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Student epistemological beliefs and learning attitudes in STEM education in a work integrated learning setting: an empirical assessment

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Student Epistemological Beliefs and Learning Attitudes in STEM Education in a Work Integrated Learning Setting: An Empirical Assessment

Theories such as cognitive learning theory and fuzzy trace theory suggest that factors such as gender, age, qualification, work experience define learners' epistemological beliefs and learning attitudes, which in turn affect their learning. This study aims to investigate the relationship between learner attributes such as age-group, gender and program stage, and their epistemological beliefs and learning attitudes. The study is conducted in a Work Integrated Learning (WIL) setting grouping the learners as young adults (aged 18-21), middle (22-29), and seniors (30+). About 650 learners from STEM disciplines undertaking undergraduate and graduate programs are included. The study employs an instrument based on the CLASS (Colorado Learning Attitudes about Science Survey) suitably modified for Mathematics to assess the epistemological beliefs and learning attitudes of these learners who are also working professionals. While such studies have been conducted in the past, they were limited to traditional students on campuses, all of whom belonged to a single age group. Findings suggest that there are significant differences across all three attributes. We believe that understanding such patterns will help to develop instructional strategies that are better suited for the learners in this setting.

I. Introduction:

Cognitive learning theory such as cognitive load theory [1] and more recently fuzzy trace theory [2] suggest that learners differ in their epistemological beliefs and attitudes, and factors such as age and gender influence them. However, the popular instructional models adopted in higher education are built with the belief that the learners are uniform [3]. This unfounded belief can adversely affect their learning. Hence it is important to understand how the epistemological beliefs and attitudes evolve over the years and whether gender influences them.

This study is undertaken to find the differences in the epistemological beliefs and attitudes among learners in a set of higher education programs that are offered to a wide range of participants in a work integrated learning setting. The methodology and findings are discussed.

II. Background:

A. Epistemological beliefs and Attitudes

Beliefs are "part of a system that includes our values and attitudes, plus our personal knowledge, experiences, opinions, prejudices, morals and other interpretive perceptions of the social world" [4]. Belief formation is often based on personal experience and evolves gradually over time [5]

[6]. Beliefs also play an important and complex role in culture, social systems, and socialization processes because they serve as group norms and values [7]. Educational researchers have even argued that beliefs are the most valuable psychological construct to study in education [8] [9]

Epistemological beliefs refer to the individuals' views about the nature of knowledge and learning. Studies have linked several factors such as educational level, field of study and gender to epistemological beliefs [10] [11]. Jehng et al. connected educational level and field of study to epistemological beliefs. They found that students in "soft" fields and graduate programs tend to view knowledge as more uncertain and learning as less orderly. Epistemological beliefs are related to gender role attitudes, with more sophisticated beliefs predicting less stereotypical attitudes [11]. Students with "sophisticated" epistemological beliefs tend to be more intrinsically motivated, use higher-level learning strategies, and report better academic performance [12]. Conversely, "naïve" beliefs can hinder knowledge integration and promote superficial learning. Therefore, we can infer that creating opportunities for knowledge construction, providing guidance in knowledge organization, and emphasizing sophisticated perspectives in classroom discussions can lead to more sophisticated epistemological beliefs.

Attitudes are beliefs the students hold about a given subject. In particular, engineering students bring with them a set of perceived attitudes about engineering and their own self-assessed abilities. These attitudes and how they change throughout a student's education potentially affects his/her perceptions of engineering, motivation to learn, self-confidence, competency, performance, and retention in an engineering program [13]. Further, attitudes developed during the undergraduate years can affect the extent that the graduate "engages in lifelong learning," understands "the impact that engineering solutions have on society," and remains knowledgeable of "contemporary issues." Hence, using attitudes to assess aspects of engineering programs provide valuable information for making programmatic and pedagogical improvements [13].

Most studies of epistemological beliefs and student attitudes have focused on students in traditional settings, which are homogenous and focused on a single age group. This limits the ability to understand the influence of various demographical variables on beliefs and attitudes. This study has been conducted in a work integrated learning setting with students from multiple programs, which ensured a level of diversity in terms of age, gender and program stage.

III. Methodology:

A. Research context

1. Work Integrated Learning (WIL):

Rowe et al. [14] define work-integrated learning and its defining elements as an educational approach involving three parties – the student, educational institution, and an external stakeholder – consisting of authentic work-focused experiences as an intentional component of the curriculum. Students learn through active engagement in purposeful work tasks, which enable the integration of theory with meaningful practice that is relevant to the students' discipline of study and/or professional development. There are two popular modes in which WIL is offered; cooperative education for campus students or continuing education for working professionals. In the case of the latter, which is the chosen setting for this study, the population of learners is usually heterogeneous. They differ in gender, age, qualification, work experience, and other factors.

2. Attitudes towards Mathematics:

The WIL setting chosen for this study offers a range of programs in engineering. Studies show that Mathematics is critical for achievement in STEM disciplines [15]. Hence, learning attitudes towards Mathematics have been chosen as the subject for this study.

3. Heterogeneity:

This particular WIL setting offers undergraduate and graduate programs in STEM fields to working professionals across various levels and fields of employment. The programs have varying entry criteria with some bachelor's programs admitting students directly after high school with little to no experience, master's programs that require a bachelor's degree, and master's programs that require a bachelor's degree along with work experience as an eligibility criteria for admission. These criteria result in the cohorts consisting of students in 3 distinct age groups; young adults (aged 18-21 years), middle group (22-29 years), and seniors (30+ years). The programs are described in the Design section of this paper.

B. Research Questions

Given this heterogeneity, this study attempts to assess the attitudes of students towards mathematics and the influence of age and gender. The study also attempts to track the change in the attitude as they progress through the program. The research questions in particular are:

1. Are there differences in attitudes towards Mathematics based on age-group?
2. Are there differences in attitudes towards Mathematics based on gender?
3. Are there differences in attitudes based on semester of study?

C. Design

In order to answer these research questions, a sample was needed from the programs that have mathematics as an essential subject. The sample had to contain representative populations across age groups and gender. Considering these requirements, students were drawn from the following three categories of programs:

1. Bachelor of Science, Design and Computing: a three-year program admitting high school graduates employed in the IT industry.
2. Integrated MTech programs in Computing Systems, Software Systems, and Software Engineering: Four-year programs admitting students with Bachelor in Science degrees employed in the IT industry.
3. MTech programs in Design Engineering, and Data Science and Engineering: Two-year programs admitting students with undergraduate degrees in engineering employed in the engineering or IT industries.

The students from the first and second semesters were included, as these semesters had at least one math course. Students from the first category of programs formed the young adult group (aged 18- 21 years), those from the second category formed the middle group (22- 29 years). The selected survey instrument was shared with all the participants in the first and second semesters of the first two categories of programs. For category 3, we adopted a purposive sampling strategy, by which students who were 30+ years of age were included in the survey. These students formed the senior group (30+ years).

D. Participants

The survey was circulated among students from six programs that had at least one math course across the WIL offerings. The participants were grouped as young adults (aged 18-21), middle (22-29), and seniors (30+). A total of 675 students participated in the survey. The survey was circulated online through the coordinators of the respective programs. Details of the participants are listed in the Table I.

Table I

Participants

Adult Group	No. of Respondents	No. of Female Respondents	No. of Male Respondents	No. of Respondents from Semester I	No. of Respondents from Semester II
Young	237	102	134	35	202
Middle	333	143	190	60	273
Senior	105	21	84	33	47
Total	675	266	408	128	522

E. Instrument

We considered 7 popular instruments meant for studying attitudes towards STEM subjects. The Fennema Sherman Mathematics Attitude Scale developed in the 1970’s is a survey with 108 items that looks at 9 scales of attitudes towards the learning of Mathematics [16]. The Mathematics Attitude Scale for Adults looks at the Affective, Behavioural and Cognitive dimensions of dispositions towards Mathematics [17]. The Abbreviated Mathematics Anxiety Scale [18] particularly looks at mathematics anxiety related to learning and testing. There is a Single Item Math Anxiety Scale [19] looking at self-reported general anxiety towards the subject, while the Math Anxiety Questionnaire for Adults [20] looks at anxiety towards problem solving.

In 2006, Adams et. al. designed a survey, Colorado Learning Attitudes About Science Survey (CLASS) to understand learning attitude towards physics [20]. This survey probed students' beliefs about physics and learning physics, and distinguished the beliefs of experts from those of novices. There are eight categories of attitudes in this survey; Personal Interest, Real World Connection, Problem Solving (General), Problem Solving Confidence, Problem Solving Sophistication, Sense Making/Effort, Conceptual Understanding, and Applied Conceptual Understanding. This instrument is widely used for pre and post analysis after an intervention such as a course, as a predictor of performance, and to select instructional strategies. The CLASS was originally meant to study attitudes towards Physics, and was later repurposed for Chemistry and Biology [21] [22].

CLASS was selected for this study considering its popularity, comprehensiveness and availability. As this study focuses on Mathematics, we have repurposed the CLASS instrument to study attitudes towards Mathematics, which is an essential subject in the program under investigation. A similar attempt was also made by Firouzian in 2019 for Mathematics [23]. The CLASS for Physics was used as the basis for creating the instrument for Mathematics adopting the following process. The term "Physics" in the CLASS Physics was replaced with "Mathematics" in each of the items in the instrument. The resulting instrument was reviewed by two experts in Mathematics and Physics, who suggested minor changes in the questions. This resulted in 42 statements that were to be rated on a 5-point Likert Scale ranging from Strongly Disagree to Strongly Agree. The experts also discussed 8 tentative categories of attitudes towards Mathematics based on the Physics categories. Similar to the development of the CLASS Physics, our approach was a combination of using a Confirmatory Factor Analysis (CFA) and Exploratory Factor Analysis (EFA) [21].

In the Confirmatory Factor Analysis, the Cronbach's Alpha values for the constructs revealed varying levels of internal consistency. Constructs like Conceptual Understanding (0.816) and Problem Solving Confidence (0.718) demonstrated good reliability, indicating strong interrelatedness among their items. Constructs such as Personal Interest (0.697), Advanced Conceptual Understanding (0.697), Real World Connection (0.642) and Problem Solving Sophistication (0.679) exhibited moderate reliability, and may require slight refinement for improvement. However, constructs like Sense Making Effort (0.432) and Problem Solving General (0.561) showed lower reliability, suggesting a need for reviewing the questions within these constructs to enhance clarity and alignment with their respective dimensions. Overall, while some constructs were robust, others required refinement to ensure their consistency and validity.

Furthermore, the CFA model did not meet acceptable thresholds for a good fit across multiple indices such as Chi-square Test, Comparative Fit Index, Tucker Lewis Index, etc. These results supported the decision to use Exploratory Factor Analysis (EFA) to identify a new, more reliable set of factors that better capture the underlying structure of the data.

The Bartlett's Test of Sphericity (chi-square p value < 0.001) confirmed that the variables were sufficiently correlated to perform factor analysis. A Kaiser-Meyer-Olkin factor adequacy of 0.89 was obtained. A value above 0.80 indicates that the dataset is highly suitable for factor analysis, with strong shared variance among the variables. These results suggest that there was adequate shared variance in the dataset, and the correlations among variables were sufficient to uncover latent dimensions. After the Exploratory Factor Analysis was performed, five different constructs emerged. These constructs included 32 of the 42 statements in the survey. 10 statements were unused. Table II shows the values of Cronbach's Alpha for each of the five constructs:

Table II

Internal Consistency

Construct No.	**Cronbach's Alpha**
1	0.9098
2	0.8592
3	0.6379
4	0.6073
5	0.6590

On examining the questions that came under each construct, it was noticed that they aligned with some of the predetermined categories, as well as with the categories and questions in earlier Math attitude instruments. This led to the creation of 5 categories of attitudes towards Mathematics;

1. Math Anxiety and Dependence on Memorization,
2. Interest and Real-world Relevance,
3. Need for Deep Understanding and Clarity,
4. Doubt and Lack of Confidence in Understanding, and
5. Perseverance and Adaptability in Problem Solving.

F. Research Methods:

This study employs quantitative research methods such as ANOVA to determine whether there are significant differences between the three adult groups and Post hoc Tukey HSD tests to identify specific differences between groups. T tests are used to identify whether there were significant differences in attitudes based on gender and semester. The study considers an alpha value of 0.05 as the threshold for significance.

IV. Findings

A. Differences in attitudes towards Mathematics based on age-group

A one-way ANOVA was used to determine whether there are significant differences between the three adult groups; young adults (aged 18-21 years), middle (22-29 years), and seniors (30+ years). Post hoc Tukey HSD tests were conducted to identify specific differences between groups. The ANOVA results shown in Table III indicate that there are statistically significant differences among the three adult groups for all five factors.

TABLE III

Differences by Age-group

Factor	Construct Name	F-value	p-value	Interpretation
ML1	Math Anxiety and Dependence on Memorization	18.01	3.14e-08	Significant difference ($p < 0.001$)
ML2	Interest and Real-World Relevance	5.15	6.19e-03	Significant difference ($p < 0.01$)
ML3	Need for Deep Understanding and Clarity	5.88	3.03e-03	Significant difference ($p < 0.01$)
ML4	Doubt and Lack of Confidence in Understanding	13.70	1.73e-06	Significant difference ($p < 0.001$)
ML5	Perseverance and Adaptability in Problem Solving	8.49	2.42e-04	Significant difference ($p < 0.001$)

The post HOC Tukey HSD tests report the following:

Math Anxiety and Dependence on Memorization: The senior group reported significantly higher levels of math anxiety and reliance on memorization compared to the middle group (diff = 0.538, $p < 0.001$). Young group reported significantly lower levels than the middle group (diff = -0.251, $p = 0.048$). Young group reported much lower levels than the senior group (diff = -0.789, $p < 0.001$). This shows that the senior group experiences the highest levels of math anxiety and reliance on memorization, followed by the middle group, and then the young group, who report the lowest levels.

Interest and Real-world Relevance: The senior group reported significantly higher interest and perceived real-world relevance of math compared to the middle group (diff = 0.410, $p = 0.004$). No significant differences were observed between young vs. middle and young vs. senior groups. The senior group perceives math as more interesting and relevant to real-world situations compared to the middle group. There is no significant difference between the Young and other groups, suggesting that this construct is more pronounced among seniors relative to the Young and middle groups.

Need for Deep Understanding and Clarity: Seniors report a significantly higher need for deep understanding and clarity compared to the middle group (diff = 0.429, $p = 0.003$). Young group reports significantly lower need for deep understanding and clarity compared to the senior group (diff = -0.381, $p = 0.014$). The senior group exhibits the highest levels of need for deep understanding and clarity, followed by the middle and then the young group.

Doubt and Lack of Confidence in Problem Solving: Senior group reported significantly higher doubt and lack of confidence compared to the middle group (diff = 0.472, $p < 0.001$). Young group reported significantly lower levels of doubt, thus, a higher level of confidence compared to the senior group (diff = -0.696, $p < 0.001$). The senior group experiences the most self-doubt and lack of confidence in understanding math concepts, followed by the middle and then the young group.

Perseverance and Adaptability in Problem Solving: Senior group shows significantly lower perseverance and adaptability in problem solving compared to the middle group (diff = -0.497, $p < 0.001$). Young group shows higher perseverance and adaptability in problem solving than the senior group (diff = 0.485, $p = 0.001$). The senior group has the lowest perseverance and adaptability in problem solving, while the young group shows the highest.

The findings related to age-group are summarized in TABLE IV below.

Table IV
Learning Attitudes Towards Mathematics and Age-group

Dimension	**Statistically Significant Difference Between Age Groups**	**Details**
Math Anxiety and Dependence on Memorization	Yes	Senior > Middle > Young
Interest and Real-world Relevance	Yes	Senior > Middle Young ~ Middle Young ~ Senior
Need for Deep Understanding and Clarity	Yes	Senior > Middle > Young
Doubt and Lack of Confidence in Understanding	Yes	Senior > Middle > Young
Perseverance and Adaptability in Problem Solving	Yes	Young > Middle > Senior

B. Differences in attitudes towards Mathematics based on gender:

Based on the findings of the T-test, there is no statistically significant difference in "Math Anxiety and Dependence on Memorization", “Need for Deep Understanding and Clarity”, and “Perseverance and Adaptability in Problem Solving” between male and female participants. The difference between males and females on "Interest and Real-World Relevance" is marginally significant ($p = 0.085$) considering an alpha of 0.1. Males reported a slightly higher intrinsic interest and perceived real-world applicability of math concepts compared to females, though this difference is not statistically significant at the 0.05 level. There is a statistically significant difference in "Doubt and Lack of Confidence in Understanding" between genders ($p = 0.004$), with females scoring lower (mean = -0.163) than males (mean = 0.111). This suggests that females may experience higher levels of self-doubt and lack of confidence in understanding math concepts compared to males. Table V shows the consolidated findings based on gender.

Table V

Learning Attitudes Towards Mathematics and Gender

Construct Name	t-value	p-value	Degrees of Freedom	Mean (Male)	Mean (Female)	Interpretation
Math Anxiety and Dependence on Memorization	-0.91	0.365	366.85	0.039	-0.051	No significant difference
Interest and Real-World Relevance	-1.73	0.085	362.20	0.070	-0.102	Marginally significant (considering $\alpha = 0.1$) Males > Females
Need for Deep Understanding and Clarity	0.51	0.614	388.97	-0.020	0.029	No significant difference
Doubt and Lack of Confidence in Understanding	-2.87	0.004	401.78	0.111	-0.163	Significant difference ($p < 0.01$) Females > Males
Perseverance and Adaptability in Problem Solving	1.62	0.105	409.48	-0.063	0.092	No significant difference

C. Differences in attitudes towards Mathematics based on semester:

The survey participants were either in the first or second semesters of their respective programs. Based on the findings of the t-test, there is no statistically significant difference in “Perseverance and Adaptability in Problem Solving”. There is a statistically significant difference in the other four constructs. Students in Semester 1 have a much higher mean score in “Math Anxiety and Dependence on Memorization”, “Need for Deep Understanding and Clarity”, and “Doubt and Lack of Confidence in Understanding” than the students in Semester 2. When it comes to “Interest and Real-world Relevance”, students in Semester 2 have a higher mean score than those in Semester 1. From this, we can see that student attitudes on most constructs seem to improve with time from Semester 1 to Semester 2. Table VI summarizes these findings.

TABLE VI

LEARNING ATTITUDES TOWARDS MATHEMATICS AND SEMESTER

Construct Name	**t-value**	**p-value**	**Degrees of Freedom**	**Mean (Semester 1)**	**Mean (Semester 2)**	**Interpretation**
Math Anxiety and Dependence on Memorization	5.77	2.88e-08	204.12	0.439	-0.137	Significant difference (p < 0.001) Semester 1 > Semester 2
Interest and Real-World Relevance	-2.19	0.030	140.12	-0.216	0.069	Significant difference (p < 0.05) Semester 2 > Semester 1
Need for Deep Understanding and Clarity	4.15	5.60e-05	153.02	0.376	-0.120	Significant difference (p < 0.001) Semester 1 > Semester 2
Doubt and Lack of Confidence in Understanding	4.84	3.00e-06	160.43	0.422	-0.134	Significant difference (p < 0.001) Semester 1 > Semester 2
Perseverance and Adaptability in Problem Solving	-0.80	0.424	125.87	-0.088	0.028	No significant difference

V. Discussion:

The one-way ANOVA results indicate significant differences across adult groups (Young, Middle, Senior) for all five constructs, suggesting that attitudes and approaches toward math differ by age-group.

The Senior group reported the highest levels of Math Anxiety and Dependence on Memorization, Need for Deep Understanding and Clarity, and Doubt and Lack of Confidence in Understanding, but the lowest levels of Perseverance and Adaptability in Problem Solving. They also perceive

Interest and Real-World Relevance of math more strongly than the Middle group. This pattern suggests that while older adults understand that math has real-world relevance and feel the need to understand it deeply, they have more doubts and lesser confidence in their abilities, which leads them to feel more anxious and depend on memorization.

The Middle group showed intermediate levels across most factors, with no significant differences from the Young group on several constructs. They scored lower than the Senior group on Interest and Real-World Relevance, and Need for Deep Understanding and Clarity.

The Young group reported the lowest levels of Math Anxiety and Dependence on Memorization, and Doubt and Lack of Confidence in Understanding, and the highest Perseverance and Adaptability in Problem Solving. This indicates a more positive attitude toward math in terms of anxiety, confidence and perseverance.

In a K-12 study, it was found that confidence in one's own mathematics abilities decreased with age, as a student transitioned from elementary to middle school to high school [24]. Given the results seen in this study, it could well be that this pattern continues for higher age-groups as well. These findings suggest that certain age-group targeted educational interventions might be of value within this WIL setting. This is feasible as many of the programs are naturally segregated by age-group based on their entry criteria. For older adults, interventions focusing on building confidence in math and reducing reliance on memorization might be of value. Encouraging deeper conceptual understanding and leveraging on their existing awareness of real-world connections might help with the Senior group's anxiety, self-doubt and perseverance. For younger adults, strategies to bring forth real-world connections, possibly within their workplace given the WIL setting, could help to enhance understanding, problem-solving skills and encourage long-term engagement with Mathematics.

When it comes to gender, the findings highlight that gender may influence certain attitudes toward math, specifically in relation to confidence and perceived understanding. This aligns with findings from several studies that women tend to hold more negative attitudes towards mathematics, specifically when it comes to confidence in their abilities [24] [25]. Educational interventions that focus on building confidence and reducing self-doubt could help address the observed gender differences in Doubt and Lack of Confidence in Understanding. Additionally, further exploration of interest in real-world applications of math could provide insights into how to engage both male and female students in math learning.

The results of independent samples t-tests indicate several significant differences between Semester 1 and Semester 2 students across the various math attitude related constructs. Semester 1 students showed higher levels of math anxiety and a tendency to rely on memorization, while Semester 2 students demonstrated greater interest in the subject, found more real-world relevance in math concepts, and displayed increased confidence in their understanding. However, semester 1 students demonstrated a higher need for deep understanding and clarity.

These findings imply that as students progress in their studies, they may develop more positive attitudes toward math and move away from anxiety and dependence on memorization. Instead, they are likely to develop confidence and perceive math as more applicable to real-world situations. The finding for the reduced need for deep understanding as students move from Semester 1 to 2 needs more investigation.

The results suggest that educational interventions aimed at building confidence and reducing math anxiety could be particularly beneficial in the earlier semesters. Encouraging students to explore real-world applications of math early on might also help boost interest and intrinsic motivation. Over time, such interventions could promote a smoother transition to more advanced semesters, where students naturally exhibit increased confidence, reduced anxiety, and a more profound interest in math.

These findings highlight the importance of providing supportive resources in Semester 1, helping students overcome initial doubts and fostering positive attitudes that contribute to long-term academic success in mathematics.

VI. Limitations

An exploratory factor analysis and review of past literature was conducted, which pointed towards the five categories or dimensions of attitudes towards Mathematics learning. In order to ascertain these categories, a Confirmatory Factor Analysis on another set of data using the same instrument would be required.

The semester-wise data is cross-sectional and not longitudinal in nature. This study has not compared Semester 1 and Semester 2 perceptions of the same students as they progress through the program. The results, while indicative of an overall pattern of improvement in attitudes towards learning Mathematics from semester 1 to semester 2, will have to be confirmed with longitudinal data.

While this study considered demographic variables such as age-group, gender and program stage, it would be interesting to see whether socio-economic factors and location have an influence on attitudes. Further, studies exploring relationships between attitudes and variables such as attendance, grades, engagement would enhance the understanding of how attitudes affect learning, and support the selection of appropriate instructional strategies.

VII. Conclusion

Cognitive learning theories, as well as studies on epistemological beliefs and learning attitudes, all point towards differences based on backgrounds and experiences. The results obtained from this study reinforce such findings. This study concludes that in this WIL setting, attitudes towards learning Mathematics change distinctly with age, are different based on gender, and also go through transformation as students progress through the program.

The Senior group (aged 30+ years) reported the highest levels of math anxiety and reliance on memorization compared to the younger cohorts. Seniors also reported the highest interest in math and its real-world relevance. The Senior group showed the greatest need for deep understanding and clarity. In terms of self-doubt and lack of confidence, the Senior group had the highest levels, followed by the Middle (22- 29 years) and Young (18- 21 years) groups. Finally, the Senior group exhibited the lowest perseverance and adaptability in problem-solving, while the Young group showed the highest. With regards to gender, the most notable difference is in "Doubt and Lack of Confidence in Understanding," where females expressed lower confidence and greater self-doubt compared to males across age-groups and semester. With regards to program stage, the overall attitudes towards mathematics improved from Semester 1 to Semester 2 across age-groups and gender.

Understanding these larger attitude patterns would enable educators to select instructional strategies that leverage on a group's overall strengths and support their problem areas.

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