University of Campinas in Campinas, SP, who responded freely to the questionnaire presented. **Data collection and analysis**: Data were obtained from responses to the questionnaire used in this study, comprising 20 Likert-scale items ranging from "strongly disagree" to "strongly agree". We then conducted an exploratory factor analysis (EFA) using SPSS version 22. **Results**: The instrument demonstrated high reliability (Cronbach's alpha = .91). The method indicates that the factors are independent, suggesting that the methodological processes were aimed at understanding how these emotional and cognitive factors influence student success and professional identity. Computer Engineering students demonstrated a high level of self-efficacy. Simultaneously, the students of Food Engineering exhibited lower levels of self-efficacy and higher levels of anxiety, suggesting disengagement with mathematics. **Conclusions**: The ATMI is a reliable and efficient instrument for measuring mathematical attitudes, providing an important tool for future research in engineering

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curricula. Our results are consistent with the pattern that mathematical self-efficacy and anxiety are inversely related.

Keywords: Mathematical attitude, psychometry, ATMI, anxiety, self-efficacy.

Inventário de Atitudes em Matemática para Estudantes Universitários de STEM: Um Exemplo de Cursos de Engenharia

RESUMO

Contexto: A atitude dos estudantes em relação à matemática é um fator fundamental para o progresso e o desempenho acadêmico. Nesse contexto, é importante contar com instrumentos confiáveis capazes de captar essas atitudes, como o *Attitudes Toward Mathematics Inventory* (ATMI), que consiste em 49 itens, projetado para medir seis diferentes dimensões psicológicas. **Objetivos**: Apresentamos um instrumento desenvolvido por pesquisadores do Brasil e da República Tcheca para identificar a autoeficácia matemática e a ansiedade. Primeiro, buscamos testar a validade estatística desse instrumento, com base no ATMI, adaptado ao contexto do ensino superior. Em seguida, utilizamo-lo para avaliar as atitudes matemáticas de estudantes de engenharia de uma universidade no Brasil. **Design**: Adaptamos e validamos uma versão de 20 itens do *Attitudes Toward Mathematics Inventory* (ATMI), utilizando uma escala Likert de cinco pontos, variando de “discordo totalmente” a “concordo totalmente”. Realizamos uma Análise Fatorial Exploratória (AFE) no software SPSS 22 e obtivemos resultados sobre a autoeficácia e a ansiedade da população estudada. **Ambiente e participantes**: O estudo foi conduzido com 323 estudantes de primeiro ano de graduação na área de STEM da University of Campinas, em Campinas, SP, que responderam livremente ao questionário apresentado. **Coleta e análise de dados**: Os dados foram obtidos a partir das respostas ao questionário deste estudo, com 20 itens em escala Likert, variando de “discordo totalmente” a “concordo totalmente”. Em seguida, realizamos uma análise fatorial exploratória (AFE) no SPSS 22. **Resultados**: O instrumento demonstrou alta confiabilidade (alfa de Cronbach = 0,91). O método indica a independência dos fatores, sugerindo que os procedimentos metodológicos foram direcionados à compreensão de como esses fatores emocionais e cognitivos influenciam o sucesso dos estudantes e sua identidade profissional. Estudantes de Engenharia de Computação apresentaram um alto nível de autoeficácia. Simultaneamente, os estudantes de Engenharia de Alimentos apresentaram níveis mais baixos de autoeficácia e níveis mais elevados de ansiedade, sugerindo um afastamento em relação à matemática. **Conclusões**: A adaptação do ATMI é um instrumento confiável e eficiente para medir atitudes matemáticas, fornecendo uma ferramenta importante para pesquisas futuras sobre currículos de engenharia. Nossos resultados são consistentes com o padrão de que a autoeficácia matemática e a ansiedade estão inversamente relacionadas.

Palavras-chave: Atitude matemática, psicometria, ATMI, ansiedade, autoeficácia.

INTRODUCTION

Interest in the mental health and well-being of university students has grown over the past few decades (Hernández-Torrano et al., 2020). Well-being, encompassing both mental and physical health, is important for academic performance (Ball et al., 2024). The literature shows that students' well-being is a significant and interrelated factor in addressing their academic, emotional, and social needs (Kutsyuruba et al, 2015). This meta-analysis also highlighted the necessity of a comprehensive approach to monitoring, evaluating, and addressing various elements of the educational environment.

A key determinant of students' well-being and academic achievements is their attitude towards the subject of study, specifically mathematics, in this context. Han and Carpenter (2014) define attitudes as a combination of cognitive, affective, and behavioural responses that individuals show towards an object or environment based on their feelings or interests. Research shows that students with positive attitudes towards mathematics tend to perform better academically than those with negative attitudes (e.g., Mazana et al., 2019; Nicolaidou & Philippou, 2003). On the other hand, negative attitudes towards mathematics are often associated with lower performance and may function as barriers to effective learning (Zan & Di Martino, 2007).

Given the above, it is essential to utilise reliable tools to assess students' attitudes towards mathematics. Various instruments have been used, such as the Fennema-Sherman Mathematics Attitudes Scales (FSMAS), Aiken’s Math Attitude Scale, and the Attitudes Toward Mathematics Inventory (ATMI). Most studies, however, use adapted or bespoke scales (Wen & Dubé, 2022). This research adopts the ATMI questionnaire developed by Tapia and Marsh (2004). The original ATMI consists of 49 items designed to measure high school students' attitudes towards mathematics across six dimensions: Confidence, Anxiety, Value, Enjoyment, Motivation, and Parent/Teacher Expectations.

Responses to the ATMI using a five-point Likert scale ranging from "strongly disagree" to "strongly agree." After first testing, the Anxiety and Confidence factors were merged into a single dimension, while the Parent/Teacher Expectations factor was excluded (Tapia, 1996; Tapia & Marsh, 2004). Consequently, the questionnaire typically focuses on four domains:

- Confidence/Anxiety
- Value
- Enjoyment

- Motivation

Research has consistently shown a positive correlation between students' mathematics performance and their ATMI scores (Dorji & Dorji, 2021). Moreover, many studies have confirmed the ATMI across various cultural settings and languages (Suherman & Vidákovich, 2022; Khun-inkeeree & Fauzee, 2020).

The ATMI, designed for high school students, can be adapted for university contexts (Jancarik et al., 2023; Primi et al., 2020; Segarra & Julià, 2022). Efforts were made to develop shorter versions of the ATMI. Majeed et al. (2013) validated a 32-item version, and Lim and Chapman (2013) developed a concise 19-item version that can be completed in 10 minutes.

In the context of research on the relationship between mathematical attitudes and vocational training, this article outlines the development of a shortened version of the ATMI questionnaire for the university setting. With this new instrument, we aim to investigate the mathematical attitudes of students entering the State University of Campinas, specifically in the STEM (Science, Technology, Engineering, and Mathematics) fields. This article presents a section of a broader study on the subject, in which we use the context of engineering students to illustrate the shortened inventory's potential.

THE ROLE OF STEM EDUCATION IN ENGINEERING: MATHEMATICS, SELF-EFFICACY, AND ANXIETY

The field of STEM Education (Science, Technology, Engineering, and Mathematics) has offered valuable contributions to the discussion surrounding engineering education. The primary focus of STEM education is disciplinary integration, which involves teaching concepts in an interconnected, context-rich manner rather than in isolation. This approach is particularly relevant to the role of mathematics in engineering.

Integrating mathematics into engineering projects helps students view mathematics not as an abstract discipline, but as an important tool for solving real problems (Bybee, 2013). Rather than learning physics and calculus equations in separate classes, STEM education approaches learning by tackling an engineering challenge that requires the simultaneous application of both. This approach not only reinforces conceptual understanding but also boosts student motivation and engagement.

Given that mathematical knowledge is a structural element of any engineering curriculum, it is crucial to consider the transition from secondary school to university. This initial disconnect can lead to frustration and affect academic progression and student retention (Johnson et al., 2020). Over the years, research on professional training has provided significant insights into dropout rates (Gomes et al., 2019). The reasons that lead students to opt for early withdrawal from the course stem from both academic issues — such as the difficulties encountered in subjects like Calculus and Introductory Physics (Redish & Kou, 2015; Gomes et al., 2019).

Furthermore, STEM education emphasises the development of 21st-century skills, such as critical thinking, collaboration, and creativity, which are essential for professional engineering practice. Research in that project-based and inquiry-based learning approaches strengthen students' self-efficacy and reduce Anxiety, as they feel more in control of their own learning (Johnson et al., 2020). This methodology fosters a "calculated risk" environment in which failure is an integral part of the discovery process.

Collaboration on STEM projects is an effective way to reduce mathematics anxiety. By working in groups, students can share the cognitive load and learn from their peers, thereby alleviating individual pressure and strengthening collective self-efficacy. The exchange of ideas and joint problem-solving fosters a sense of community and mutual support, which serve as powerful antidotes to Anxiety (Becker & Park, 2011).

In summary, transitioning to an engineering education model that incorporates STEM principles may be a promising path forward. By promoting knowledge integration, project-based learning, and collaboration, it is possible not only to strengthen future engineers' mathematical knowledge but also to cultivate their self-efficacy and build the emotional resilience needed to face the challenges of their careers.

Beyond technical knowledge, mathematical self-efficacy emerges as a crucial predictor of academic success. Studies have shown that a student's belief in their ability to perform mathematical tasks is a strong predictor of performance (Zhang Zhao & Kong, 2019). Students with high self-efficacy are more willing to take on challenges and consequently achieve better results. Conversely, low self-efficacy can lead students to drop out of modules and, in extreme cases, leave the course altogether. Smith (2021) discusses how developing self-efficacy through methodologies such as problem-based learning is an essential strategy for success in engineering programs.

However, we cannot overlook mathematics anxiety, a widely documented phenomenon (Hembree, 1990; Gresham, 2007; Hannula, Pantziara

& Di Martino, 2018; Wang et al., 2020). This feeling of tension and apprehension can significantly impair performance, regardless of a student's intrinsic ability. Leppävirta (2011) demonstrate that Anxiety hinders access to working memory, rendering reasoning and the application of concepts more challenging. Combating this Anxiety requires innovative pedagogical approaches that create safer, less punitive learning environments where mistakes are seen as part of the process.

Engineering education continues to have the challenge of preparing professionals who not only possess technical fundamentals but also possess the cognitive skills and resilience necessary to drive innovation. In the centre of this training is mathematics, the fundamental language of engineering thought.

In this context, we present an instrument developed by researchers from Brazil and the Czech Republic to identify mathematical self-efficacy and anxiety. This inventory is based on the ATMI and consists of a shorter instrument that facilitates data collection and, most importantly, is adapted to the context of university education.

DEVELOPMENT OF A REDUCED ATMI

The original ATMI, as noted, consisted of 40 items designed to identify four primary factors associated with mathematical self-efficacy. Tapia and Marsh's (2004) original findings, based on a sample of 545 high school students, yielded a Cronbach's Alpha reliability score of 0.97. The questionnaire was later translated into Czech and adapted for use in university-level STEM courses at a large public university in the Czech Republic between 2022 and 2023. Data from this adaptation found four factors within the ATMI: Self-Confidence, Anxiety, Value, and Enjoyment/Motivation (Jancarik et. al., 2023).

In contrast to the original findings, Jancarik et al. (2023) observed a significant difference between Self-Confidence and Anxiety, as indicated by their correlation coefficients. Additionally, could not distinctly distinguish the Enjoyment and Motivation factors. These variations likely reflect differences between the target population and the original study. Building on these findings, the present research seeks to develop a reduced version of the ATMI tailored specifically for university-level STEM courses, drawing on the work of Jancarik et al. (2023), Primi et al. (2020), and Segarra and Julià (2022).

Finding Anchor Questions for the ATMI

The first step in this process involved analysing the original data from Jancarik et al. (2023). Five items with the highest factor loadings within each domain were selected, as shown in Table 1.

Table 1

Anchor questions for reducing questionnaires.

Factor	Questions
Motivation/Enjoyment	Q26, Q29, Q32, Q28, Q2
Self-Efficacy	Q13, Q11, Q10, Q12, Q16
Anxiety	Q17, Q19, Q18, Q23, Q21
Value	Q6, Q5, Q1, Q39, Q8

Using these selected items, we created a new dataset from the responses of university students. We recalculated Cronbach's alpha coefficients for the revised questionnaire and conducted an Exploratory Factor Analysis (EFA) to assess consistency across the identified domains.

After identifying the anchor questions, they were adapted to the research context and translated into Portuguese. Thus, the new inventory is presented in Table 2.

Table 2

New Inventory to Mathematics Attitudes for STEM University Students (ATMI-20).

Question	English	Portuguese
Q1	I want to develop my mathematical skills.	Quero desenvolver minhas habilidades matemáticas.
Q2	I enjoy solving new mathematical problems.	Gosto de resolver novos problemas de matemática.
Q3	I enjoy incorporating more mathematics into my studies.	Gosto mais de matemática nos meus estudos.

Q4	I really enjoy mathematics.	Eu realmente gosto de matemática.
Q5	I want to take more mathematics-related courses.	Eu gostaria de cursar mais disciplinas de matemática.
Q6	I feel uncomfortable when thinking about mathematics.	Eu me sinto desconfortável ao pensar em matemática.
Q7	Learning mathematics makes me nervous.	Aprender matemática me deixa nervoso.
Q8	I feel uncomfortable using mathematics.	Eu me sinto desconfortável ao utilizar a matemática.
Q9	I feel terribly tense when using mathematics.	Eu me sinto terrivelmente tenso ao utilizar matemática.
Q10	I am afraid of mathematics.	Eu tenho medo de matemática.
Q11	I am incredibly confident in my ability to use mathematics.	Eu tenho muita confiança em usar a matemática.
Q12	I solve mathematical problems without difficulty.	Resolvo problemas de matemática sem dificuldade.
Q13	I perform well in mathematics-related subjects.	Tenho bom desempenho em disciplinas de conteúdos matemáticos.
Q14	I feel confident when solving mathematical problems.	Sinto-me seguro ao resolver problemas matemáticos.
Q15	I am confident in my ability to study advanced mathematics.	Tenho confiança em estudar matemática avançada.
Q16	Mathematical concepts are essential.	Conteúdos matemáticos são muito necessários.
Q17	Mathematics is used in different contexts.	A matemática é utilizada em diferentes contextos.
Q18	Mathematics is important for everyday life.	A matemática é importante para a vida cotidiana.

Q19	Mathematics is one of the most important fields we have at university.	A matemática é uma das áreas mais importantes que temos na universidade.
Q20	Mathematics is used outside the school context.	A matemática é utilizada fora do contexto escolar.

Exploratory Factor Analysis Results

Table 3 presents the results of the Exploratory Factor Analysis (EFA) conducted on the 20 selected items of the ATMI.

Table 3

An Exploratory Factor Analysis (EFA) was conducted on the 20 selected items of the ATMI.

Item	Factor 1	Factor 2	Factor 3	Factor 4	Communality
Q32	0.733	0.228	0.259	0.280	0.715
Q26	0.722	0.189	0.247	0.216	0.641
Q2	0.717	0.214	0.139	0.329	0.689
Q28	0.711	0.322	0.171	0.240	0.672
Q29	0.674	0.382	0.301	0.195	0.651
Q13	0.312	0.751	0.170	0.204	0.693
Q11	0.197	0.706	0.292	-0.007	0.574
Q12	0.345	0.681	0.143	0.260	0.645
Q10	0.198	0.592	0.396	0.168	0.632
Q16	0.134	0.579	0.422	0.029	0.603
Q17	0.122	0.243	0.814	0.148	0.749
Q18	0.343	0.413	0.675	0.089	0.712
Q19	0.305	0.285	0.630	0.229	0.691
Q21	0.342	0.451	0.540	0.259	0.648
Q23	0.468	0.237	0.519	0.209	0.619

Q5	0.180	-0.106	0.255	0.755	0.683
Q6	0.174	0.275	-0.036	0.738	0.611
Q1	0.289	0.141	0.286	0.507	0.547
Q8	0.264	0.025	0.319	0.493	0.482
Q39	0.179	0.259	0.001	0.398	0.463

The results show that the selected items align well with the four factors, supporting high internal consistency across the questionnaire.

CHARACTERISTICS OF THE STUDIED POPULATION

Following the validation of the reduced ATMI, we focused on its application to a population at a Brazilian university. Specifically, the study works with the first-year undergraduate students in STEM subjects at a large public university in São Paulo in 2024. This work was approved by the Ethics Committee of the University os Campinas, represented by process number: CAAE [77223023.8.0000.5404].

We applied the questionnaire online. Over 2 months, 323 students responded to the online ATMI-20. The gender distribution of the participants was 106 females (32.8%) and 217 males (67.2%), reflecting typical demographic trends in STEM fields. The age distribution is in Table 4.

Table 4

Age of students who took part in the research.

Age (years)	Frequency	Percentage
17	7	2.2%
18	126	39.0%
19	93	28.8%
20	42	13.0%
21–23	36	11.1%
24–29	11	3.4%
>29	8	2.5%
Total	323	100.0%

Many students were aged 18-19 years, aligning with the typical enrolment age for Brazilian university students (Marcom & Kleinke, 2016). These characteristics facilitated ATMI's adaptation to this context, ensuring its relevance to the target population.

Racial and Academic Characteristics

Another characteristic examined was the participants' self-identification with their racial background. Table 5 presents the distribution of the sample by self-declared racial categories.

Table 5

Racial Categorisation in frequency and percentage.

Racial Category	Frequency	Percentage
Asian	12	3.7%
White	199	61.6%
Black and Brown	102	31.6%
Indigenous	3	0.9%
Undeclared	2	0.6%
Blank	5	1.5%
Total	323	100.0%

In addition to racial diversity, the study also considered the distribution of students across academic disciplines. Table 6 presents the distribution by field of study.

Table 6

Distribution by academic field of study with frequency and percentage.

Academic Field	Frequency	Percentage
Mechanical Engineering	41	12.7%
Electrical Engineering	35	10.8%
Food Engineering	40	12.4%
Computer Science	32	9.9%

Computer Engineering	21	6.5%
Control and Automation Engineering	24	7.4%
Science (Physics, Chemistry, Others)	130	40.2%
Total	323	100.0%

The distribution highlights a significant representation of engineering and technology fields, consistent with the broader trends in STEM enrolments. The inclusion of diverse academic disciplines strengthens the generalizability of the findings and supports the broader application of the reduced ATMI.

RESULTS OF FACTOR ANALYSIS AND CRONBACH'S ALPHA FOR THE STUDIED POPULATION

Using the collected data, we calculated a first Cronbach's alpha value of .91, a highly significant result showing the instrument's reliability. Alpha values above 0.9 are considered excellent (Hannula, Pantziara, & Di Martino, 2018; Ball, Walter, & Fox, 2024; Dorji & Dorji, 2021). Compared with the original work by Tapia and Marsh (2004), which reported an alpha of .96, our results are satisfactory, as in similar studies (Primi et al., 2020; Segarra & Julià, 2022).

To continue, it was necessary to verify whether the factors remained stable within the new population. We conducted an Exploratory Factor Analysis (EFA) using SPSS 22 software, applying the Varimax rotation, as used in earlier studies (Jancarik et al., 2023; Suherman & Vidákovich, 2022). The results showed a Kaiser-Meyer-Olkin (KMO) value of .916, well above the .6 threshold recommended by Kaiser (1974), confirming the adequacy of the sample for factor analysis.

Table 7

Exploratory Factor Analysis (EFA), factors and communality

Question	Factors				Communality
	1	2	3	4	
Q14	.824	.220	.299	.086	.824

Q12	.744	.073	.319	.030	.661
Q13	.712	.298	.249	.017	.658
Q11	.705	.208	.387	.085	.697
Q15	.648	.310	.288	.121	.613
Q3	.286	.811	.202	.213	.826
Q4	.251	.760	.230	.182	.726
Q5	.273	.748	.088	.182	.676
Q2	.282	.665	.214	.215	.614
Q1	.029	.525	.070	.404	.444
Q9	.303	.114	.701	.126	.612
Q10	.362	.077	.671	.106	.599
Q7	.421	.163	.566	.097	.534
Q8	.210	.220	.551	.142	.417
Q6	.268	.198	.474	.162	.363
Q18	.054	.102	.004	.744	.567
Q17	.034	.156	.188	.691	.539
Q20	.111	.070	.055	.669	.467
Q16	-.034	.315	.182	.546	.431
Q19	.117	.299	.146	.487	.362

The analysis of the rotation matrix from the Exploratory Factor Analysis (EFA) and the communalities of the reduced ATMI questionnaire reveals a well-defined structure of the factors underlying attitudes towards mathematics, thereby proving the instrument's validity in measuring psychosocial constructs within the educational context. The results indicate that the items are organised into four main factors, each representing specific dimensions of mathematical attitudes: self-efficacy, motivation/enjoyment, Anxiety, and the value attributed to mathematics. Table 7 shows the factors and communalities for each question, indicating grouping into four factors.

Factor 1, associated with self-efficacy, shows high factor loadings for items such as Q14 (.824), Q12 (.744), and Q13 (.712), writing down that these items accurately capture the construct of confidence and perceived competence in mathematics. Factor 2, related to motivation and enjoyment, is well represented by items such as Q3 (.811), Q4 (.760), and Q5 (.748). These items address positive emotional aspects and engagement with mathematical learning. Factor 3, which relates to Anxiety, includes items such as Q9 (.701) and Q10 (.671). Finally, Factor 4, reflecting the value attributed to mathematics, is characterised by items such as Q18 (.744) and Q17 (.691), which reflect beliefs about the relevance and importance of mathematics in the social context.

The item communality, with most values exceeding .6, suggests that the items explain a portion of the shared variance within each factor. Items such as Q3 (.826) and Q14 (.824) had the highest values, indicating strong representation within the factors.

The results of this analysis reinforce the robust psychometrics of the ATMI-20 questionnaire, adapted to the Brazilian context. The factor structure and high internal consistency provide evidence of the instrument's potential for use in educational contexts and in studies exploring the interactions among cognitive, emotional, and behavioural aspects of mathematics education. Thus, the adapted ATMI contributes to a deeper understanding of psychosocial variables that influence mathematical learning, offering valuable insights for pedagogical interventions and evidence-based educational policies.

The results presented in Table 8 indicate that the item grouping remains consistent with the original structure, suggesting that the reduction of the questionnaire and the shift in population did not alter the composition of the new inventory. Continuing the discussion of the new questionnaire's internal consistency, we calculated Cronbach's alpha for each factor.

Table 8

Cronbach's Alpha Value for Each Factor

Factor	ATMI Classification	Alfa
Factor I	Self-efficacy	.911
Factor II	Enjoy/Mot	.884
Factor III	Anxiety	.822
Factor IV	Value	.773

Analysis of Cronbach's Alpha and Pearson correlations among the factors further strengthens the instrument's psychometric robustness, highlighting its internal consistency and discriminant validity. The results presented demonstrate that the identified factors – self-efficacy, motivation/enjoyment, Anxiety, and value – are well-defined and independent, providing a reliable and detailed measure of attitudes towards mathematics.

The Cronbach's Alpha values for the factors ranged from .773 (Factor IV – Value) to .911 (Factor I – Self-efficacy), all falling within ranges considered adequate in the literature (Hannula, Pantziara, & Di Martino, 2018; Ball, Walter, & Fox, 2024; Dorji & Dorji, 2021). Factor I stood out for its high internal consistency, indicating that the associated items accurately capture beliefs of competence and confidence in mathematics.

Similarly, the Motivation/Enjoyment (.884) and Anxiety (.822) factors showed high indices, proving that the items related to positive emotional engagement and negative emotions, respectively, are representative of their constructs. Although Factor IV (Value) presented the lowest Alpha (.773), considered acceptable, reinforcing the adequacy of the items measuring the importance attributed to mathematics.

The internal consistency of the factors remained high within the alpha scale, once again confirming the questionnaire's reliability. In line with this, we sought to examine whether the factor correlations are close to zero, allowing us to treat them independently, thereby enhancing data analysis and ensuring a high degree of reliability for the instrument.

Table 9

Pearson Correlation in each factor

		FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
FACTOR 1	Pearson Correlation	1			
FACTOR 2	Pearson Correlation	.057	1		
FACTOR 3	Pearson Correlation	.171	.026	1	
FACTOR 4	Pearson Correlation	-.021	.084	.061	1

Cohen et al. (2009) explain that the Pearson correlation coefficient quantifies the degree of linear relationship between two variables. This coefficient ranges from -1 to 1, where values closer to -1 or 1 show a strong correlation, while values near 0 suggest little to no correlation. In the context of Exploratory Factor Analysis (EFA), the factors must remain independent, corresponding to a correlation of $r = 0$. As shown in Table 9, the Pearson correlation for each factor is approximately 0, showing an absence of autocorrelation (Matos & Rodrigues, 2019).

The Pearson correlations between the factors support the independence of the constructs, with values ranging from -0.021 (between Factors I and IV) to 0.171 (between Factors I and III). These results show that the factors do not show significant overlap, ensuring that each dimension assessed in the questionnaire measures distinct aspects of mathematical attitudes. The independence of the factors is important for studies that aim to explore relationships between specific variables, such as anxiety and academic performance or self-efficacy and motivation, without significant interference between constructs.

Thus, the results confirm the validity and reliability of the reduced ATMI questionnaire for measuring mathematical attitudes. The high Cronbach's Alpha values and lack of significant correlations among the factors indicate that the instrument is appropriate for academic research and practical applications in educational settings for university students.

RESULTS OF ENGINEERING COURSES

Mathematical self-efficacy refers to an individual's belief in their ability to complete mathematical tasks successfully. Mathematical Anxiety, in turn, is a feeling of tension and apprehension that interferes with the ability to handle numbers and solve mathematical problems in various life situations. When a student believes in their abilities, they feel more confident facing challenges, reducing the likelihood of developing fear or panic in mathematics. In contrast, low self-efficacy can lead to a negative cycle: a lack of confidence causes Anxiety, which in turn harms performance, reinforcing the belief in one's incompetence and deepening the Anxiety.

From this perspective, we present the results of our research on engineering students. Table 10 presents the results for the anxiety and self-efficacy factors, derived from the previously described factor analysis.

Table 10

Results of Anxiety and Self-efficacy Factors of Engineering Students

Academic Field	Anxiety		Self-efficacy	
	Means	Stand. Devition	Means	Stand. Devition
Mechanical Engineering	.25	.59	.10	.88
Electrical Engineering	.05	.79	.06	.95
Food Engineering	-.33	1.07	-.34	.89
Computer Science	.04	.87	.22	.98
Computer Engineering	.13	.55	.58	.64
Control and Automation Engineering	.29	.78	.15	.86

The results show that Mechanical Engineering and Control and Automation Engineering students had the highest average anxiety levels, with scores of M=0.25 and M=0.29, respectively. Food Engineering stood out at the other end, with a negative average anxiety score (M = -0.33), indicating that students in this course felt less anxious about mathematics than the overall average.

Regarding self-efficacy, which reflects a belief in one's own mathematical competence, Computer Engineering had the highest positive score (M = 0.58), followed closely by Computer Science (M = 0.22). On the other hand, Food Engineering showed the lowest perceived competence, with a negative value (M = -0.34).

The analysis of standard deviations (SD) also provided important information. Food Engineering showed the most remarkable heterogeneity in results, with an SD of 1.07 for anxiety, suggesting a wide range of emotional profiles and beliefs within this group. In contrast, Computer Engineering demonstrated greater homogeneity, with low standard deviations for both anxiety (SD = 0.55) and self-efficacy (SD = 0.64).

The discussion of the results confirms a widely documented theoretical pattern in the literature: mathematical self-efficacy is generally inversely related to mathematical anxiety (Hembree, 1990; Gresham, 2007). Courses like Mechanical Engineering and Control and Automation Engineering, where students reported higher anxiety, showed only medium levels of self-efficacy. On the other hand, Computer Engineering students stood out for their high self-efficacy, even with slightly positive anxiety. This result suggests that mathematics is a practical tool for problem-solving, which helps strengthen competence beliefs, in line with analyses by Bieg et al. (2017) and Schukajlow et al. (2017). The situation observed in Food Engineering is particular, as low levels of anxiety and self-efficacy may indicate detachment from a mathematical identity (Goldin et al., 2016). The data suggest that curricular demands and teaching practices influence how students develop their beliefs about competence and how they emotionally respond to mathematics (Hannula, Pantziara & Di Martino, 2018; Liljedahl & Hannula, 2016).

Mathematical anxiety is strongly correlated with poor performance and negatively associated with positive attitudes such as self-efficacy (Hembree, 1990). An engineering degree alone is not enough to guarantee rigorous content (Wang et al., 2020; Eskici, Ilgaz, & Arıcak, 2017). Teaching practices and curricular demands influence students' beliefs in their competence and their emotional reactions to mathematics. (Hannula, Pantziara & Di Martino, 2018;

Liljedahl & Hannula, 2016). Therefore, the data from this study suggest that the training of an engineering professional, in their knowledge and application of mathematics, is closely linked to factors that are not only cognitive but also emotional and belief-based.

CONCLUSION

The reduction of the Attitudes Toward Mathematics Inventory (ATMI) to a 20-item version (ATMI-20) was an effective instrument for investigating some attitudes toward math. The process, which involved factor analyses and the identification of items with higher factor loadings, ensured that the key dimensions of self-efficacy, anxiety, value, and motivation/enjoyment were preserved from the initial instrument. The high Cronbach's Alpha values—.91 for the overall questionnaire and for the individual factors—further reinforce the instrument's internal consistency, indicating that the simplification did not compromise its methodological rigour.

Adapting the questionnaire to the Brazilian context was crucial for confirming its applicability to culturally distinct populations. The sample, consisting of students from STEM courses at a large public university in São Paulo, reflects typical demographic characteristics, including young adults aged 18 to 19, as well as a higher representation of men, which is common in these subjects. These results highlight the versatility of the ATMI-20 in capturing the nuances of mathematical attitudes across diverse populations.

The evidence presented reinforces the intrinsic link between self-efficacy, anxiety, and engineering education. A student's success is not determined solely by their academic performance. Nevertheless, they can also navigate the emotional and psychological landscape that mathematics presents. Self-efficacy and anxiety are not mere side effects of learning; they are central factors that can either propel or sabotage academic progress and future careers.

The data analysis confirms the theoretical pattern that mathematical self-efficacy and anxiety are inversely related (Hembree, 1990; Gresham, 2007). Courses such as Computer Engineering, characterised by high self-efficacy and low anxiety, indicate an environment where mathematics is viewed as a practical tool for problem-solving. This perspective, which aligns with STEM education approaches, can strengthen a belief in competence and help reduce anxiety (Eskici, Ilgaz & Arıcak, 2017). In contrast, in fields such as Food Engineering, low self-efficacy combined with low anxiety may indicate disengagement or a belief that mathematics is not central to the student's professional identity, as discussed by Goldin et al. (2016).

The training of a well-rounded professional requires a learning environment that fosters confidence (Smith, 2021) and provides strategies for managing anxiety (Becker & Park, 2011). This includes facilitating a smoother transition from secondary school to university (Johnson et al., 2020) and implementing pedagogical practices that promote critical thinking, collaboration, and resilience. The way students develop their beliefs about their competence and their emotional response to mathematics is therefore directly shaped by both curricular demands and teaching approaches (Hannula, Pantziara & Di Martino, 2018; Liljedahl & Hannula, 2016).

In summary, the ATMI-20 is a reliable and efficient tool for measuring mathematical attitudes, with potential for application across various cultures and educational levels. The instrument, offering a practical, streamlined alternative for data collection, advances research on mathematical self-efficacy and its relationship with academic performance (Leong & Tan, 2020). Thus, the findings of this study not only corroborate the existing literature but also provide a combined, contextually adapted instrument for university students enrolled in STEM courses in Brazil.

STATEMENT ON ARTIFICIAL INTELLIGENCE

During the writing of this work, the tools Grammarly, the built-in grammar editor in Word, and DeepL, a translation tool, were used.

By submitting this manuscript, we confirm that we have adhered to appropriate ethical guidelines or approvals for the human subjects research conducted in this study, including taking into consideration any federal requirements and institutional guidelines concerning the use of AI in human subjects research.

AUTHORS' CONTRIBUTIONS STATEMENTS

B.A.M.W. contributed to conceptualisation, data curation, formal analysis, investigations, methodology and writing original draft. L.F.C.F. contributed to conceptualisation, data curation, formal analysis, investigation, methodology, software, validation, writing original draft and reviewing and editing this manuscript. M.U.K. contributed to data curation, investigation, methodology, software and validation. A.J.J. contributed to data curation, investigation, software, validation and writing the original draft. G.S.M. contributed to conceptualisation, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation and reviewing and editing this manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

This research was conducted with the approval of the Ethics and Research Committee of the University of Campinas and can be identified by the CAAE Number: [77223023.8.0000.5404].

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