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Transforming STEM Education through Inquiry-Based Collaborative Approach: Examination of Metacognition and Cognitive Presence

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Transforming STEM Education through Inquiry-Based Approach: Examination of Metacognition, Cognitive and Teaching Presence

Abstract: In this exploratory study, we examined how engineering graduate students perceived cognitive presence and metacognition in relation to teaching presence while participating in research activities organized in learning modules. These modules covered fundamental topics, including research question development, performing literature reviews, and conducting research through domain specific methods. They were implemented in STEM graduate courses, through an inquiry-based approach. The main objective was to study the levels of perceived cognitive presence and metacognition in relation to teaching presence during student participation in discussions and peer review activities within the research context. These results hold promise in helping students not only improve their research skills but also in equipping them with valuable skills that extend beyond the classroom environment and prove beneficial for their careers. The findings of this study contributed to the field of engineering education to facilitate shared learning environments for graduate engineering students.

Purpose of the Study

An increasing number of national reports emphasize the importance of developing new approaches to science, technology, engineering, and math (STEM) education to maintain the country's leadership in scientific and technological breakthroughs [1], [2]. Educators and researchers from diverse fields have been exploring a wide range of innovative ideas to enhance and refine teaching and learning methods within STEM disciplines. An inquiry-based approach stands out as a promising and effective instructional methodology, supported by findings indicating its potential to enhance STEM education [3] - [5]. This approach involves engaging students in active learning through inquiry, exploration, and collaboration, helping them develop critical thinking, problem-solving, and decision-making skills. These are the kinds of skills that industry, government, and other employment sectors expect today's graduates to possess, along with in-depth content knowledge, by the time of their employment [6], [7]. This approach can also help students develop strong transferable skills, including leadership, collaboration, innovation, and creativity. The integration of inquiry-based methods in STEM education not only enhances the academic achievement of STEM graduates but also equips them with the skills essential for success in the rapidly changing landscape of STEM jobs.

Inquiry-based learning has recently received additional attention when the metacognitive approach has been implemented into the design of online, hybrid, and face-to-face learning to support the dynamics of reflective thinking and a shared inquiry process [8]. Metacognition is a required cognitive ability to achieve deep and meaningful learning that can be viewed both from individual and shared perspectives. Moreover, when metacognition is facilitated within the Community of Inquiry (CoI) and, specifically, through the principles of the Practical Inquiry Model (PIM), it can help regulate cognitive presence of self and others [9]. Understanding how metacognition manifests in a shared learning environment, when students can share and discuss ideas together, can also help select effective course design and instructional strategies to guide deep learning outcomes [8]. However, instructors face the challenge of using new strategies to help students regulate and manage their learning in a shared learning environment. Effective teaching presence that relates to traditional instructor responsibilities can provide guidance in encouraging students to take responsibility for their learning through facilitating inquiry-based approach [9]. In this study, teaching presence is defined as "the design, facilitation, and direction of cognitive and social processes for the purpose of realizing personally meaningful and educationally worthwhile learning outcomes" [14]. Previous studies on metacognition in STEM revealed that for all course sections and delivery methods, more than 80% reported perceptions of metacognition and satisfaction with the research learning modules. Similar results were seen for subsets of the respondents: for individual vs. group perceptions, for field of study, and for online vs. in-person instruction [10]. Similarly, our previous studies on students' cognitive presence revealed that an overall 86.2% of students reported being satisfied or extremely satisfied with the proposed research learning modules. Subsets of the respondents (e.g., online vs in-person instruction) showed consistently similar results. While the sample size was small there was a strong indication that the research learning modules were successful in promoting cognitive presence and metacognition for applied research concepts and methods [11].

However, there is still limited research to understand how instructors should design and facilitate cognitive presence and metacognition in shared inquiry-based courses that can help students regulate their own learning and learn from others [12]. Therefore, this exploratory study is an attempt to fill this gap by providing examination of STEM students' perceived metacognition and cognitive presence in relation to teaching presence when they work in research learning modules. The following research questions were asked:

1. What are STEM graduate students' perceptions of cognitive presence in an inquiry-based shared learning environment in relation to teaching presence?

2. What are STEM graduate students' perceptions of metacognition in an inquiry-based shared learning environment in relation to teaching presence?

3. Are there differences in cognitive presence and metacognition across course modalities, i.e., in-person versus online in relation to teaching presence?

Research Design

This exploratory quantitative research study examined STEM graduate students' perceptions of cognitive presence and metacognition in relation to teaching presence. All the participants completed a version of the learning modules during the Fall 2023 semester, in which they learn how to perform research and developed a research project related to their course. This study continues previous exploratory studies [10-11] and examined how the inquiry-based collaborative approach impacted STEM students' perceived individual (self-regulation) and group (co-regulation) metacognition but also their perceived cognitive presence. A new element of the study is related to the influence of the teaching presence with respect to the metacognition and cognitive presence.

Research Participants

Participants in this study were 64 graduate students who enrolled in various courses at George Mason University. The participants were part of different programs in the College of Engineering and Computing with the most students being in the Master of Science in Data Analytics Engineering (26), Master of Science in Applied Information Technology (23), Master of Science in Information Sciences (7), and Ph.D. in Information Technology (3). The students were enrolled in various sections of 3 different courses: AIT 502 Programming Essentials (14), AIT 524 Database Management Systems (20), and AIT 580/INFS 580 Analytics: Big Data to Information (30). The students were enrolled both in-person (27) and asynchronous on-line (37). Also, there were 39 international students and 25 domestic students.

Context

The research modules were integrated in several 15-week/modules courses and were designed in a consistent way by following the principles of inquiry-based learning and by creating a collaborative research environment through discussions and peer activities. The goal of instruction was to introduce students to systematic activities to help them develop research, collaboration, and communication skills. Students were involved in a scaffolded research experience to solve the real-world problems in various fields in STEM.

The course modules' design included the following learning tasks: identify research questions, conduct a literature review, and conduct research. Each module was divided into sections to scaffold each learning task. Students completed quizzes, online discussions, and peer review activities. By the end of the course, students submitted self-reflections where they shared their research experience, what they learned, what challenges they faced, and what suggestions for collaborative assignment improvement they would offer.

This intervention is based on previously developed learning modules [11] but they are customized based on the learning objectives and teaching style of each instructor. For instance, in one course the students will perform systematic literature research for a selected topic, concentrating on how to identify, summarize, synthesize, and analyze previous research done on that topic. In another course, they will compare two different methods in a provided context based on various metrics, designing, performing, and interpreting a research experiment. In a third context, the students will analyze real-world datasets and will draw conclusions about their significance. While there are differences in the type of research performed, these experiences share the use of the learning modules and the same teaching philosophy. This constitutes the design power of the implemented learning modules, allowing easy reuse, customization, and adaptation to the instructor’s teaching style or in our case teaching presence.

Data Collection and Analysis

The data was collected at the end of the fall semester of 2023 through the use of a combined survey containing 5 demographic items, 16 cognitive presence, and 13 teaching presence items having a five-point Likert scale anchored by “Very Dissatisfied” and “Very Satisfied” developed by Arbaugh et al. [13] and 24 metacognition items constructed by Garrison and Akyol [9] with a five-point Likert scale anchored by “Strongly Disagree” and “Strongly Agree.” The cognitive presence survey items were validated with 0.95 Cronbach alpha and teaching presence survey items were validated with 0.94 Cronbach alpha [13]. The data was collected independently in each section of the course using an anonymized survey and integrated for processing.

Results and Conclusion

Metacognition results: The survey consisted of 24 metacognition questions on a scale from 1 to 5. The average answers per question varied between 3.8 and 4.6 with an average of 4.3.

Cognitive Presence results: The survey consisted of 16 questions on a scale from 1 to 5. The average answers per question varied between 4.1 and 4.3 with an average of 4.2. The lower results were obtained for cognitive presence. The questions are grouped in 3 categories based on the level of cognitive presence: low (question 1-3) with an average of 4.17, medium (question 4-10) with an average of 4.22 and high (question 11-16) with an average of 4.21. *Teaching Presence results:* The survey consisted of 13 questions. The average of the answers per question varied between 4.4 and 4.6 with an average of 4.5. *Comparison:* An ANOVA single factor analysis shows that the means are different with a p-value of 0.04.

Question 1: Cognitive Presence with respect to Teaching Presence: The correlation coefficient between the average answers for cognitive presence questions with the average for teaching presence is: 0.74, showing medium-high correlation.

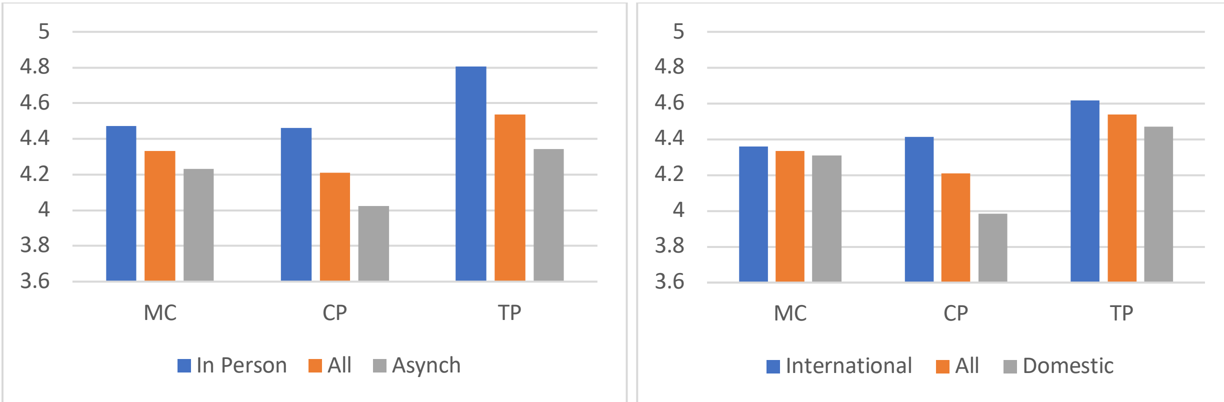
Our findings are similar to the previous studies that students usually tend to stay in their comfort zone at the medium level of cognitive presence. The medium level is when students explore and brainstorm relevant information to resolve the questions. On the contrary to previous studies [15,16], our findings confirmed that the inquiry-based activities promoted higher perceived cognitive presence among students. These empirical findings supported Garrison's statement [8] that more appreciation should be done to empirically explore the process and strategies of shared learning environment. In addition, similarly to the previous studies, our study confirmed that among examined presences, teaching presence received a higher score than cognitive presence [15]. It is not surprising because teaching presence is a good predictor of cognitive presence [15]. Our study confirmed if teaching presence is high, cognitive presence is also high.

Question 2. Metacognition Results with respect to Teaching Presence: The correlation coefficient between the average answers for metacognition questions with the average for teaching presence is: 0.39, showing low-medium correlation.

Our findings showed that teaching presence can explain metacognitive development among students as metacognitive learning is located between cognitive presence and teaching presence within the COI [8]. In our study, students tend to take more responsibilities over their learning (self-regulation) through facilitation and resolving questions while participating in peer review discussions (co-regulation). Moreover, it seems students created teaching themselves when they were engaged in interactions with each other.

Question 3: Differences based on course modalities: There is a significant difference between the answers of the in-person and virtual students for all three categories and in cognitive presence between domestic and international students as shown in the graphs below.

These differences can be explained by the types of learning environments where virtual students might have less teaching presence while in-person students did have more in-class interactions. This suggests that the virtual design of the research modules requires more interactive opportunities with their course instructors and peers. Our findings showed that international students perceived higher cognitive presence in shared environments than domestic students. This may be explained by international students' prior experience working in groups.



Significance of Contribution

This exploratory study contributed to the field of engineering education to understand how STEM graduate students learn in shared learning environments. Based on our knowledge this is the first study to connect metacognition with cognitive and teaching presence.

References

[1] National Science Foundation (NSF). "STEM Education for the Future – A Visionary Report," National Science Foundation, Alexandria, Virginia, Spring 2020. [Online]. Available: NSF, https://www.nsf.gov/edu/Materials/STEM%20Education%20for%20the%20Future%20-%202020%20Visioning%20Report.pdf. [Accessed November 15, 2023].

[2] National Center for Science and Engineering Statistics (NCSES). "Diversity and STEM: Women, Minorities, and Persons with Disabilities 2023," National Science Foundation, Alexandria, Virginia, Special Report NSF 23-315, 2023. [Online]. Available: NSF, https://ncses.nsf.gov/wmpd. [Accessed November 15, 2023].

[3] C. Attard, N. Berger, and E. Mackenzie, "The positive influence of inquiry-based learning teacher professional learning and industry partnerships on student engagement with STEM," *Frontiers in Education*, sec. STEM Education, vol. 6, August 16, 2021, doi: 10.3389/feduc.2021.

[4] C. Deák, B. Kumar, I. Szabó, G. Nagy, and S. Szentesi, "Evolution of new approaches in pedagogy and STEM with inquiry-based learning and post-pandemic scenarios," *Education Sciences*, vol. 11, no. 7, p. 319+, Basel, Switzerland: MDPI, June 2021, doi: 10.3390/educsci11070319.

[5] C. S. Lai, "Using inquiry-based strategies for enhancing students' STEM education learning," *Journal of Education in Science Environment and Health*, vol. 4, no. 1, pp. 110-117, February 2018. [Online]. Available: JESEH, https://www.jeseh.net/index.php/jeseh/article/view/143. [Accessed November 15, 2023].

[6] L. Cassuto, *The graduate school mess: What caused it and how we can fix it*. Cambridge, Massachusetts: Harvard University Press, 2015.

[7] D. Denecke, K. Feaster, and K. Stone, “Professional development: Shaping effective programs for STEM graduate students,” Council of Graduate Schools, Washington, DC, Report, 2017.

[8] D. R. Garrison, “Shared metacognition in a Community of Inquiry,” *Online Learning*, vol. 26, no. 1, pp. 6-18, March 2022, doi: 10.24059/olj.v26i1.3023.

[9] D. R. Garrison, and Z. Akyol, “Toward the development of a metacognition construct for the community of inquiry framework,” *Internet and Higher Education*, vol. 24, pp. 66–71, January 2015, doi: 10.1016/j.iheduc.2014.10.001.

[10] Olesova, L., Liao, D., Rytikova, L., Boicu, M., & Foxwell, H., (2023, June). Metacognition in graduate engineering courses [Paper presentation]. American Society for Engineering Education the 2023 Annual Conference & Exposition. Baltimore, MD., United States. https://peer.asee.org/43629

[11] Rytikova, L., Liao, D., Olesova, L., Boicu, M., & Foxwell, H. (2023, March). Cognitive presence learning for graduate engineering education. In The ASEE (American Society for Engineering Education) Southeastern Section Annual Conference Proceedings. Arlington, VA.

[12] A. A. Koehler, Z. Cheng, H. Fiock, H. Wang, S. Janakiraman, and K. Chartier, “Examining students' use of online case-based discussions to support problem solving: Considering individual and collaborative experiences,” *Computers & Education*, vol. 179, 104407, April 2022, doi: 10.1016/j.compedu.2021.104407.

[13] J. B. Arbaugh, M. Cleveland-Innes, S. R. Diaz, D. R. Garrison, P. Ice, J. C. Richardson, and K. P. Swan, “Developing a Community of Inquiry instrument: Testing a measure of the Community of Inquiry framework using a multi-institutional sample,” *The Internet and Higher Education,* vol. 11, no. 3-4, pp. 133-136, 2008.

[14] T. Anderson, L. Rourke, D.R. Garrison, and W. Archer, “Assessing teaching presence in a computer conferencing environment,” *Journal of Asynchronous Learning Networks*, vol. 5, no.2, pp.1-17, 2001. https://doi.org/10.24059/olj.v5i2.1875.

[15] A. Sadaf, T. Wu, and F. Martin, “Cognitive presence in online learning: A systematic review of empirical research from 2000 to 2019,” *Computers and Education Open,* vol. 2, 2021. https://doi.org/10.1016/j.caeo.2021.100050.

[16] H.L. Chen, and C.Y. Chang, “Integrating the SOP2 model into the flipped classroom to foster cognitive presence and learning achievements,” *Journal of Educational Technology & Society*, vol.20, no.1, pp. 274-291, 2017.