Critical Thinking In Stem: A Qualitative Study Of Community College Teaching Techniques

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Abstract

There is evidence in the literature that teaching critical thinking in college courses at both community colleges and four-year universities helps students gain critical thinking skills. However, students are not learning the critical thinking skills that employers expect in freshman-level science, technology, engineering, and mathematics (STEM) courses. There is a lack of research on what community college STEM teachers are doing to teach critical thinking skills. This qualitative research study was conducted to discover and describe community college teachers' methods and techniques in STEM disciplines to teach critical thinking skills. The research was conducted using a basic qualitative research design that employed interviews to discover community college teachers' instructional experiences in STEM disciplines. Interview transcripts were analyzed using a constant comparative method to determine common themes. Findings of the study included descriptions of modeling critical thinking skills, allowing students to practice using the skills, and assessing the critical thinking skills using a skills-based assessment. The described useful techniques also included the requirement of analysis throughout, including analysis of data, analysis of the process, and analysis of thinking. The conclusions of this study align with what other research in teaching critical thinking skills has reported, despite the differences in teaching STEM disciplines compared to teaching other disciplines. It is recommended that community college teachers receive professional development to help them understand what critical thinking is and how to teach it in their classrooms.

What is Critical Thinking, and can it be taught?

Henry Ford, American industrialist and founder of the Ford Motor Company, once said, "Thinking is the hardest work there is, which is the probable reason why so few engage in it" (as cited in Maina et al., 2016, p. 28). The skills necessary to think critically have been a subject of the educational literature for many years. This study was conducted to explore the teaching of the skills required to think critically in science, technology, engineering, and mathematics (STEM). There has been a focus in education to improve learners' skills in critical thinking in response to the needs of the workforce for employees that can analyze situations and data and solve problems (Jang, 2016; Vilorio, 2014). However, the literature shows that despite the available knowledge of various techniques to teach critical thinking, the students graduating from educational programs still lack the requisite thinking skills (Demaria et al., 2018). In response to the need for teachers that can teach critical thinking skills in STEM, this study was conducted to discover what teachers in STEM disciplines in community colleges are doing in their classrooms to teach critical thinking skills by asking effective critical thinking teachers about techniques they employ when teaching critical thinking.

Dewey (1933) described critical thinking as self-reflection and was one of the first theorists to consider this skill an essential one. Many theorists have followed Dewey, adding to and refining the idea of critical thinking. As the research has accumulated, several researchers, such as Ennis (1990), Facione (2000), Moore (2013), and Paul and Elder (2001), defined critical thinking to include certain dispositions and a set of skills. Facione (1990) used the Delphi method to work with an international group of experts to develop a consensus definition of critical thinking. The Facione (1990) final report, which has come to be commonly known as the Delphi report, defined critical thinking in this way

> We understand critical thinking to be purposeful, self-regulatory judgment, which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based... CT is essential as a tool of inquiry. As such, CT is a liberating force in education and a powerful resource in one's personal and civic life... While not synonymous with good thinking, CT is a pervasive and self-rectifying human phenomenon. (p. 3)

The question of whether critical thinking can be taught has been examined, determining that critical thinking skills can be taught in classroom settings. Ennis (1990) summarized four alternate ways to incorporate critical thinking into classrooms, ranging from implicit and embedded within the content to explicit and separate from content. Other researchers that followed determined that each of Ennis's (1990) descriptions were valid and beneficial (Ennis, 2018; El Soufi & See, 2019; Halpern, 1998; Larsson, 2017). Critical thinking skills could be taught, and any mixture of content and skills was more helpful than none at all (Huber & Kuncel, 2016). The literature has included evidence that the teaching of these skills improves the acquisition of critical thinking skills over the sequence of a college education (Ennis, 2018). Multiple studies (Ennis, 2018; Holmes et al., 2015; Nelson et al., 2018; Kim et al., 2013; van Vondel et al., 2017; Wu & Pope, 2019) were conducted to examine what teaching techniques are effective to teach critical thinking and offered suggestions for teaching critical thinking skills.

College teachers can and do teach critical thinking skills (Huber & Kuncel, 2016). Huber and Kuncel (2016) noted significant gains in critical thinking skills in college students across all domains and included both formats of explicit instruction and non-explicit instruction in critical thinking skills. Success in college is one of the factors measured when examining the benefits of critical thinking skills. Fong et al. (2017) found a positive relationship between critical thinking and community college success when they conducted a meta-analysis of studies on critical thinking and college success. The greater the critical thinking skill level, the greater the success in community college courses (Fletcher & Carter, 2010; Fong et al., 2017). However, it is not just success in college that critical thinking can affect. Butler et al. (2017) found that critical thinking skills were a strong predictor of life decisions and how many negative life events a person might have. The participants in Butler et al.'s (2017) study with lower critical thinking skill levels had more negative life events than those with higher critical thinking skill levels. Even intelligence, which many people hold in high regard, was not as strong a predictor for life events as critical thinking skills (Butler et al., 2017). A positive aspect of the finding that critical thinking skills are a predictor for positive life events is that critical thinking skills can be taught, whereas intelligence cannot be taught (Ennis, 2018; Halpern, 1998).

What About Critical Thinking in STEM?

Although the teaching of critical thinking has been studied extensively in other disciplines, there is a surprising lack of critical thinking research in STEM. The reason for the lack of research in STEM is not often addressed in the literature. The lack of focus on critical thinking in STEM may be due to confusion between critical thinking and scientific thinking (Dowd et al., 2018). Dowd et al. (2018) described scientific thinking as a subset of critical thinking. Dowd et al. (2018) cautioned that just teaching scientific thinking was not enough to encompass critical thinking. The idea that scientific thinking is not the same as critical thinking may be one explanation why critical thinking is not emphasized in STEM classrooms. Teachers may think they are teaching critical thinking because they teach scientific thinking, which is not the case. Heft and Scharff (2017) believed that the deficiency in critical thinking education was due to the faculty not having the knowledge needed to teach these skills effectively, and Bray et al. (2019) demonstrated how professional development of faculty could improve teachers' ability to teach critical thinking skills in STEM courses. In the study done by Bray et al. (2019), STEM educators were required to participate in professional development on critical thinking and then asked to redesign the courses they taught in response to what they learned. The study revealed that students in nearly all of the redesigned courses had improved critical thinking skills at the end of the course (Bray et al., 2019). Bray et al. (2019) described that each discipline was different in how they redesigned their course, but Bray et al. (2019) did not describe those tools and techniques. There is a lack in the literature of descriptions of the specific techniques that effective teachers of critical thinking in STEM utilize to teach critical thinking skills.

Many studies explore how students gain critical thinking skills and what methods work best to teach them (Wyss et al., 2013). However, Alzen et al. (2018) found students were not making the gains in critical thinking skills that educators and employers require in freshman-level STEM courses. Multiple entities involved in education, including government leaders, administrators, and educators, know that students need critical thinking skills for the workforce, and they expect these skills to advance in educational courses (Pearl et al., 2019; Vilorio, 2014; White House Office of Science and Technology Policy, 2018). While nearly half of all students pursuing an undergraduate degree start in a community college, there is surprisingly little research into what educators do in community college STEM courses to teach critical thinking skills (Bray et al., 2019; Fletcher & Carter, 2010).

The research that exists on critical thinking in STEM is limited. Nelson (2017) explored the teaching of critical thinking in nursing education, while Loveland (2019) discussed best practices for teaching critical thinking in technology and engineering. The research on the effective teaching of critical thinking is scarce when examined from the viewpoint of teachers and nearly non-existent when focused on STEM teachers. Nelson's (2017) study is one of very few that explored what techniques teachers employ in the classroom to teach critical thinking. Redesign of courses was discussed by Rowe et al. (2015) and Nelson (2017) within the parameters necessary for STEM courses. Techniques used to teach critical thinking skills were addressed: scientific reasoning in writing was discussed by Dowd et al. (2018), and the inefficacy of reading textbooks was lamented by Wyss et al. (2013). Problem-based learning has been examined in the literature through a lens of STEM disciplines multiple times, most recently by Badescu and Stan (2019) and Loveland (2019).

There are many methods described in the literature of incorporating critical thinking into classroom instruction. Course revision can be useful in promoting critical thinking skills. Courses that are designed with critical thinking skills acquisition as the goal take advantage of active learning and inquiry-based teaching techniques as well as the physical spaces available (Deksissa et al., 2014; Soneral & Wyse, 2017; Stroupe, 2017; Zandvakili et al., 2019). Mentorship and communication can make a difference in the students' dispositions toward critical thinking (Alzen et al., 2018; Nelson et al., 2018; Oyler & Romanelli, 2014). The practice of critical thinking skills is an important feature of teaching critical thinking successfully (Co, 2019). Assessment of critical thinking needs to be performance-based (Ernst & Glennie, 2015; Rear, 2019). The constructivist view of learning is the theoretical framework for each of the suggestions for teaching critical thinking skills found in the literature and incorporates the importance of experiences in learning and active engagement with the skills and materials (Hacisalihaglu et al., 2018; Shively, 2015; Tunca, 2015).

Despite the knowledge of theoretical frameworks and techniques for teaching critical thinking, STEM students are not gaining critical thinking skills in college courses. Jang (2016) stated that

> Educational efforts to construct curricula with interdisciplinary collaboration, active learning, and learner-centered instruction have been stressed as core strategies for change. However, those efforts have not shown substantial success when considering the significant resources invested in research and development to improve STEM education. (p. 285)

There is a little research from the teacher's point of view to determine what methods work in teaching critical thinking in STEM courses specifically, so the purpose of this study was to attempt to fill that gap.

Purpose and Research Question

Community colleges are the starting point for nearly half of all college undergraduate students, and many more continue their education at a community college (Fletcher & Carter, 2010). Research has included evidence that students are not gaining the critical thinking skills in freshman-level STEM courses that employers require (Alzen et al., 2018). However, there is a lack of research in the literature that discusses what educators do in STEM courses to teach critical thinking skills, despite the evidence that critical thinking is essential in college and in life (Bray et al., 2019; Butler et al., 2017; Fletcher & Carter, 2010; Fong et al., 2017). This qualitative study aimed to discover and describe the methods and techniques used by the interviewed STEM instructors at community colleges to teach critical thinking skills. The primary research question was, What strategies and techniques have community college STEM instructors found most and least useful in teaching and assessing critical thinking skills in their STEM courses?

Methods

Target Population and Sample

The population addressed in this study is community college teachers in science, technology, engineering, and mathematics. The population faculty include adjunct and full-time teachers, some with master's degree-level education, and some with doctorate-level degrees, from eight different community colleges, all within one state in the United States. Community college faculty often do not have any pedagogical education, instead having expertise in their field via workforce experience. Some participant faculty were newly hired, while some faculty have been in the field for many years.

The sampling of participants for this study is a one-point-in-time sample, as described by Patton (2015). Each interview consists of only one contact with the participant, with all data collection conducted during that visit. The sample is a purposeful sample done in the snowball or network method (Merriam & Tisdell, 2016). The initial participants were located via contact with professional organizations and administrators. Recommendations for contacts were given by a vice president of a community college and included industry leaders, administrators in other colleges, and key figures in critical thinking programs and movements across the state. The key figures recommended were contacted, and they gave recommendations of other administrators or of possible participants at various community colleges in the state. Recommended faculty were then contacted directly via the published contact information at their school websites and asked if they would be willing to participate with an IRB-approved recruitment email. Additional participants were contacted through recommendations from the initial participants.

The population sampled for this study consisted of teachers in STEM disciplines at community colleges. In the United States, 81% of STEM faculty are White males, so a representative sample of participants for this study is biased (Belser et al., 2018; Smith et al., 2015). Inclusion criteria included faculty at the community college level and who were currently teaching in one or more of the STEM disciplines. The sample consisted of teachers from STEM disciplines with a variety of experience and backgrounds for a range of 8-12 participants. A range was proposed due to the uncertainties of obtaining participants

Sex	Ethnicity	Age	Discipline	Experience (yrs) Teaching
M	White	48	T	5
M	White	69	STEM	19
F	White	53	M	29
F	Hispanic/White	47	S	17
F	Hispanic	32	SEM	7
F	White	36	S	4
M	White	32	M	7
M	White	32	M	10
M	White	52	E	6
M	White	31	S	2

Table 1. Participant Demographics

exacerbated by the beginning of the COVID-19 pandemic. Although the goal was to obtain the minimum number of 12 participants, the sample was ultimately determined by reaching saturation at 10 participants. The participants consisted of 60% male, 40% female teachers; 80% identified their race as White, with the other 20% identifying as Hispanic. Two of the participants taught in multiple STEM disciplines, while the other eight identified with only one discipline; three in mathematics, three in science, one in technology, and one in engineering (see Table 1). Participants were not specifically asked if they were employed as adjunct or full-time, but the information did come up in several interviews, and the sample had a mixture of both employment types.

Data Collection and Analysis

Interviews were scheduled according to the availability of the researcher and participants. Interviews were conducted using virtual means due to the COVID-19 pandemic that required people to stay home. Participants were able to choose the technology they preferred to use for interviews, and seven of the ten interviews were via Facetime or Google Duo. The audio was recorded, but the video was not recorded. One interview was via Adobe Connect, and two were audio-only calls. The interview style was a semi-structured interview conducted in an inquiry-based conversational style, giving participants time to respond and including probing questions for clarification when needed. Guiding interview questions were written and used in interviews. Interview questions were open-ended to allow participants to interpret and elaborate on their teaching techniques and beliefs, with probing questions asked if their statements' meaning was unclear to the interviewer. Interviews lasted an average of one hour, depending on how much or how little the participant wished to share.

Analysis of the data collected in this study began with the first interview as it was transcribed and then coded. Coding consisted of reading the printed transcript and looking for themes that designated what the participant was telling the researcher in response to interview questions. These initial themes were highlighted or underlined in the text of the transcript, then noted in the margins in short descriptive notes. The descriptive notes were assembled into categories or codes. As suggested by Merriam and Tisdell (2016), a constant comparative method was employed. As interviews were conducted, each subsequent interview was compared to the ones before. Themes that arose multiple times were noted on notepaper to track common ideas across all transcripts. Further analysis of the notes and codes required the creation of categories determined by the research questions and then refined by the findings in the transcripts. As data collection and analysis progressed, the researcher reviewed the data collected for this study multiple times.

Findings

The research question was, what strategies and techniques have community college STEM instructors found most and least useful in teaching and assessing critical thinking skills in their STEM courses? The findings of this study include multiple answers to the research question, as different teachers employ different techniques (see Table 2). However, the common themes within the described techniques can be extrapolated to form a general answer to the research question. The most useful techniques described by STEM teachers for teaching critical thinking skills included analysis of data, analysis of the process, and analysis of thinking, which clearly aligns with the skills defined by Facione (1990). Strategies mentioned included having students analyze the thoughts that brought them to their solution and to explain their thought process. Participant number 4 (P4) described this as "working backward, trying to think around the process of getting the wrong answer, to better their process of getting the right answer."

The analysis described was encompassed in a teaching progression of modeling by the teacher, practice by the student, and then assessment of the skills gained. One example of this progression described by P5 was the semester-long use of scientific data from research to make decisions. This project began with modeling by the teacher of how to read and interpret scientific research papers, progressed with additional opportunities for students to practice reading and interpreting data, and culminated with a final project that required students to use scientific data gathered to make a decision. P1 described their process as a short lecture for modeling, followed by having students work through problems using critical thinking. "I don't even give a right answer. It would be unhelpful. You ask them a question. You provide them several answers. And you know the right answer; you just don't tell them," P1 said. P1 then described further analysis by students by asking students to try to convince their peers and criticize their ideas and thinking processes.

In addition to the techniques related to teaching practice, participants also stated that communication and interactions with students were important in promoting critical thinking dispositions and skills. Communication of clear expectations to students using rubrics and examples and how students were treated with respect and encouragement were important aspects of teaching critical thinking. P3 stated, "Just give them those critical thinking, give them those opportunities, give them those scenarios, but back off. You know? Let them impress you." Positive feedback and encouragement were designated in multiple strategies, including the modeling-practice-creation arc previously described. P6 marveled at how students became more open and willing to try new skills and ideas when they felt safe and supported in their efforts by how the teacher interacted with them in class.

Teachers who participated reported as least useful strategies focused on fact memorization and assessments that only required regurgitation of facts (see Table 3). Lecture and multiple-choice tests were the most commonly reported versions of fact-based teaching and assessment. P1 stated that "the time in which we [as teachers] are a depository of knowledge is gone. Nobody is that anymore. That's done by servers and internet and books." P1's experience in a mathematics class included questioning, "Why in the world do I need to remember that formula? I just need to know how to apply it and when to apply it, and I always thought that was the best skill you could teach someone."

Conclusions and Implications

The conclusions based on the findings for this study are supported by research in the previous literature. The introduction of this paper included (a) the possibility of instruction of critical thinking skills, (b) the best formats for including critical thinking skills in education, and (c) methods for teaching critical thinking skills in courses. These conclusions align well with and confirm what previous research has demonstrated. Critical thinking skills

Theme: % of participants (n = 10)	Description	Representative Quotes
Analysis: 80%	Students analyze text, data, thinking, processes	"You read them and tell me what's wrong in them if there are mistakes… they have to critically analyze the text." -P1
Communication of expectations: 70%	Teachers clearly articulate what is expected from the student	"I show them the rubric upfront. So they read exactly what they're being judged on." -P2
Modeling: 60%	Teachers show, demonstrate, or tell students how to accomplish the stated goal, use the skill, or demonstrate desired dispositions	"I use that as an opportunity to tell them; you see that? That's what I want you to do on your own because that's critical thinking. When you don't know something, instead of having the answer explained to you, you need to start looking for the answer." -P1
Practice: 60%	Students practice the skills	"So you need to give them practice and practice and practice in lots of different kinds of scenarios." -P5
Creation: 60%	Students create new ideas by compiling their knowledge and skills and relating them in new ways	"Open-ended questions are much better for assessing critical thinking because you see them struggle with it and come up with their own ideas." -P5
Interactions with students: 50%	Teachers interact with students in ways that are respectful and supportive	"It's a skill to be able to reach out to the student without making them feel dumb and close up." -P1
Collaboration: 50%	Students work together with peers	"I need them to generate the answer on their own and struggle with it and talk with their team members about it, and then come back to me." -P5
Application: 50%	Students apply their ability to analyze, evaluate, and create	"The way I teach critical thinking to my students is by asking them to use data to support claims." -P5
Evaluation: 40%	Students consider the data, materials, methods, etc. that they are presented with	"I tell them I want to hear you talk to your neighbors and ask them what did you answer, and then try to convince your neighbor." -P1
Engagement: 40%	Students engage with materials in hands-on activity, and with peers in discussions	"When you can engage them in the hands-on real-world setting like we have set up, there's nothing better." -P2
Questioning: 40%	Teacher ask probing questions that require critical thinking in students	"I ask questions that they don't have the answer to, but they've had enough given to them that they can figure it out." -P8
Presentations as instruction: 30%	Students prepare and give presentations that require them to use their critical thinking skills	"I do short reports, and I do presentations…its not on the assessment side, but on the actual instruction side." -P6
Understanding: 30%	Students understand the basis and background for key concepts, not just memorize the concepts	"I have to judge and make sure that they not only understand what they're doing, but they're also understanding why they're doing it this exact way." -P2
Metacognition: 30%	Students think about their thinking and their process	"Getting them to judge, criticize, analyze how they're thinking." -P1
Adaptability: 20%	The adaptability of the teacher and of the student	"Teaching students how to learn and how to be accommodable like adaptable in different situations." -P1

Table 2. Techniques Useful for Teaching Critical Thinking

can be taught (Holmes et al., 2015), and a mixture of explicit and content-centered instruction is best (Ennis, 2018). Suggested teaching techniques included skills-based rather than fact-based instruction and assessment (Ernst & Glennie, 2015; Nelson, 2017). Specific techniques suggested in the literature included similar techniques as STEM teachers in this study suggested, modeling the desired outcome, allowing students to practice, and assessing based on skills learned (Co, 2019; Hacisalihaglu et al., 2018; Nelson et al., 2018). The techniques described by participants included tools such as (a) active learning, (b) Socratic questioning, (c) mentoring, and (d) inquiry-based or problem-based learning, all of which were mentioned in the literature as well. Interactions between students and teachers were also described in the literature (vanVondel et al., 2017) as important for teaching critical thinking and supported by the findings of this current study.

The conclusions of this study have a few implications. First, the expectations and assumptions about constructivism and its link to teaching critical thinking skills apply to STEM courses; thus, this study supports previous research that has shown this link to be accurate (see Tunca, 2015). The recommendations of constructivist design have previously been focused on other disciplines; thus, the link between constructivism and teaching practice in STEM is new in the literature. This knowledge has practical implications for the practice of STEM teachers as they seek to understand what works and what is necessary to achieve the goal of increased critical thinking skills. The conclusion that constructivist methods are needed in STEM courses is important because it is widely believed that STEM courses teach critical thinking due to their format and content, and this study's findings disprove that belief.

Another implication is the need to provide teachers with professional development specific to teaching critical thinking skills. The findings in this study contained comments from community college STEM teachers who had years of experience and those new to teaching. There were participants who were adjunct teachers, and those were full-time faculty. The common experience of the teachers that participated was that they did not understand how critical thinking was defined, and they did not come to teaching with an understanding of how to teach critical thinking skills. The participant teachers who had had previous education in pedagogy had a better understanding of how to employ strategies to enhance learning. Those teachers who had years of experience had discovered through trial and error in their courses how to promote critical thinking skills. However, there is a need for community college STEM teachers to receive professional development education that is targeted at critical thinking definitions and effective strategies for teaching critical thinking skills.

Previous research on the topics of teaching critical thinking skills contained suggestions for effective

Theme: % of participants (n = 10)	Description	Representative Quotes
Lecture (just telling or showing): 40%	Lecture used as fact communication only	"When I just tell them the answer and then I ask them to tell me the answer back." -P5
Memorization: 30%	Memorization of facts or concepts	"We ask them questions like Can you remember that fact? Can you just tell me what was that number? Can you just spit out that formula? But I feel like Dr. Google has all the answers and, in this day and age, it seems ludicrous to have students being held to the standard of can you just repeat the things I've told you." -P1
Giving a "how-to" recipe: 20%	Giving students a step by step process to follow to get a known result	"Everybody was teaching that this is how you bake a cake, that this is the recipe, follow this recipe, and everything will be okay. Engineering is not like that. There is no recipe for problem-solving." -P8
Active learning that is not explicit about the goal: 20%	Active learning tasks that engage students but are not introduced or summarized with goals	"Sometimes with the hands-on activities, the students get really involved and have a lot of fun… It's a good thing because I know they are having so much fun they don't realize they are learning, but it's a bad thing at the same time because then they're giving me the feedback that they didn't learn anything." -P6
Online assignments: 20%	Online assignments or assessments that are fact-based and do not give feedback for learning	"Every semester I give them the [online] lab; students hate it. They say they aren't learning that they think they learn more when they write this stuff down. And if they have questions, when they're doing the computer stuff, they never write down the questions." -P6
Telling them to think: 10%	Telling students to think critically about a topic	"Asking someone to think critical about it…If you say I need you to think critically, think about the pros and cons of this environment, somebody is going online to look for a list of pros and cons, and they're not going to take the next step." -P9

Table 3. Techniques Not Useful for Teaching Critical Thinking

techniques and revealed that there was a belief that the structure of a STEM course, having lecture and laboratory time, negated the need for consciously integrated critical thinking education. This study concludes that techniques that work must be consciously integrated into both the lecture and laboratory portions of courses. An in-depth understanding of the practice of teachers is important to postsecondary and adult education practitioners in any discipline. The information described in this study can also inform researchers and educators as they explore the acquisition of critical thinking skills in other environments, such as social situations, family dynamics, and the workforce. Professionals in education and other areas can use the information presented in this current research to advise professional development and training decisions to increase critical thinking skills education.

Further research is needed in critical thinking education. Research needs to be conducted on critical thinking practice in other education levels, mainly the elementary and secondary education settings, to determine what teachers at these levels are doing in their classrooms to teach critical thinking. Research into four-year universities and medical, dental, and veterinary programs could better understand how often these settings employ critical thinking education to determine the level of critical thinking needed to enter such professional programs. A review of assessments used for program entry might also be in order to determine if the kind of assessment used for program entry measures critical thinking skills required for success in the program. The skills-based assessments used for critical thinking could be a better way to determine program entry than the current examinations.

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