UNDERSTANDING THE INFLUENCE OF PROGRAM OF STUDY AND AGE ON SHARED METACOGNITION WITHIN THE COMMUNITY OF INQUIRY IN STEM EDUCATION

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ABSTRACT

Graduate STEM students need to cultivate transferable skills for effective research before entering the workforce. This study examined the influence of STEM students' program of study (study (MS Data Analytics Engineering -DAEN, MS Applied Information Technology -AIT, PhD Information Technology - IT, MS INFS, and Accelerated MS Applied Information Technology -AIT) and age on their perceived shared metacognition (individual and group) within the Community of Inquiry (CoI) that consists of three presences–teaching, social and cognitive. 149 STEM students participated in the pre-developed inquiry-based research learning modules across different courses and course instructors during one semester. This study found that the program of study can influence cognitive presence (p=0.01) while age influences teaching presence (p=0.02) among three CoI presences. We did not find any influences for the shared metacognition based on the program of study or age. Students had similar perceptions of shared metacognition independent of their age group or the program of study. The findings will help others who are interested in shared metacognition for graduate STEM students.

KEYWORDS

Community of Inquiry, Shared Metacognition, STEM Education

1. INTRODUCTION

Current trends in Science, Technology, Engineering, and Math (STEM) Education dictate the need for more innovative learning approaches to equip a new generation of students with purposeful workforce-related skills. Inquiry-Based Learning (IBL) stands out as one of the most effective and promising instructional strategies to help STEM students develop a range of transferable skills, such as critical thinking, problem-solving, decision-making, and collaborative skills. These are the examples that industry, government, and other employment sectors expect current graduates to demonstrate, along with in-depth content-specific knowledge, by the time of their employment in the rapidly changing landscape of the STEM jobs market (Denecke et al., 2017). As educators actively look for innovative ideas to design IBL, learning that is designed based on the principles of the Community of Inquiry (CoI) shows good promise in its ability to support STEM students with the development of those needed transferrable skills. This design can help promote inquiry skills through collaboration where students learn from each other. CoI admits that IBL occurs at the intersection of the three presences: 1) social presence (SP); 2) teaching presence (TP); and 3) cognitive presence (CP). CP is the construction of meaning through reflection and discourse; SP is the ability to project oneself as an actual person both socially and emotionally in a learning environment; and TP is the design, facilitation, and direction of CP and SP (Garrison et al., 2001). The CoI requires collaborative learning where STEM students not only develop transferrable skills for their future workforce but also develop shared metacognitive skills. Shared metacognition is a cognitive ability to achieve meaningful learning that can be viewed from individual and collaborative perspectives. When shared metacognition is facilitated within the CoI, it can help regulate the cognitive processes of self and others within collaborative learning activities (Garrison & Akyol, 2015).

From an educational approach, knowledge of shared metacognition can guide the implementation of effective facilitation techniques in the collaborative IBL and realize meaningful learning outcomes. In the long term, shared metacognition is the key to understanding how to learn in a collaborative IBL. In our previous studies, we found that more than 80% of the participants who were enrolled in the IBL reported positive perceived shared metacognition across delivery methods (on-site and online) and students' status (domestic in the USA and international) (Olesova et al., 2023, 2024). We also found that international students perceived higher shared metacognition than domestic students. Similarly, on-site students perceived shared metacognition higher than online students. These findings are consistent across all the exploratory studies we have been collecting from Fall 2022 until Spring 2024. While the findings show consistency across the students' status and course delivery mode, our other findings haven't still revealed any consistent patterns on how STEM students' program of study (MS Data Analytics Engineering -DAEN, MS Applied Information Technology -AIT, PhD Information Technology - IT, MS INFS, and Accelerated MS Applied Information Technology -AIT) and age can influence shared metacognition when they are enrolled in the IBL. Arbaugh et al. (2010) found that the program of study influences the students' perceptions of SP, TP, and CP within the CoI in the applied disciplines. The hard, applied disciplines such as engineering and nursing have an emphasis on problem-solving while soft, applied disciplines such as health sciences emphasize transferrable skills for reflective practice and lifelong learning. CP is higher among health disciplines than engineering and nursing. Shea and Bidjerano (2009) found that the program of study can influence how students perceive SP and CP differently while students' academic level can influence the TP. However, Garrison et al. (2010) did not find differences in how the program of study can influence CP. Previous studies on how age influences CoI did not reveal significant differences (Horzum, 2015; Shea & Bidjerano, 2009). However, Akyol et al. (2010) found that young people between the ages of 18 and 22, and elderly between the ages of 48 and 62, perceived CP and TP as the same element of learning. Therefore, our study is an attempt to understand the influence of STEM students' program of study and their age on their perceived shared metacognition within the CoI when students participated in IBL. The research questions were: 1) What is the influence of the STEM students' program of study on the perceived shared metacognition within the CoI in IBL? and 2) What is the influence of the STEM students' age on the perceived shared metacognition within the CoI in IBL?

2. METHODS

This exploratory study used quantitative research methods to examine the influence of the program of study and age on students' perceptions of shared metacognition within the CoI. STEM students were enrolled in IBL courses that were offered both on-site and online in the spring of 2024. The IBL courses in STEM used pre-developed three generic research learning modules and were implemented into three domain-specific courses. The research modules were implemented across different courses and instructors with one common learning goal to introduce students to research activities gradually, consistently, and systematically. The research modules were implemented into the following courses: 1) Algorithms and Data Structures Essentials through a project-based approach intended to put the basis of quantitative research by analyzing various sorting and searching methods on different data samples and comparing their efficiency; 2) Database Management Systems through a research paper to support students in developing and applying research skills to explore and produce creative solutions to relevant industry problems of their choice in data science fundamental knowledge and core data analytics technologies; and 3) Analytics: Big Data to Information through a hands-on, project-based approach to understanding and practicing the nature of data and data analytics, with a focus on the tools and methods of data exploration, statistical summarization, and effective visualization. The final project is prepared and presented in the form of a traditional research report. Three learning modules follow real-world research processes (identifying questions, conducting literature reviews, and performing research). Each module is based on a generic template that includes the following sections: 1)

Selected and annotated learning materials of textbooks, papers, and videos. All materials are grouped into three categories: (a) required: to build a strong foundation in scientific knowledge and understanding, (b) recommended: to provide additional examples and illustrations on the topics covered in the required section, (c) optional: to support students interested in going beyond the required level; 2) Knowledge tests include tests to assess mastery, featuring 10 randomized questions from a large pool of questions in multiple-choice, true/false, and fill-in-the-blank formats. These tests can be retaken as needed, with only the highest score counting towards the final grade; 3) Discussion boards facilitate engagement by having students post drafts and provide meaningful feedback on peers' work; 4) Self-reflection is based on the collaborative assignment where students summarize their experience on the discussion board, present and provide an explanation of one suggestion to improve their assignment or one aspect that they learned or was challenging related to the assignment; and 5) A written assignment aims at organizing their findings, making connections, elaborating ideas, and constructing an argument based on the research they have conducted.

2.1 Participants

A purposefully self-selected sample of 149 graduate STEM students were enrolled in five sections of the three selected Applied Information Technology (AIT) courses that participated in this study in the spring of 2024. All participants were from a public university in the Mid-Atlantic area of the USA. The majority (44.30%, n=66) were from other STEM areas while 39 (26.17%) were from computer science, 38(25.50%) were from information technology, and only six (4.03%) were non-STEM students. Out of 149 students, 87 participants were from MS DAEN; 43 from MS AIT; 10 from PhD IT, 5 from MS INFS, and 4 from Accelerated MS AIT (Figure 1). From this, more than double were taught on-site (n=102/68.46%) compared with online (n=47/31.54%). The sample was 46 (30.87%) domestic students in the USA and 103 (69.13%) international students outside of the USA. Most of the participants were male (60.14%, n = 89) while there were 59 females (39.86%) and approximately half (68.24%, n = 101) of them were 24 or below years old (Figure 2).

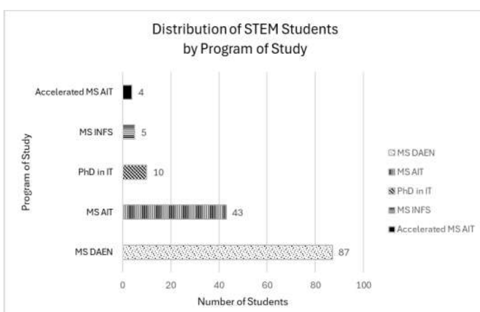

Figure 1. By the program of study (n=149)

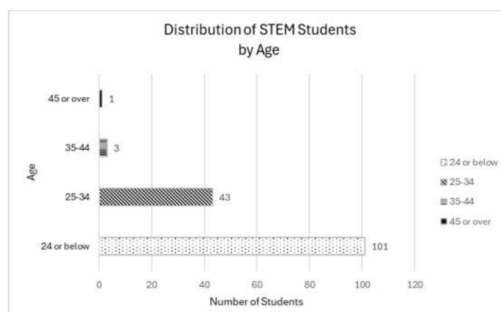

Figure 2. By age (n=149)

2.2 Data Collection and Analysis

The data were collected from the end-of-the-semester anonymous survey based on the 24 shared metacognition items constructed by Garrison and Akyol (2015) at the five-point Likert scale anchored by “Strongly Disagree” and “Strongly Agree.” To analyze the CoI, we used the 16 CoI survey items on a five-point Likert scale where five is “Extremely Agree” and one is “Extremely Disagree.” The CoI survey was validated with Cronbach's Alpha and yielded internal consistencies equal to 0.94 for TP, 0.91 for SP, and 0.95 for CP (Arbaugh et al., 2008). For this study, to examine shared metacognition, we adjusted the original 16 CoI items for the context of our study. We used the five-point Likert scale anchored by “Very Dissatisfied” and “Very Satisfied.” All students were contacted via announcements and asked to complete the survey for bonus points. The collected survey data were analyzed by descriptive statistics to understand the overall patterns across all the sections and track descriptive differences between STEM students by their age and the program of study. Then, we ran a t-test to understand the statistical differences between the age and the program of study. Finally, we applied ANOVA to understand statistical differences across the programs of study.

3. RESULTS AND DISCUSSION

3.1 By the Program of Study

To see if there is a significant difference between the answers based on their program of study, we performed ANOVA tests for each of the categories. The answers to all the questions in a category were averaged per each student and then a single factor ANOVA test was applied for these averages. For instance, for the individual shared metacognition the results are presented in the table below.

Table 1. ANOVA single factor summary by the program of study (n=149)

	Count	Sum	Average	SD
Accelerated MS AIT	4	16.38	4.10	0.62
MS AIT	43	188.54	4.38	0.80
MS DAEN	87	382.60	4.40	0.77
MS INFS	5	21.85	4.37	1.09
PhD in IT	10	41.38	4.14	0.77

Table 2. ANOVA single factor results for the program of study

	SS	df	MS	F	p-value	F crit
Between Groups	0.91	4	0.23	0.37	0.83	2.43
Within Groups	89.35	144	0.62			
Total	90.26	148				

The results indicate that students had similar individual shared metacognition perception in all programs of study (p=0.83). Similar global results were obtained for the other criteria except for CP for which the means were reported as different (p=0.045). For CP, the ANOVA single factor test indicated that there is a difference between groups by the program of study (p=0.045<0.05). Further, to get a clearer image of the differences between the two most representative groups (MS DAEN and MS AIT) we performed t-tests for each of the questions and the cumulative results. All the answers were similar except for the following questions (for the first three the results of the t-test are included). It is important to remark that in all these situations the average results of the MS AIT were lower than the average of MS DAEN.

Table 3. T-test results for shared metacognition differences by the program of study (n=149)

Shared Metacognition Survey Items	MS DEAN	MS AIT	t-test p-value
Item 8: When I am engaged in the learning process as a member of a GROUP in the Discussion Boards in the Research Modules [I request information from others.]	M=4.34 SD=0.90	M=3.91 SD=1.23	p=0.013
Item 10: When I am engaged in the learning process as a member of a GROUP in the Discussion Boards in the Research Modules [I help the learning of others.]	M=4.41 SD=0.92	M=4.09 SD=1.06	p=0.039
Item 11: When I am engaged in the learning process as a member of a GROUP in the Discussion Boards in the Research Modules [I monitor the learning of others.]	M=4.23 SD=1.04	M=3.84 SD=1.35	p=0.035

Table 4. T-test results for the CoI differences by the program of study (n=149)

CoI Survey Items	MS DEAN	MS AIT	t-test p-value
The instructor communicated important course goals (TP).	M=4.68 SD=0.66	M=4.40, SD=1.00	*p*=0.02
The instructor helped to keep course participants engaged and participating in productive dialogue (TP).	M=4.65 SD=0.62	M=4.40, SD=1.11	*p*=0.05
Getting to know other course participants gave me a sense of belonging in the course (SP).	M=4.43 SD=0.71	M=4.00, SD=1.31	*p*=0.01
I felt comfortable interacting with other course participants (SP).	M=4.49 SD=0.73	M=4.20, SD=1.08	*p*=0.03
Research module activities enhanced my curiosity (CP).	M=4.45 SD=0.76	M=4.05, SD=1.29	*p*=0.01
I felt motivated to explore course content-related questions (CP).	M=4.51 SD=0.66	M=4.02, SD=1.14	*p*=0.00
I utilized a variety of provided information sources to explore the topics in research modules (CP).	M=4.49 SD=0.70	M=4.23, SD=0.95	*p*=0.04
Research learning activities helped me construct explanations/solutions about my selected research topic (CP).	M=4.55 SD=0.61	M=4.21, SD=1.08	*p*=0.04
Reflection on research module content and discussions helped me understand fundamental concepts in this class (CP).	M=4.53 SD=0.61	M=4.21, SD=1.08	*p*=0.02
I can describe ways to test and apply the research knowledge created in this course (CP).	M=4.52 SD=0.70	M=4.16, SD=1.11	*p*=0.01
Based on my research experience, I can describe ways to test and apply the domain knowledge created in this course (CP).	M=4.52 SD=0.71	M=4.07, SD=1.20	*p*=0.00
In my research activities, I have developed solutions to course problems that can be applied in practice (CP).	M=4.52 SD=0.71	M=4.05, SD=1.20	*p*=0.00
Based on my research activities, I can develop solutions to problems that can be applied in practice (CP).	M=4.53, SD=0.71	M=4.07, SD=1.26	*p*=0.00
I can apply the research knowledge created in this course to my work or other non-class related activities (CP).	M=4.48, SD=0.76	M=4.16, SD=1.02	*p*=0.02
CP Overall	M=4.49, SD=0.62	M=4.17, SD=0.98	*p*=0.01

3.2 By Age

To see if there is a significant difference based on their age, we performed ANOVA tests for each of the categories. The answers to all the questions in a category were averaged per each student and then a single factor ANOVA test was applied for these averages. For instance, for the individual shared metacognition the results are presented in Tables 5-6 below.

Table 5. ANOVA single factor summary by the STEM students' age (n=149)

	Count	Sum	Average	Variance	t-test p-value
24 or below	101	446.35	4.42	0.52	0.60
25-34	43	181.94	4.23	0.87	
35-44	3	13	4.33	0.33	0.39

Table 6. ANOVA single factor results by the STEM students' age (n=149)

	SS	df	MS	F	p-value	F crit
Between Groups	1.07	2	0.54	0.87	0.42	3.06
Within Groups	88.78	144	0.62			
Total	89.85	146				

The results indicate that students had similar individual shared metacognition perception independent of their age group (*p*=0.42). Similar global results were obtained for the other criteria. Further, to get a clearer image of the differences between the most representative two groups (24 or below and 25-34), we performed t-tests for each of the questions and the cumulative results. All the answers were similar except for the following questions below. It is important to remark that in all these situations the average results of the 25-34 were lower than 24 or below (Tables 7-8).

Table 7. T-test results for shared metacognition differences by the STEM students' age (n=149)

Shared Metacognition Survey Items	24 or below	25-34	t-test
I am aware of my level of motivation.	M=4.50, SD=0.81	M=4.21, SD=1.05	*p*=0.038
I question my thoughts.	M=4.31, SD=0.93	M=3.95, SD=1.15	*p*=0.028
I observe how others are doing.	M=4.39, SD=0.95	M=4.07, SD=1.08	*p*=0.04

Table 8. T-test results for the CoI differences by the STEM students' age (n=149)

CoI Survey Items	24 or below	25-34	t-test
The instructor provided clear instructions on how to participate in course learning activities (TP).	M=4.66 SD=0.62	M=4.42 SD=0.93	*p*=0.03
The instructor communicated important due dates/time frames for learning activities (TP).	M=4.69 SD=0.66	M=4.44 SD=1.02	*p*=0.04
The instructor helped identify areas of agreement and disagreement on course topics that helped me to learn (TP).	M=4.64 SD=0.66	M=4.35 SD=1.02	*p*=0.02
The instructor helped to keep course participants engaged and participating in productive dialogue (TP).	M=4.64 SD=0.64	M=4.33 SD=1.06	*p*=0.01
The instructor helped keep the course participants on task in a way that helped me to learn (TP).	M=4.64 SD=0.64	M=4.30 SD=1.01	*p*=0.01
The instructor encouraged course participants to explore new concepts in this course (TP).	M=4.66 SD=0.66	M=4.26 SD=1.07	*p*=0.00
Instructor actions reinforced the development of a sense of community among course participants (TP).	M=4.61 SD=0.69	M=4.37 SD=0.95	*p*=0.05
The instructor helped to focus the discussion on relevant issues in a way that helped me to learn (TP).	M=4.60 SD=0.68	M=4.37 SD=0.93	*p*=0.05
The instructor provided feedback that helped me understand my strengths and weaknesses relative to the course goals and objectives (TP).	M=4.59 SD=0.69	M=4.30 SD=1.01	*p*=0.02
The instructor provided feedback in a timely fashion (TP).	M=4.63 SD=0.67	M=4.35 SD=0.95	*p*=0.02
TP Overall	**M=4.64 SD=0.60**	**M=4.37 SD=0.91**	***p*=0.02**
Research module activities enhanced my curiosity (CP)	M=4.40 SD=0.68	M=4.12 SD=1.12	*p*=0.05
I utilized a variety of provided information sources to explore the topics in research modules.	M=4.46 SD=0.73	M=4.21 SD=0.94	*p*=0.04
Based on my research experience, I can describe ways to test and apply the domain knowledge created in this course (CP).	M=4.48 SD=0.79	M=4.09 SD=0.99	*p*=0.01
In my research activities, I have developed solutions to course problems that can be applied in practice (CP).	M=4.46 SD=0.79	M=4.14 SD=0.99	*p*=0.02
Based on my research activities, I can develop solutions to problems that can be applied in practice (CP).	M=4.49 SD=0.79	M=4.12 SD=1.05	*p*=0.01

4. DISCUSSION

Our findings indicate that although students exhibited similar perceptions of individual shared metacognition across all programs of study, global results demonstrated significant influences on CP related to the program of study. Additionally, we observed that age shows noticeable differences in TP and CP across different age groups within the CoI framework.

4.1 Influence of Program of Study

Our analysis revealed that students enrolled in different STEM programs demonstrated varying levels of CP, with a notable difference between the MS DAEN and MS in AIT programs. Similarly to Arbaugh et al. (2010), we can assume how hard, applied disciplines can influence the CP to compare with soft, applied disciplines where reflection and transferrable skills are emphasized. More analysis should be completed to understand this phenomenon in more detail. However, this variation could be explained, to some extent, by the different curricular emphases and admission criteria of the two programs. For instance, the DAEN program, with its strong focus on data science and analytics, specifically enhances CP through rigorous statistical analysis and data-driven decision-making. This approach aligns with the findings of Garrison et al. (2001), who identified CP as a crucial element for meaningful learning. Conversely, the MS AIT program, while also fostering complex problem-solving, offers a comprehensive curriculum that extends beyond the focused technical training of programs like MS DAEN, covering a broader spectrum of IT topics. The observed differences between MS DAEN and MS AIT students indicate that cognitive engagement is not uniformly experienced even within STEM disciplines. This finding reinforces that curriculum design, rather than merely discipline, plays a crucial role in shaping cognition and metacognitive skills (Al-Gaseen et al., 2020). This shows that cognitive engagement in STEM is not solely dependent on individual students' capabilities but also on how the curriculum demands critical reflection, analysis, and integration of knowledge. It places a strong emphasis on practical implementation, equipping students with the necessary skills to oversee and guide IT operations within organizations.

4.2 Age and Its Effects on Teaching Presence

Our results indicate that perceptions of shared metacognition among STEM students do not significantly differ based on age, revealing no strong age-related trends. This finding reinforces prior research by Al-Gaseen et al. (2020), who also found that STEM students' metacognitive skills weren't different in gender and class standing. This suggests that educational approaches to developing metacognition could be universally effective across different age groups. However, a closer examination through t-tests of two key age groups, those 24 or below and those between 25-34, reveals subtle variances in specific aspects, with the latter group consistently scoring lower. Aligning with the findings of Akyol et al. (2010), our study suggests that while the overall perception of metacognitive practices may not vary, the depth and way these practices are engaged could differ slightly between younger and older students. This is consistent with observations by Akyol et al. (2010) that different age groups may perceive learning objectives and the educational process differently, potentially influencing their engagement and the outcomes of their learning experiences. These findings reinforce the necessity of adopting more personalized educational strategies that effectively support the unique cognitive needs of different age groups to optimize learning outcomes. This study aligns with Kovanović et al. (2015), who advocate for a more refined course design approach that considers the specific cognitive challenges presented by different STEM disciplines.

5. FUTURE RESEARCH

More research on STEM students' demographic background, such as age and program study is needed. Specifically, how hard applied programs of study influence overall students' perception of CP and TP when they are enrolled in IBL courses. In addition, while this study focused on perceived shared metacognition, future studies could explore objective measures of shared metacognition, such as the quality of group discussions or performance outcomes. This would offer a more comprehensive understanding of how metacognitive awareness manifests in IBL and its direct impact on STEM students' learning outcomes. Additionally, expanding this research to include a broader range of STEM disciplines could provide further insights into how instructional design and program characteristics shape shared metacognition.

6. CONCLUSION

This exploratory study's findings significantly contributed to the field of teaching and learning in IBL environments, specifically in STEM Education. Moreover, this study's findings revealed that more attention needs to be provided to how the program of study and students' age can influence shared metacognition within the CoI. While the influence of the program of study on CP and age on TP highlights the varied ways in which students engage with the learning process, the lack of a significant relationship between either program or age and shared metacognition suggests that the development of metacognitive skills occurs independently of these factors. This finding is crucial for educators and curriculum designers, as it indicates that shared metacognition can be cultivated across diverse student populations, regardless of their academic program or age group.

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