Analyzing Open Mindedness and Critical Thinking in Research Mindset: A Quantitative Approach for Engineering Doctoral Students

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Abstract

Context

A research mindset corresponds to cognitive procedures, mental filters, or beliefs that help in performing a successful research task. A previous qualitative study examining doctoral students' research mindsets revealed six attributes: (1) open mindedness, (2) believing in oneself and the research, (3) persistence, (4) honesty, (5) being critical, and (6) a writing mindset.

Purpose or Goal

This current study uses a quantitative approach to: (1) assess the research mindset attributes of open mindedness and being critical, and (2) explore possible gender and engineering disciplinary differences within these attributes.

Methods

A total of 89 doctoral students belonging to different engineering disciplines participated in the survey. An exploratory factor analysis was performed to reveal an initial factor structure for 'open mindedness' and 'being critical.' Kruskal Wallis tests and multiple linear regression analyses were performed to further understand the differences in these attributes across the demographic characteristics of gender and engineering discipline.

Outcomes

The exploratory factor analysis revealed a two-factor solution in line with the research mindset's attributes of 'open mindedness' and 'being critical.' Further analysis revealed no significant evidence to claim that gender differences exist when examining 'open mindedness' and 'being critical' scores. Some differences were observed for 'being critical' across disciplines for the doctoral student sample.

Conclusion

The study contributes valuable insights related to research mindset of doctoral students. The two attributes, open mindedness and being critical, are gender neutral but have differences in engineering disciplines leading to potential implication on how doctoral education can be designed and delivered. This also necessitates further research to gain a deeper understanding of the research mindset.

Keywords—Critical thinking; Doctoral students; Mindset; Open mindedness; Research Mindset.

I. INTRODUCTION

MINDSET has been defined in a variety of ways. Cognitive psychology identifies mindset as the sum total of the activated cognitive procedures that consist of the cognitive orientation most conducive to successful task performance (French II, 2016; Gollwitzer & Bayer, 1999). Positive psychology views mindset as a set of beliefs that shape how one perceives this world and themselves (Brooks et al., 2012; Dweck, 2011; French II, 2016). Social psychology considers mindset as a cognitive filter or a frame of reference (French II, 2016; Gupta & Govindarajan, 2002). Each of these definitions of mindset suggest mindsets are crucial for the performance of any task.

Literature is abundant with studies related to many mindsets. The studies related to growth and fixed mindset (Dweck, 2006) can be considered pivotal in the research related to mindsets and have inspired many other researchers to investigate new spaces of mindsets. Having a certain mindset to suit specific task performances is beneficial (Eilers et al., 2022; Fang et al., 2022; Zingoni & Corey, 2017) and could be the reason for studies on different mindsets in the literature. Many non-discipline specific mindsets such as global mindset (Gupta & Govindarajan, 2002) and developmental mindset (Thurbon, 2016) and discipline-specific mindsets such as maker mindset (Dougherty, 2013) and entrepreneurial mindset (Naumann, 2017) have emerged in recent years.

Research can also be considered as a cognitive task or set of cognitive tasks as explained by the previous definitions of mindset. Conducting research may also need cognitive orientation, beliefs or mental filters that can be termed as 'research mindset' for the successful conduct of research tasks. The concept of 'research mindset' has gained attention in different contexts, and many scholars have explored its significance in multiple ways. For example, Kveven et al. (2014) have considered research mindset as a transformative process, empowering students to become critical thinkers who are adept at asking pertinent questions, conducting scientific research, and navigating complex data. On a similar note, Clark

& Johnstone (2018) have explored undergraduate music students for research mindset seeking to uncover not only their information-seeking behaviors but also their attitudes, comfort levels, and approaches towards research and writing within their academic journey. Conversely, Lee Chuen et al. (2019) advocate the cultivation of research mindset by actively engaging students in inquiry-based learning, promoting hands-on experience, interdisciplinary collaboration, and innovation. McEachern & Horton (2016) extend the concept's reach by explaining the necessity of research mindset for the development of researcher identity among faculty and students. Moreover, within the context of undergraduate engineering research experiences, other scholars, such as Branch et al. (2015) and Prasad and Bhat (2021), have also recognized the need for a research mindset. Despite the considerable attention given to the concept of a research mindset in the literature, it is noteworthy that an explicit and universally accepted definition of what constitutes a research mindset remains elusive. This gap in the literature underscores the complexity and evolving nature of this concept, necessitating further exploration and clarification.

Prior work undertaken by the research team revealed six different attributes of the research mindset held by doctoral engineering students: (1) open-mindedness, (2) believing in oneself and the research, (3) persistence, (4) honesty, (5) being critical, and a (6) writing mindset (Kavale & Carberry, 2023). It is interesting to see that some of the attributes of research mindset are attributes that have been cited as attributes of other mindsets (e.g., open-mindedness or be open minded is an attribute of entrepreneurial mindset (Brunhaver et al., 2018) and design thinking mindset (Maier et al., 2017), while truth-seeking, analyticity, systematicity, and inquisitiveness noted in critical thinking mindset (Bramhall et al., 2012; Facione et al., 2016) are closely related to the being critical attribute of the research mindset.

The current study is an extension of previous qualitative studies aimed to assess the elements of research mindset. The current study also examines potential differences across gender and engineering disciplines for two attributes of the research mindset: open-mindedness and critical thinking. Specifically, the current study's research questions are:

1. How do open mindedness and critical thinking manifest among doctoral students?
2. What, if any, gender differences exist for open-mindedness and critical thinking aspects of the research mindset held by doctoral students?
3. What, if any, engineering disciplinary differences exist for open-mindedness and critical thinking aspects of the research mindset held by doctoral students?

Recent scholarly articles mention the need for a research mindset (Branch et al., 2015; Prasad & Bhat, 2021). Such efforts are part of a larger effort happening in the field of mindsets. The topic resonates with engineering education researchers as a core capability of researchers. This study lays the foundation for understanding research mindset at a larger scale in various domains of STEM education that can become useful for the scientific community.

II. Conceptual Framing

The six attributes of research mindset identified by (Kavale & Carberry, 2023) - open-mindedness, believing in oneself and the research, persistence, honesty, being critical, and a writing mindset - were used to form a conceptual framework for the current study (Figure 1). The conceptual framework was used to create an instrument that informed the study's research questions. This study explores the attributes of 'open mindedness' and 'being critical.'

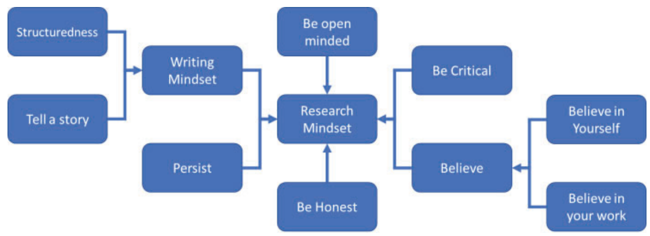

Fig. 1. Attributes of research mindset (Conceptual Framework).

Numerous studies within the field of engineering education have explored and measured open-mindedness among undergraduate engineering students. Some studies suggest that open mindedness improves doctoral education (Albertyn, 2022; Boud & Lee, 2005; Ortwein, 2015), but investigations of open-mindedness among engineering doctoral students, considering gender and disciplinary differences, is notably scarce.

A similar pattern is observed in the examination of critical thinking. A substantial body of research exists examining and assessing critical thinking among undergraduate engineering students (Ahern et al., 2019; Caratozzolo et al., 2019; Douglas, 2012). Developing and enhancing critical thinking skills is a fundamental responsibility of any educational program, particularly in doctoral education. A noticeable gap exists in the literature regarding graduate students. This is somewhat surprising considering the deliberate focus that has been placed in STEM doctoral education in the U.S. on fostering critical thinking throughout the Ph.D. journey (Golde, 2005; Leshner & Scherer, 2018).

III. Methods

A survey-based study was undertaken with engineering doctoral students. The study was approved by the Institutional Review Board (IRB) at the first author's institution. An exploratory factor analysis was conducted to address the first research question. Kruskal Wallis tests and multiple regression analyses were performed to address the remaining two research questions. The following subsections explain the methods in

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detail.

A. Researcher Positionality

The authors of this paper all hold degrees in engineering and have substantial experience in the field of engineering education. The first author, currently pursuing a doctoral degree in engineering education, acknowledges a personal perspective that believes in the existence of a research mindset. It is important to recognize that this belief may have influenced the deliberations presented in this paper.

B. Participants and Data Collection

Doctoral students belonging to different schools of engineering at a research-intensive public university in the Southwestern region of the United States were surveyed to capture their research mindsets. The engineering college at the chosen university has an average enrolment of 1194 Ph.D. students per year for the last 5 years. Participant recruitment was undertaken through advising offices within the college. Personal email invitations were also shared with all students whose information was publicly available through lab or other university websites. It was not possible to assess the response rate of the participants because the total number of students receiving the invite is unknown. Ten participants were randomly selected to receive a $10 gift card as an incentive.

TABLE I
PARTICIPANT SAMPLE DEMOGRAPHICS

Gender	Female	26 (29.21%)
	Male	61 (68.53%)
	Genderqueer	1 (1.12%)
	Preferred not to say	1 (1.12%)
Racial and ethnic groups	Asians	53 (59.55%)
	Middle Eastern or North African	7 (7.86%)
	White	14 (15.73%)
	Hispanic, Latino or Spanish origin	4 (4.49%)
	Jewish	1 (1.12%)
	Multiracial	7 (7.86%)
	Preferred not to say	3 (3.37%)
Ph.D. major	Chemical engineering, biomedical engineering, and biotechnology	11 (12.35%)
	Computer or information technology engineering	36 (40.44%)
	Electrical engineering	4 (4.49%)
	Mechanical engineering, aeronautical engineering, civil engineering, and material science engineering	16 (17.97%)
	Human systems engineering	12 (13.48%)
	Engineering education	10 (11.23%)
International Student status	Yes	59 (66.29%)
	No	30 (33.70%)
Current year in Ph.D.	1st or 2nd year	38 (42.69%)
	3rd or higher	51 (57.30%)
No. of articles published	2 or less	40 (44.94%)
	3 or more	49 (55.05%)

A total of 114 responses were obtained. Responses from graduate students not currently enrolled in a Ph.D. program were removed from the data set (13 responses). Incomplete responses were also eliminated (12 responses). A total of 89 responses were included in the final analysis, which is approximately 7.5% of all engineering Ph.D. students enrolled at the institution. The demographic information of the sample is presented in Table I.

C. Measures

A total of 25 items were included in the survey. Sixteen items captured the independent variables of open mindedness (9 items) and being critical (7 items) using a 5-point Likert scale. The remaining items captured student demographics – gender, Ph.D. major, year in Ph.D., number of articles published, and international student status, which were used as dependent variables. The measures of the two constructs were created based on the codes found in the work by (Kavale & Carberry, 2023).

D. Validation of the instrument

Validity testing of the instrument was performed using recommendations provided by the *Encyclopedia of Social Measurement* (McGartland Rubio, 2005). Four engineering education research faculty examined the content embedded in the instrument. A spreadsheet containing all items was shared with each faculty reviewer. The faculty rated each item for representativeness and clarity. An option was also given to provide additional comments. The feedback led to the removal of 5 items.

The modified instrument was then pilot tested by two engineering doctoral students. Pilot testing was done using think aloud session to allow participants to voice their opinions in real time about the items in the instrument (Ericsson & Simon, 1993; Someren et al., 1994). The students were also asked to comment on overall relevance, number of items, response alternatives, wording, or additional comments. The instrument was further refined based on the inputs from the students. The total number of items remained at 16.

E. Exploratory Factor Analysis

An exploratory factor analysis was conducted to further reduce the number of items in the survey and to address the first research question. The analysis was performed using R version 4.2.2. Responses of all items were checked for means, standard deviations, Kurtosis, and skewness. Then, the Kaiser-Meyer-Olkin measure of sampling adequacy and Bartlett's test for sphericity were conducted to ensure that the sample was adequate for further analysis (McCoach et al., 2013). An exploratory factor analysis using the principal axis factoring method (McCoach et al., 2013) was performed on the data set. Scree plots (Cattell, 1966; Horn & Engstrom, 1979), parallel analysis (Slocum-Gori & Zumbo, 2011), and MAP test

(Velicer, 1976) were used to determine the appropriate number of latent factors,. The Oblimin rotation method (Clarkson & Jennrich, 1988) was employed to anticipate that the factors would be somewhat correlated. The factor structure was considered acceptable based on the following criteria (McCoach et al., 2013). Items were retained if they had a minimum factor loading value of 0.40 and a value less than 0.30 on all other factors. Cross-loaded items were not included in the factors. Inter-item correlations for all items were checked to be less than 0.85, and each factor had at least three loaded items. The reliability of the items within the factors was checked using Cronbach's alpha for a minimum value of 0.7 (Cronbach, 1951). Lastly, the factor correlations were examined, and a maximum value of 0.85 was deemed acceptable (McCoach et al., 2013).

F. Kruskal Wallis test and Regression Analysis

The second and third research questions were addressed using multiple regression analysis (Kutner et al., 2005) and Kruskal Wallis test (Theodorsson-Norheim, 1986; Vargha & Delaney, 1998). The composite scores of the constructs 'open mindedness' and 'being critical' were calculated based on the weighted averages using the loadings obtained from the exploratory factor analysis. Before further analysis, diagnostic tests were performed to check the assumptions of normality, linearity, and homoscedasticity. Histograms, scatter plots, and quantile-quantile plots were used to confirm these assumptions. The generalized Variance Inflation Factor (VIF) was calculated to identify multicollinearity issues in the regression models for a cutoff of 10 (Kutner et al., 2005). It is observed that the generalized variance inflation factor values for all dependent variables were within the cut-off value of 10. A visual inspection of residual plots suggested that there exists heteroscedasticity in the given data. Also, quantile-quantile plots suggested that the data is non normal and there exist a few outliers. The dependent variables were suitably dummy coded as needed by the multiple regression analysis.

IV. RESULTS

The results section is divided into two sections. The first section addresses the first research question on generalizing the attributes of the research mindset. The second section addresses the second and third research questions exploring potential impacts of demographic differences for research mindset.

A. Section 1: Exploratory Factor Analysis

Simple descriptive statistics of the responses for all items were checked first. Skewness and Kurtosis were evaluated for the normality of the data. The thresholds used to evaluate normality were ± 2 for skewness and Kurtosis (Aron et al., 2013). The skewness of all items varied between -4.74 to -1.13, 8 items failed to fall within the threshold. Similarly, the Kurtosis of all items varied between 3.61 to 29.71; 9 items failed to fall within the threshold. These findings indicate the

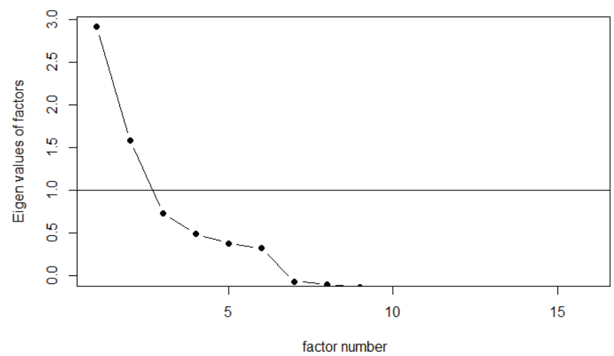

Fig. 2. Scree plot.

TABLE II
EXTRACTED FACTORS WITH ITEMS AND THEIR LOADINGS

Sl. No	Item	Factor Loading
	Factor 1: Open Mindedness	
1	I believe being open to other researchers' suggestions during any research activity is important.	0.429
2	I believe that my peers' opinions, criticisms, suggestions, and feedback are important for my research.	0.386
3	I am willing to learn from others to do improve my research activities.	0.677
4	I am willing to learn new things needed to do my research.	0.500
5	I believe my advisors' opinions, criticisms, suggestions, and feedback are important for my research	0.421
6	I believe getting feedback on the research activities is very crucial.	0.325
7	I believe that taking other researchers' opinions will give me different perspectives to work on my research.	0.613
8	Being open-minded while doing any research related activity is important.	0.612
9	Being open to feedback is an important aspect of research.	0.631
	Factor 2: Being Critical	
10	It is crucial for me to critically evaluate every step of the research process by questioning each task performed.	0.803
11	It is essential for me to validate each task performed during the research process.	0.578
12	It is important for me to have a clear understanding of my research tasks.	0.427
13	It is important for me to pay attention and be observant while conducting research tasks.	0.302
14	It is important for me to critically evaluate my views and perspectives while performing research tasks.	0.463
15	It is important for me to critically examine the views and perspectives of others while performing research tasks.	0.473
16	I believe that staying focused is crucial in performing research-related tasks.	0.477

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presence of non-normally distributed data in this study. Exploratory factor analysis was conducted using the principal against violations of the assumption of multivariate normality in the data (Fabrigar et al., 1999). Therefore, no additional steps were taken to address this issue. Inter-item correlations were checked for all items, and no items were found to have correlations beyond 0.85. The sample can be considered adequate (n = 89) because it meets the minimum of 5 to 10 participants per variable or item. Bartlett's test of sphericity was significant (p = 0.000). The KMO measure obtained was 0.60, which meets the minimum threshold of 0.60 to determine sample adequacy, indicating a sufficient correlation between variables to proceed with the analyses.

The number of factors that can be extracted based on eigenvalues (Kaiser criterion) from a visual inspection of the Scree plot and the original MAP test suggest two factors. The Scree plot is shown in Figure 2. Parallel analysis suggested six factors. For verification, models with one, two, and three factors were created. The one-factor and three-factor models had multiple cross-loadings, suggesting the two-factor model best fit the data (Table II). This result also aligns with the expected number of constructs.'

Three items (items 2, 6 and 13) were removed due to low factor loadings. Cronbach's alpha for the factors 'open mindedness' and 'being critical' were 0.756 and 0.701, respectively. The correlation between the two factors was 0.13.

B. Section 2: Kruskal Wallis Test and Regression Analysis

Considering the non-normal nature of the data, the Kruskal Wallis test was performed to check if there were any differences in 'open mindedness' and 'being critical' scores based on gender or engineering discipline. There were no significant differences found (open mindedness based on gender: H(3) = 2.801, p = 0.423; being critical based on gender: H(3) = 3.086, p = 0.378; open mindedness based on Ph.D. Major: H(5) = 2.290, p = 0.807; being critical based on Ph.D. Major: H(5) = 8.132, p = 0.149).

Multiple linear regression analysis was also performed to address the second and third research questions. Table III represents the regression model for predicting the two attributes 'open mindedness' and 'being critical' of the research mindset. The created models with included demographic variables explain close to zero variance in 'open mindedness' and 'being critical' attributes of the research mindset. There is no sufficient evidence to say that there exist gender differences in the 'open mindedness' and 'being critical' attributes of the research mindset. This indicates a potential need for a study with a larger sample size to make statistical inferences. Despite this, an effort was made to investigate the results to inform future research.

TABLE III
EXTRACTED FACTORS WITH ITEMS AND THEIR LOADINGS

Variables	Open mindedness	Being critical
Intercept	4.847 ***	4.786 ***
Gender (base: Female)		
Genderqueer	-0.083	-0.483
Male	-0.006	0.077
Preferred not to say	-0.553	-0.257
Racial and Ethnic background (base: Asian)		
Hispanic, Latino or Spanish origin	-0.081	0.115
Jewish	0.139	0.411
Middle Eastern or North African	-0.081	-0.139
Multiracial	-0.154	-0.048
Preferred not to say	0.160	0.244
White	0.024	0.031
Ph.D. Major (base: Chem, Biotech, BioMed Engg)		
Computer or Information technology engineering	0.082	-0.227
Electrical Engineering	0.073	-0.176
Human Systems Engineering	0.020	-0.275
Mech, Civil, Materials and allied Engg	0.054	-0.473**
Engineering Education	0.150	-0.487**
International Student (base: No)		
Yes	-0.028	0.127
Number of articles published (base: 2 or less articles)		
3 or more articles	-0.051	0.123
Current year in Ph.D. (base: 1st or 2nd year)		
3rd or higher	-0.045	-0.241*
Adjusted R squared	-0.115	0.017
F Test	0.480	1.092
n	89	89

Note: All terms are standardized regression coefficients. *p<0.1.; **p<0.05.

No significant differences were observed for the individual item scores of 'open mindedness' based on participant majors. Some significant differences were observed for 'being critical' items based on Ph.D. majors. Comparing the scores of 'being critical' among students from different engineering disciplines (Note: Chemical, Biotechnology, and Biomedical Engineering were used as the baseline), it was found that students from Mechanical, Civil, Materials Science, and allied engineering disciplines had significantly lower scores (-0.473 points, p = 0.018) after controlling for other variables. Similarly, the students belonging to engineering education also had significantly lower scores (-0.487, p = 0.040). It is important to remember that the study had a limited sample size of 89 students, and that the measure was based on a self-reported survey data only. These findings suggest that there may be differences in critical thinking skills among engineering disciplines, but further research is needed to confirm these results and explore potential factors that may explain these differences.

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V. Discussion and Implications

The presented study quantitatively examines two research mindset attributes: open mindedness and being critical. Exploratory factor analysis revealed a two-factor solution in line with the research mindset's two constructs considered for the study. Kruskal Wallis test and multiple linear regression analysis were performed to explore differences in the scores of 'open mindedness' and 'being critical' based on gender and major of engineering doctoral students.

Analyses performed yielded intriguing results. There was no observed sufficient evidence to claim that there exist gender differences in 'open mindedness' and 'being critical' scores. Some differences in the scores of 'being critical' based on major were observed. Interestingly, the highest difference in the scores were obtained with students pursuing a Ph.D. in engineering education. This observation raises interesting questions and warrants further exploration.

The findings from our study hold significant implications for the cultivation of a research-oriented mindset among early career researchers, particularly within the realm of doctoral education. STEM doctoral programs in the U.S. are designed to promote critical thinking, persistence, teamwork, and communication (Golde, 2005; Golde & Dore, 2001; Leshner & Scherer, 2018), yet there is paucity of literature exploring gender and disciplinary or major differences in the critical thinking mindset of doctoral students. Numerous studies have shown that a critical thinking mindset can improve critical thinking (Abrami et al., 2008; Tiruneh et al., 2014). There are numerous studies suggesting no gender differences in critical thinking of undergraduate engineering students (Özyurt, 2015, Sola et al., 2017). This could be a possible reason for the lack of gender differences among engineering doctoral students' 'being critical' scores in this study.

The scores of Ph.D. students in the engineering education domain being lower than those in other engineering disciplines is worth noting. This could be because engineering education as a discipline connects more closely to the social sciences than other engineering disciplines. As argued by Brookfield, critical thinking is influenced by various traditions and assumptions, which essentially represent different epistemological positions. Disciplines may hold alternative views on the nature or meaning of critical thinking (Brookfield, 2012). This context sheds light on potential factors contributing to the observed differences and underscores the importance of understanding the nuances within different academic majors or disciplines.

Open-mindedness has been identified as a crucial attribute for success in doctoral education (Albertyn, 2022; Boud & Lee, 2005; Ortwein, 2015). There are minimal explorations of how doctoral education integrates open-mindedness into its curriculum and pedagogy nor investigations on whether gender or disciplines effect open-mindedness.

VI. Limitations and Future Scope

The most important limitation of this study is the small sample size. There is a lack of sufficient representation of all demographic variables considered in the study. Many levels within a few demographic variables were merged to form simple categorical variables. This affected how the interpretations could be made from the regression models built. Also, the adjusted r-squared value is close to zero, indicating that the regression models explain a minimal variance. In the case of EFA results, the variance in the inter-item correlations for both factors is greater than 0.01. The inter-item correlations for a few items are lesser than 0.30. These findings suggest that there may be differences in critical thinking skills among engineering disciplines, but further research is needed to confirm these results and explore potential factors that may explain these differences.

It is interesting to note that some significant differences in the 'being critical' scores were observed between a few disciplines. Conducting a focused study on these particular disciplines would be beneficial to understand how critical thinking varies among different engineering disciplines. In particular, a study to understand if differences exist between social science and engineering researchers could provide valuable insights to the community.

The current study focused on the attributes of the research mindset found by (Kavale & Carberry, 2023). The items in the survey instrument were created based on the codes generated in this qualitative study. The opinions on 'open mindedness' and 'being critical' are limited to this study and the biases of the participants. A deeper understanding of how 'open mindedness' and 'being critical' are available within doctoral education is needed.

Finally, the current study focused on generalizing only two attributes, 'open mindedness' and 'being critical' of the research mindset. Further studies are needed to explore the remaining four attributes of the research mindset to provide a fuller understanding of research mindset.

References

Abrami, P. C., Bernard, R. M., Borokhovski, E., Wade, A., Surkes, M. A., Tamim, R., & Zhang, D. (2008). *Instructional Interventions Affecting Critical Thinking Skills and Dispositions: A Stage 1 Meta-Analysis.* Review of Educational Research, 78(4), 1102–1134. https://doi.org/10.3102/0034654308326084

Albertyn, R. (2022). *Making a case for Doctoral Intelligence: Conceptualisation and insights for researcher development.* Innovations in Education and Teaching International, 59(6), 623–633. https://doi.org/10.1080/14703297.2021.1899033

Aron, A., Coups, E. J., & Aron, E. (2013). *Statistics for psychology* (6th ed). Pearson.

Ahern, A., Dominguez, C., McNally, C., O'Sullivan, J. J., & Pedrosa, D. (2019). *A literature review of critical thinking in engineering* *education.* Studies in Higher Education, 44(5), 816–828. https://doi.org/10.1080/03075079.2019.1586325

Boud, D., & Lee, A. (2005). *'Peer learning' as pedagogic discourse for research education.* Studies in Higher Education, 30(5), 501–516. https://doi.org/10.1080/03075070500249138

Bramhall, M. D., Gray, L., Corker, C., Garnett, K., & Hill, R. (2012). *Analysis of Critical Thinking Skills in an International, Cross-Institutional Group of Engineering Master's Students.* Industry and Higher Education, 26(4), 323–327. https://doi.org/10.5367/ihe.2012.0109

Branch, S. E., Woodcock, A., & Graziano, W. G. (2015). *Person Orientation and Encouragement: Predicting Interest in Engineering Research: Predicting Interest in Engineering Research.* Journal of Engineering Education, 104(2), 119–138. https://doi.org/10.1002/jee.20068

Brookfield, S. (2012). *Teaching for critical thinking: Tools and techniques to help students question their assumptions* (1st ed). Jossey-Bass.

Brooks, R., Brooks, S., & Goldstein, S. (2012). *The Power of Mindsets: Nurturing Engagement, Motivation, and Resilience in Students.* In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), Handbook of Research on Student Engagement (pp. 541–562). Springer US. https://doi.org/10.1007/978-1-4614-2018-7_26

Brunhaver, S. R., Bekki, J. M., Carberry, A. R., London, J. S., & McKenna, A. F. (2018). *Development of the Engineering Student Entrepreneurial Mindset Assessment (ESEMA).* Advances in Engineering Education, 7(1). https://eric.ed.gov/?id=EJ1199672

Caratozzolo, P., Alvarez-Delgado, A., & Hosseini, S. (2019). *Strengthening critical thinking in engineering students.* International Journal on Interactive Design and Manufacturing (IJIDeM), 13(3), 995–1012. https://doi.org/10.1007/s12008-019-00559-6

Cattell, R. B. (1966). *The Scree Test For The Number Of Factors.* Multivariate Behavioral Research, 1(2), 245–276. https://doi.org/10.1207/s15327906mbr0102_10

Clark, J., & Johnstone, J. (2018). *Exploring the Research Mindset and Information-Seeking Behaviors of Undergraduate Music Students.* College & Research Libraries, 79(4), 499–516. https://doi.org/10.5860/crl.79.4.499

Clarkson, D. B., & Jennrich, R. I. (1988). *Quartic rotation criteria and algorithms.* Psychometrika, 53(2), 251–259. https://doi.org/10.1007/BF02294136

Cronbach, L. J. (1951). *Coefficient alpha and the internal structure of tests.* Psychometrika, 16(3), 297–334. https://doi.org/10.1007/BF02310555

Dougherty, D. (2013). *Design, make, play: Growing the next generation of STEM innovators* (M. Honey & D. Kanter, Eds.). Routledge.

Douglas, E. P. (2012). *Defining and Measuring Critical Thinking in Engineering.* Procedia - Social and Behavioral Sciences, 56, 153–159. https://doi.org/10.1016/j.sbspro.2012.09.642

Dweck, C. S. (2006). *Mindset: The new psychology of success* (1st ed). Random House.

Dweck, C. S. (2011). *Implicit Theories. In Handbook of Theories of Social Psychology* (pp. 43–61). Sage. https://www.torrossa.com/en/resources/an/4912667

Eilers, K., Peters, C., & Leimeister, J. M. (2022). *Why the agile mindset matters.* Technological Forecasting and Social Change, 179, 121650. https://doi.org/10.1016/j.techfore.2022.121650

Ericsson, K. A., & Simon, H. A. (1993). *Protocol Analysis: Verbal Reports as Data.* The MIT Press. https://doi.org/10.7551/mitpress/5657.001.0001

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., & Strahan, E. J. (1999). *Evaluating the use of exploratory factor analysis in psychological research.* Psychological Methods, 4(3), 272–299. https://doi.org/10.1037/1082-989X.4.3.272

Facione, P. A., Gittens, C. A., & Facione, N. C. (2016). *Cultivating A Critical Thinking Mindset.* Academia. Edu. Weekly Digest, 28. http://www.measuredreasons.com/

Fang, Z., Chang, B., & Dang, J. (2022). *Growth mindset matters: Influences of socioeconomic status on Chinese secondary vocational students' learning engagement.* Journal of Pacific Rim Psychology, 16, 183449092211419. https://doi.org/10.1177/18344909221141984

French II, R. P. (2016). *The fuzziness of mindsets: Divergent conceptualizations and characterizations of mindset theory and praxis.* International Journal of Organizational Analysis, 24(4), 673–691. https://doi.org/10.1108/IJOA-09-2014-0797

Golde, C. M. (2005). *The Role of the Department and Discipline in Doctoral Student Attrition: Lessons from Four Departments.* The

Journal of Higher Education, 76(6), 669–700. https://doi.org/10.1080/00221546.2005.11772304

Golde, C. M., & Dore, T. M. (2001). *At Cross Purposes: What the Experiences of Today's Doctoral Students Reveal about Doctoral Education.* Wisconsin Univ., Madison.

Gollwitzer, P. M., & Bayer, U. C. (1999). *Deliberative versus implemental mindsets in the control of action.* In Dual-process theories in social psychology (pp. 403–422). Guilford Pr.

Gupta, A. K., & Govindarajan, V. (2002). *Cultivating a global mindset.* Academy of Management Perspectives, 16(1), 116–126. https://doi.org/10.5465/ame.2002.6640211

Horn, J. L., & Engstrom, R. (1979). *Cattell's Scree Test in Relation to Bartlett's Chi-Square Test and Other Observations on the Number of Factors Problem.* Multivariate Behavioral Research, 14(3), 283–300. https://doi.org/10.1207/s15327906mbr1403_1

Kavale, S. M., & Carberry, A. R. (2023, June). *Attributes of Research Mindset for Early Career Engineering Researchers.* 2023 ASEE Annual Conference & Exposition, Baltimore, Maryland. https://peer.asee.org/42344

Kutner, M. H., Nachtsheim, C. J., Neter, J., & Li, W. (2005). *Applied linear statistical models* (5th ed). McGraw-Hill Irwin.

Kveven, A., Searle, J., & Araniva, R. (2014). *Creating a Research Mindset. In Tapping the potential of all: Undergraduate research at community colleges* (p. 51). Council on Undergraduate Research.

Lee Chuen, K., Chee Siaw, S., & Loh, L. (2019). *Young Researcher Programme: An Inquiry-based Learning to Cultivate Innovation and Research Mindset.* 730–740.

Leshner, A., & Scherer, L. (Eds.). (2018). *Graduate STEM Education for the 21st Century* (p. 25038). National Academies Press. https://doi.org/10.17226/25038

Maier, A., Škec, S., Kim, H., Kokkolaras, M., Oehmen, J., Fadel, G., Salustri, F., & Van der Loos, M. (2017). *Towards a DT mindset tool evaluation: Factors identification from theory and practice.* Design Processes, Design Organisation and Management, 2, 367–376.

McCoach, D. B., Gable, R. K., & Madura, J. P. (2013). *Instrument development in the affective domain: School and corporate applications* (3rd ed). Springer.

McEachern, K. P., & Horton, J. L. (2016). *Developing a Research Identity: Promoting a Research Mindset Among Faculty and Students.* The Educational Forum, 80(4), 444–456. https://doi.org/10.1080/00131725.2016.1206159

McGartland Rubio, D. (2005). *Content Validity. In Encyclopedia of Social Measurement* (pp. 495–498). Elsevier. https://doi.org/10.1016/B0-12-369398-5/00397-2

Naumann, C. (2017). *Entrepreneurial Mindset: A Synthetic Literature Review.* Entrepreneurial Business and Economics Review, 5(3), 149–172.

Ortwein, M. J. (2015). *The Regulation of Understanding through Intellectual Virtue: Some Implications for Doctoral Education.* Journal of Thought, 49(1–2), 71. https://doi.org/10.2307/jthought.49.1-2.71

Özyurt, Ö. (2015). *Examining the Critical Thinking Dispositions and the Problem Solving Skills of Computer Engineering Students.* EURASIA Journal of Mathematics, Science and Technology Education, 11(2). https://doi.org/10.12973/eurasia.2015.1342a

Prasad, S., & Bhat, R. S. (2021). *India Industry-University Collaboration—A Novel Approach Combining Technology, Innovation, and Entrepreneurship.* 2021 IEEE Global Engineering Education Conference (EDUCON), 373–380. https://doi.org/10.1109/EDUCON46332.2021.9454090

Sola, E., Hoekstra, R., Fiore, S., & McCauley, P. (2017). *An Investigation of the State of Creativity and Critical Thinking in Engineering Undergraduates.* Creative Education, 08(09), 1495–1522. https://doi.org/10.4236/ce.2017.89105

Someren, M. W. van, Barnard, Y. F., & Sandberg, J. A. (1994). *The think aloud method: A practical guide to modelling cognitive processes*. Academic Press.

Slocum-Gori, S. L., & Zumbo, B. D. (2011). *Assessing the Unidimensionality of Psychological Scales: Using Multiple Criteria from Factor Analysis.* Social Indicators Research, 102(3), 443–461. https://doi.org/10.1007/s11205-010-9682-8

Theodorsson-Norheim, E. (1986). *Kruskal-Wallis test: BASIC computer program to perform nonparametric one-way analysis of variance and multiple comparisons on ranks of several independent samples.* Computer Methods and Programs in Biomedicine, 23(1), 57–62. https://doi.org/10.1016/0169-2607(86)90081-7

Thurbon, E. (2016). *Developmental Mindset: The Revival of Financial Activism in South Korea.* Cornell University Press. https://doi.org/10.7591/9781501704178

Tiruneh, D. T., Verburgh, A., & Elen, J. (2014). *Effectiveness of Critical Thinking Instruction in Higher Education: A Systematic Review of Intervention Studies.* Higher Education Studies, 4(1), p1. https://doi.org/10.5539/hes.v4n1p1

Vargha, A., & Delaney, H. D. (1998*). The Kruskal-Wallis Test and Stochastic Homogeneity.* Journal of Educational and Behavioral Statistics, 23(2), 170–192. https://doi.org/10.3102/10769986023002170

Velicer, W. F. (1976). *Determining the number of components from the matrix of partial correlations.* Psychometrika, 41(3), 321–327. https://doi.org/10.1007/BF02293557

Zingoni, M., & Corey, C. M. (2017). *How Mindset Matters: The Direct and Indirect Effects of Employees' Mindsets on Job Performance.* Journal of Personnel Psychology, 16(1), 36–45. https://doi.org/10.1027/1866-5888/a000171

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