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Considering the Community of Inquiry Framework in Online Engineering Education – A Literature Review

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The Community of Inquiry (CoI) framework has gained considerable attention as a theoretical and methodological means to understand and facilitate online learning experiences. Following calls for more studies investigating disciplinary differences and blended learning environments, this semi-systematic literature review summarizes and synthesizes CoI's application in online engineering education, to provide a base for informed judgments about its potential for educational research and practice in this particular context. Based on 22 reviewed articles, we show that CoI is a promising framework not only as an evaluation tool for online and blended learning environments in engineering education but also for the design of online engineering courses that want to build their learning design on a collaborative constructivist view of learning. However, compared to the richness of the general literature on CoI and in other fields, the utilization of CoI in engineering education is still very new and appears to still be in a junior state. Accordingly, we suggest several directions for improvement and further research.

Keywords: Community of Inquiry, CoI, engineering education, online learning, blended learning

INTRODUCTION

Engineering education – as in most areas of education – is shifting towards increased digitalization of teaching and learning environments. Examples include the emergence of Massive Open Online Courses, adapted pedagogical approaches such as flipped classrooms and – propelled by the Covid-19 pandemic – the rapid transition of traditional courses into the online realms which has been summarized under the term emergency response teaching. For engineering education, the increased digitalization can also be seen as a response to major societal developments such as the need for sustainability, the fourth industrial revolution,

and a more diverse student population. Future engineers need to be able to understand problems and develop sustainable solutions in complex and chaotic contexts (Hadgraft & Kolmos, 2020).

Educational researchers are trying to understand the effects of digitalization on students' learning experiences and the conditions under which teaching and learning in online environments can be fostered. In a generally undertheorized field of educational technology (Hew et al., 2019), the Community of Inquiry (CoI) framework (Garrison et al., 1999) has gained considerable attention as a theoretical and methodological means to understand and facilitate learning experiences in online learning environments (Kozan & Caskurlu, 2018). Rooted in a (social) constructivist view of learning through a sense-making process of learners' interactions in a social-cultural context (Vygotsky & Cole, 1978), the framework proposes conditions that are expected to provide learners with comprehensive and meaningful learning experiences. Thus, the CoI framework focuses on the learning process rather than learning outcomes per se (Akyol et al., 2009).

In its original form, these conditions are conceptualized around three interdependent dimensions: (1) cognitive presence which represents the students' interaction with the course content; (2) social presence which demonstrates the students' interaction with other learners and cultural aspects of the learning environment; and (3) teaching presence which illustrates the students' interaction with instructional tools and learning activities.

Cognitive presence refers to the extent to which learners are cognitively active, i.e., can construct and validate meaning as a result of critical and continuous thinking and communication (Garrison et al., 1999; Garrison et al., 2001). Specifically, this presence comprises an iterative or even cyclical move through four phases that are based on the practical inquiry model by John Dewey (1933). The phases consist of (a) a triggering event that presents the problem (problem conceptualization), (b) the exploration of ideas about how to solve the problem (idea generation), (c) the integration of those ideas (knowledge synthesis), and (d) the resolution through which the best solutions are chosen and applied (knowledge application and vicarious testing) (Garrison & Arbaugh, 2007).

Social presence refers to the learners' ability to project their identity in the community, communicate purposefully in a trusting environment, and develop interpersonal relationships (Garrison, 2009) and therefore consists of (a) emotional expression concerning a learning experience, (b) open communication as reciprocal and respectful exchanges, and (c) group cohesion, which refers to the activities that create and maintain a sense of group commitment (Garrison et al., 1999).

Finally, teaching presence is the design, facilitation, and direction of the learners' cognitive and social processes to achieve meaningful and worthwhile learning outcomes (Garrison et al., 1999). Thus, its main function is to sustain cognitive and social presence through learning design and facilitation and while it typically lies within the teachers' realm, it can extend to students or other agents as well. Teaching presence comprises (a) instructional design and organization of the process, structure, evaluation, and interaction including guidelines and tips (b) facilitating discourse, by enhancing reflective and sustained communication as well as the learners' motivation and engagement, and (c) direct instruction as a means to provide students with expert knowledge and leadership to achieve the learning objectives.

The CoI framework has been used in many studies in online learning including the online parts of blended learning, particularly concerning learner populations from (teacher) education and business disciplines (Befus, 2016; Kim & Gurvitch, 2020). Its considerable popularity has resulted in several review studies and research syntheses over the years (Befus, 2016; Caskurlu et al., 2021; Castellanos-Reyes, 2020; Garrison et al., 2010; Garrison & Arbaugh, 2007; G. Kim & Gurvitch, 2020; Stenbom, 2018). As a process model, CoI attempts to outline not only its three elements but also the dynamics of an online educational experience by examining the relation of those presences to each other (Garrison et al., 2010). For example, social presence is expected to have a mediating role between teaching and cognitive presence, and functions as the underlying concept that brings everything together, and teaching presence is most likely to affect social and cognitive presence (Kozan & Richardson, 2014). Although most studies utilizing the framework cover all three elements, there is a special interest in social presence as this aspect is often overlooked in online learning environments (Kim & Gurvitch, 2020). The framework gradually evolved from a

descriptive framework into a design framework, where the categories outlined in the framework inform a supposedly more effective design of online courses.

Looking back at the 20 years of CoI's history, the most influential shift occurred after the first decade of its development. The early, seminal work on the CoI framework was developed for text-based online environments, and the presence of the three CoI dimensions was mainly identified through the occurrence of certain keywords or phrases. The second decade was heavily influenced by the development and validation of the 34-item CoI survey instrument (Arbaugh et al., 2008; Castellanos-Reyes, 2020; Kim & Gurvitch, 2020). This development was crucial for studying the interrelationships among the presences and had an enormous impact on the theoretical and practical development of the CoI framework as it provides support for the validity of the framework and is efficient for studying large student samples (Garrison et al., 2010). Thus, the CoI survey turned the focus of CoI research towards the perceptions of learners and their experience of the three presences and it has been used effectively to compare different premises in many online contexts (Jaksic, 2021).

In sum, promoters of CoI have concluded that the framework accounts for much of the complexity of the teaching and learning transaction (Garrison & Arbaugh, 2007) and guides both research in online teaching and practical design of learning experiences (Castellanos-Reyes, 2020; Kim & Gurvitch, 2020). However, despite these excellent contributions, there is a concern about the effect of the disciplinary context and there are calls for more studies investigating disciplinary differences (Castellanos-Reyes, 2020). In line with this statement, we observe that no study to date has summarized and synthesized CoI's application in engineering education in particular.

Engineering education employs particular pedagogical approaches and learning environments that are supposed to best prepare students for working life. They are generally framed around the image of the engineer as a "problem-solver," and common approaches that are characteristically present in engineering education involve hands-on laboratories, collaborative project-based learning, or authentic learning with industry partners. Applying these in online learning appears far from trivial and CoI might provide a helpful framework to conceptualize and evaluate approaches to online education.

Given the increasing calls for studying the CoI framework in specific disciplinary contexts and the lack of such work on engineering education with its particular educational nature and traditions, we aim to explore the usage of the CoI framework in engineering education by identifying and reviewing the relevant literature to summarize the state of knowledge, propose directions for further research and contribute to the development of CoI and engineering education. The review is guided by the following research questions:

(1) How is the CoI framework used in Engineering Education Research?
(2) What methodologies are applied?
(3) What are the main results and conclusions?

METHODOLOGY

Semi-systematic review is a research method to overview a topic. A requirement for the approach is that the research process should be transparent both for the chosen topic and from a methodological perspective (Snyder, 2019). The purpose of this literature review is to gain knowledge about the usage of the CoI framework in engineering education, thus only peer-reviewed full papers were included in this study. We searched for articles written in English on June 30, 2022, in the databases Scopus, IEEE Xplore Digital Library, Web of Science, and the Education Resources Information Center (ERIC), which are considered most relevant within the fields of education and engineering. In all the databases, we searched in title, abstract, and keywords. Articles were included in this review based on the search terms presented in Table 1. In the search, * in Communit* was used to include both community and communities. Similarly, * in Inquir* was used to include both inquiry and inquiries. W/2, NEAR/2, or N2 were used to ensure a more comprehensive search.

A total of 189 articles were found in the search of the four databases. First, we conducted an initial screening of titles and abstracts. Articles that only explore the CoI framework but do not address engineering or that only discuss engineering but do not use the CoI framework were excluded. In all the

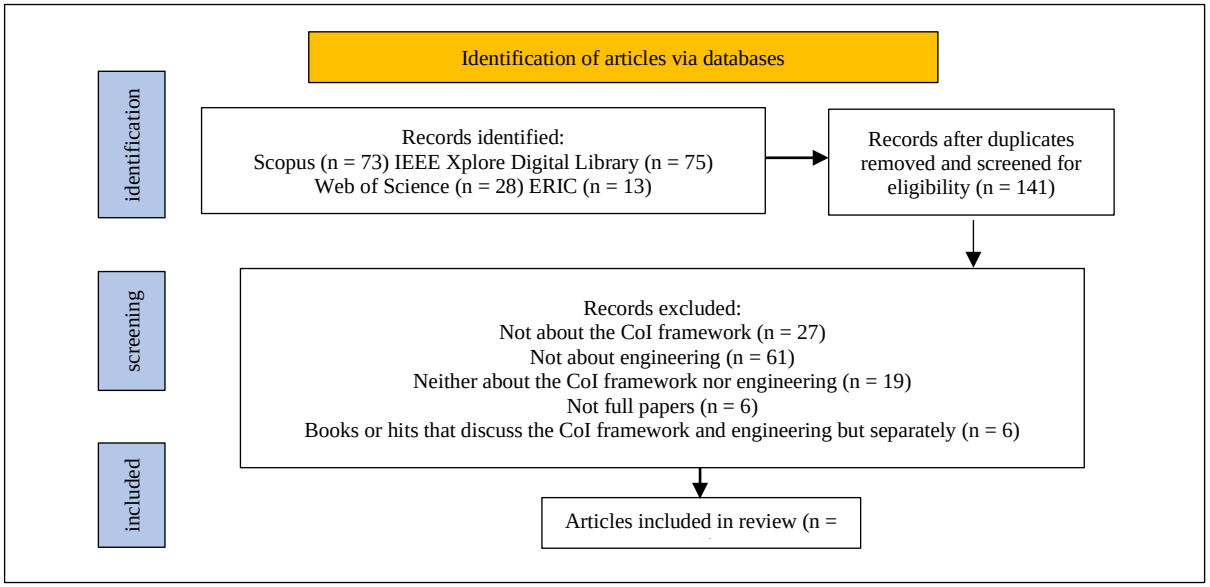
included articles, the CoI framework addresses the context of online engineering education, either in pure web-based or blended course formats. 22 articles were selected to be included in the detailed review.

TABLE 1
SEARCH TERMS AND RESULTS

Database	Search Terms
Scopus	TITLE-ABS-KEY (communit* W/2 inquir*) and TITLE-ABS-KEY (engineering)
IEEE Xplore Digital Library	("Document Title": Communit* NEAR/2 Inquir*) OR ("Abstract": Communit* NEAR/2 Inquir*) OR ("Index Terms": Communit* NEAR/2 Inquir*) OR ("Author Keywords": Communit* NEAR/2 Inquir*)
Web of Science	TS=(communit* NEAR/2 inquir*) AND TS=(engineering)
ERIC	TI (Communit* N2 Inquir* AND engineering) OR AB (Communit* N2 Inquir* AND engineering) OR KW (Communit* N2 Inquir* AND engineering)

The search process is presented in Fig. 1 and an overview of the search results is shown in Table 2. For each of the research questions, the articles were analyzed thematically. The resulting themes under each research question were summarized by identifying joint patterns and topics.

FIGURE 1
SEARCH PROCESS



RESULTS

The 22 articles from thirteen different publication sources (journals and conferences) employ the CoI framework and cover a variety of subject areas and disciplines, including chemical engineering, environmental engineering, mathematics, software engineering, civil engineering, mechatronics, and industrial engineering, and comprise both pure online environment and blended learning environments with online parts. The studies are geographically distributed around the world, including Asia, Africa, Oceania, North America, and Europe. In addition, occur in the review. The reviewed papers are listed in Table 2.

TABLE 2
LIST OF INCLUDED ARTICLES

Author	Title
N. I. Jaksic (2021)	Pair-to-Pair Peer Learning: Comparative Analysis of Face-to-Face and Online Laboratory Experiences
J. C. Dunlap et al. (2016)	Presence+Experience: A Framework for the Purposeful Design of Presence in Online Courses
Y. Y. Lau et al. (2021)	COVID-19 Crisis: Exploring Community of Inquiry in Online Learning for Sub-Degree Students
D. Beneroso and J. Robinson (2022)	Online project-based learning in engineering design: Supporting the acquisition of design skills
V. Kovanović et al. (2015)	Analytics of communities of inquiry: Effects of learning technology use on cognitive presence in asynchronous online discussions
J. Chernosky et al. (2021)	Students as Consumers: Retaining Engineering Students by Designing Learner-Centric Courses of Value
E. P. Purwandari et al. (2022)	Exploring e-learning community of inquiry framework for engineering education
B. H. W. Guo et al. (2022)	Civil engineering students' perceptions of emergency remote teaching: a case study in New Zealand
R. Nihlawi et al. (2018)	Engineering students' perceptions of flipped learning: Benefits, challenges, and recommendations
K. A. Douglas et al. (2022)	How engineering instructors supported students during emergency remote instruction: A case comparison
T. Hattingh et al. (2020)	Engineering student experiences of a remotely accessed, online learning environment
K. Junus et al. (2017)	The Community of Inquiry Model Training for Beginners: Patterns of Interaction and Student Learning Strategies
H. Baytiyeh (2018)	Progreen online engineering diploma in the Middle East: assessment of the educational experience
I. Cabrera et al. (2017)	Blending Communities and Team-Based Learning in a Programming Course
N. Eteokleous and D. Ktoridou (2012)	Community of inquiry developed through cloud computing for MIS courses
D. Williams-Dobosz et al. (2021)	A Social Network Analysis of Online Engagement for College Students Traditionally Underrepresented in STEM
E. Szeto (2015)	Community of Inquiry as an instructional approach: What effects of teaching, social and cognitive presences are there in blended synchronous learning and teaching?
T. S. N. Rachmawati et al. (2020)	Comparison of online group discussion and class discussion learning for a soil mechanics class
J. Lim and J. C. Richardson (2022)	Considering how disciplinary differences matter for successful online learning through the Community of Inquiry lens
E. Rutz and S. Ehrlich (2016)	Increasing Learner Engagement in Online Learning through Use of Interactive Feedback: Results of a Pilot Study
M. Jansson et al. (2021)	Online question and answer sessions: How students support their own and other students' processes of inquiry in a text-based learning environment
P. Padayachee and A. L. Campbell (2022)	Supporting a mathematics community of inquiry through online discussion forums: towards design principles

The research findings are summarized in three sub-sections following the research questions in the review: How is the framework used; what methodologies are applied; and what are the main results and conclusions?

Usage of the Framework

The CoI framework is used differently regarding purpose. Two main approaches emerge in the articles: (1) CoI for the evaluation of learning designs and (2) CoI as a design instrument. 18 of the 22 articles evaluate learning designs with the help of CoI and 9 employ the framework as a design instrument. Thus, 5 of them use the framework to both evaluate and design.

The articles that approach the CoI framework from an evaluation point of view mainly use it as a conceptual framework. It is used for two different purposes: to evaluate learning environments and learning experiences (Baytiyeh, 2018; Eteokleous & Ktoridou, 2012; Guo et al., 2022; Jansson et al., 2021; Kovanović et al., 2015; Lau et al., 2021; Nihlawi et al., 2018; Purwandari et al., 2022) including five comparative case studies (Douglas et al., 2022; Lim & Richardson, 2022; Rachmawati et al., 2020; Rutz & Ehrlich, 2016; Williams-Dobosz et al., 2021) and, to analyze the relationships between the different presences (social, teaching and cognitive) in the CoI framework (Nihlawi et al., 2018; Purwandari et al., 2022). An evaluation of learning environments and experiences includes questions about student satisfaction, performance, and learning. The comparative case studies include examining differences between different levels of engineering courses (Douglas et al., 2022), traditionally underrepresented students in the field of science, technology, engineering, and mathematics, and students who are non-underrepresented (Williams-Dobosz et al., 2021), group discussion and class discussion as two types of online discussions (Rachmawati et al., 2020), different disciplines (Lim & Richardson, 2022), as well as text-based and audio feedback (Rutz & Ehrlich, 2016). Through targeting the differences, Douglas et al. (2022) aim at identifying the challenges of online learning and ways to support a successful online learning experience. How online learning behaviors affect learning outcomes is examined in three articles (Lim & Richardson, 2022; Rachmawati et al., 2020; Williams-Dobosz et al., 2021). Rutz and Ehrlich (2016) discuss how the CoI presences are influenced by text-based and audio feedback as two forms of feedback. The studies of the relationships among the elements of the CoI framework include several themes. Exploration of the elements is used to assess students' perceptions of their learning experiences concerning flipped classrooms (Nihlawi et al., 2018). Their relationships are also investigated to determine ways to strengthen cognitive, social, and teaching presence to promote collaboration and critical thinking (Purwandari et al., 2022).

Four articles employ the CoI framework as a design instrument. They use it for different purposes: to guide online instructional practices in courses (Beneroso & Robinson, 2022); to redesign courses (and evaluations) (Cabrera et al., 2017; Dunlap et al., 2016); and, to propose training designs for specific parts of online courses (Junus et al., 2017).

Finally, the CoI framework is used to both evaluate and design (Chernosky et al., 2021; Hattingh et al., 2020; Jaksic, 2021; Padayachee & Campbell, 2022; Szeto, 2015). Chernosky et al. (2021) identify key components of student satisfaction and engagement and develop an equitable instructional design model. Hattingh et al. (2020) evaluate engineering student experiences of an emergent remote online teaching and learning environment and provide insights into the design of online teaching and learning environments. Jaksic (2021) compares online laboratory experiences with what is already known about face-to-face learning and uses the CoI presence to establish an online environment. Szeto (2015) employs the CoI framework as an instructional approach to explore the effects of the presence on shaping online and face-to-face learning and teaching experiences. Padayachee and Campbell (2022) evaluate online discussion forums and recommend design principles.

Methodologies

Methodologically, the three CoI elements, cognitive, social, and teaching presence, are included in all articles but one (Kovanović et al., 2015). Nihlawi et al. (2018) and Hattingh et al. (2020) consider a fourth presence, a learning presence (Shea & Bidjerano, 2012). Learning presence refers to self-directed learning

skills. Jansson et al. (2021) also discuss another presence, emotional presence (Stenbom et al., 2016). The one article that does not employ all three CoI elements solely focuses on a cognitive presence to assess critical thinking (Kovanović et al., 2015).

More than half of the articles that use the CoI framework as an evaluation tool employ the standardized CoI survey (Arbaugh et al., 2008) as a method of quantitatively collecting and analyzing data (Baytiyeh, 2018; Eteokleous & Ktoridou, 2012; Lau et al., 2021; Nihlawi et al., 2018; Purwandari et al., 2022; Rachmawati et al., 2020; Rutz & Ehrlich, 2016), as do the articles that use the CoI framework to both evaluate and design (Chernosky et al., 2021; Hattingh et al., 2020; Padayachee & Campbell, 2022; Szeto, 2015). The articles apply the survey strictly or use it with minor modifications. Jansson et al. (2021) utilize the Relationship of Inquiry (RoI) (Stenbom et al., 2012) coding scheme adapted from the CoI framework. The RoI framework is an adaption of CoI for studying learning environments with one student and one tutor. Open-ended questions are used in addition to the survey instrument (Chernosky et al., 2021; Hattingh et al., 2020; Nihlawi et al., 2018; Rachmawati et al., 2020; Rutz & Ehrlich, 2016). Nihlawi et al. (2018) include questions about what students like, dislike, and recommend about the teaching method to gain additional qualitative insights into students' perceptions of flipped learning experiences. The other four combine the survey instrument with open-ended discussion questions about students' experiences and challenges in online learning environments. Padayachee and Campbell (2022) adopt a mix of data including interviews, surveys, discussion forum content, and learning platform analytics.

Six articles using CoI as an evaluation tool have developed other ways of evaluating than the above-mentioned standardized CoI survey. Douglas et al. (2022) employ a case study protocol to examine how different relationships change during the move to emergency remote teaching and how instructor decisions affect those relationships. Guo et al. (2022) designed a survey to measure students' perceptions of online learning and interprets the results from a CoI perspective concerning not only the three main elements but also the dynamic relationship among them. The survey consists of participants' demographics, perceptions, and understandings of the benefits and challenges of online teaching and learning, and the selection of the main factors that contribute to effective online teaching and learning respectively. Yet, Jaksic (2021) evaluates both quantitative and qualitative data by using a self-designed questionnaire that resembles the CoI survey and students' test grades, as well as students' lab performances and lab reports. Kovanović et al. (2015) measure the levels of cognitive presence by implementing the practical inquiry model (Garrison et al., 2001) that explores the nature and quality of cognitive presence, as defined and assessed by four phases including a) triggering event, which is often a problem or dilemma, b) exploration, c) integration, which represents the synthesis of information, and d) resolution. Williams-Dobosz et al. (2021) use social network analysis (Wasserman et al., 1994) and nested regression models to explore how different measures of forum engagement including the total number of posts written, number of help-seeking posts written and replied to, and level of connectivity are related to performance gains. Lim and Richardson (2022) conduct semi-structured interviews to explore students' perceptions of their learning experiences and outcomes across academic disciplines.

The four articles that employ the CoI framework as a design instrument and one of the articles that use it for evaluation and design use the framework as a guide when developing courses or parts of courses. They adopt the framework very differently. The CoI framework, based on the intersection of the three presences, is used to ensure deep and meaningful online learning (Beneroso & Robinson, 2022; Szeto, 2015). Three articles combine the CoI framework with other theoretical and pedagogical frameworks in redesigning courses. Cabrera et al. (2017) combine the CoI framework with Team-Based Learning (Michaelsen & Sweet, 2008) and Web community (A. J. Kim, 2006), and uses the combination as a basis for the redesign of a programming course. The CoI framework is merged with the experiential learning cycle (Kolb, 2014) to guide the redesign of courses (Dunlap et al., 2016). Junus et al., (2017) use a cognitive apprenticeship approach as a training design where students first observe how instructors model the application of skills and then practice under the guidance of the instructors. The study proposes the cognitive apprenticeship approach for the training of the CoI model to improve students' preparedness to take active parts in online discussion forums.

Main Findings

As stated in a previous section, there are two different, and in some cases connected, purposes of employing the CoI framework in engineering education, either as an evaluation tool or as a design instrument, or both. Dependent on which approach, evaluative or design-motivated, the perspective and focus of the results differ significantly. Generally, the presented results focus mainly on implications for teaching practice and surprisingly little on implications for research and theoretical development.

As an Evaluation Tool

Some articles that use the CoI framework as an evaluation tool argue that social presence is the most important factor in online education. Baytiyeh (2018) identifies the importance of five factors in learners' educational experiences where a sense of belonging is argued to be the highest-rated one. Other important factors are self-directedness, self-actualization, interaction, and instructional guidance, where the latter is found to highly correlate with self-directedness and self-actualization. Similarly, Douglas et al. (2022) recognize the importance of access to relationships and support from people, which learners believe influences their success and persistence. Therefore, it recommends the establishment of informal conversations among students as well as between students and instructors. Guo et al. (2022) also identify the social presence, represented by student-lecturer interactions, as a supportive online environment, and student-student interactions, as a significant factor. Nihlawi et al. (2018) echo this view by observing that social presence has the highest level of student satisfaction in undergraduate classes. However, Williams-Dobosz et al. (2021) disagree by saying that one does not need to be well-connected in a class network to achieve positive learning outcomes. Lim and Richardson (2022) come to a similar conclusion that engineering students do not perceive the importance of social presence for achieving learning outcomes. Rachmawati et al. (2020) find that cognitive presence is dominant, while Lim and Richardson (2022) stress the importance of teaching presence. Szeto (2015) also emphasizes teaching presence as it reveals that the attainment of intended learning outcomes relies more on teaching presence than on social and cognitive presence. Rutz and Ehrlich (2016) add that teaching presence is improved due to audio feedback. Jansson et al. (2021) acknowledge the role of teaching presence in question-and-answer sessions. Padayachee and Campbell (2022) conclude from a more comprehensive point of view and point out that discussion forums contribute to all three CoI presences.

Purwandari et al. (2022) show how/that the different elements in the CoI framework, social, teaching, and cognitive presences are interrelated and affect each other. This article finds that the role of teaching presence is essential and has a higher contribution to cognitive presence than social presence for engineering education. The article concludes that lecturers should be equipped with pedagogical competence and trained to develop learning material with diversified teaching plans, to facilitate students learning, or more specifically, by providing facilitation and direction they will ensure students' progress through the phases of cognitive presence (Garrison et al., 2010).

Some articles end up with rather narrow and limited findings when employing the CoI framework for evaluative purposes. While recognizing the value of creating and sustaining a purposeful online learning community, it is noted that when students determine the value of the perceived cognitive, social, and teaching presence, the network speed is more significant than gender and academic discipline (Lau et al., 2021). Douglas et al. (2022) focus on cognitive presence and indicate that the availability of different tools in a learning environment is not enough for their successful use. Students also need to have adequate meta-cognitive capabilities, skills, and motivation to use the available tools. Chernosky et al. (2021) have used the CoI framework to redesign courses as well as to evaluate and indicate that redesigning the courses improves the grades though the failure rate remains static. Interestingly, it also notices that there is no significant correlation between student satisfaction and their grades.

As a Design Instrument

Some articles employ the CoI framework primarily as a design instrument. The importance of social presence is acknowledged as it is pointed out that the extent to which social presence alongside cognitive presence is developed influences students' response to learning (Beneroso & Robinson, 2022). It thus

proposes to strengthen social presence that involves broader open communication and social cohesion. Cabrera et al. (2017) further prove the effectiveness of the CoI framework as a design tool. According to it, students who combine a community of inquiry learning with team-based learning outperform those who use traditional approaches as the former achieves a higher level of understanding in a shorter period due to increased participation rates. The value of the CoI framework is also presented when the integration of the CoI framework and experiential learning cycle is found to contribute to the creation of productive, meaningful, and flexible learning experiences (Dunlap et al., 2016). The integrated approach can both be used online through blog posts on students' reflections on their learning experiences or web-conferenced lectures and on-campus via playing a game or working on a collaborative project without degradation of social, cognitive, or teaching presences. In addition, the article also states the potential risk for the approach to be too rigid when used in the design of online learning experiences in different contexts and with different instructional goals and audiences. Besides revealing the prominent relevance of the framework in an online learning environment, Hattingh et al. (2020) reiterate the importance of self-directed learning skills and enhancing student engagement, not only with the content but also with other students and instructors. Jaksic (2021) uses the CoI presence to establish an online environment. Teaching presence is attained through synchronous video conference meetings and various asynchronous text writing. Social presence is accomplished through small group interaction via video conference systems and discussion forums in learning management systems. By applying the CoI framework, Chernosky et al. (2021) suggest different areas for enhancement including faculty interaction, authenticity, student-to-student engagement, feedback, multimedia, and homework. Padayachee and Campbell (2022) also propose design principles for discussion forums, such as integrating discussion forums with collaborative course activities and monitoring and checking in with students who are not participating.

Eteokleous and Ktoridou (2012) use the CoI framework as a model to create and implement a community of inquiry which they define as an environment where educators and students function as inquirers, collaboratively working with an inquiry-based approach. The setting is a cloud learning environment. The implementation of such a community is proven to be able to develop students' abilities of problem-solving, critical thinking, self-directed learning, communication, collaboration, and knowledge construction. Junus et al. (2017) observe that in their training design, social presence is the most dominant presence, followed by the cognitive presence and teaching presence. They also note that social, cognitive, and teaching presences develop with the same pattern. The three presences are high at the beginning as learners are triggered by a problem, then they decline and further decline as the problem is already defined before finally rising again as learners attempt to solve the problem on time.

DISCUSSION

This study sets out to examine how the Community of Inquiry (CoI) framework has been used to understand and improve online learning in engineering education. Through a semi-structured literature review, we identify 22 relevant articles that we analyze in terms of how CoI is used, the empirical methods applied, and the key findings. On a general level, we observe that in line with the fact that CoI is only two decades old, the application of CoI in engineering education is a very recent development that has only gained popularity in the last few years. 17 of the 22 articles are less than five years old and over half of them date 2020 or later. It is noteworthy that the articles generally do not discuss the CoI framework from a more critical perspective. Compared to other fields, the total number of studies published in journals appears also quite low, which resonates with reviews (e.g. Befus, 2016) that show that most studies were conducted in the education and business disciplines, none in engineering, and only one in computer science. However, we expect the observed trend to continue with an increasing number of contributions in the coming years.

Concerning how CoI is used, the majority of studies either apply CoI to evaluate learning environments or student experiences in online engineering courses or as a design framework to develop or re-design online courses. From the evaluation perspective, the key research questions evolve around the contribution of the different presences in CoI to learning as well as the relationship between the presences. Thus, the

existing studies focus mainly on the practical implications of their results for teaching and the development of online learning environments. Little to no research targets the theoretical development of the CoI framework to enable statements about the applicability and eventual necessary revisions of the CoI framework for the specific context of engineering education, e.g., for studying online and hybrid laboratories, project-based learning, and authentic learning environments. In line with this observation, we also assert that except for three articles (Hattingh et al., 2020; Jansson et al., 2021; Nihlawi et al., 2018), all papers use the original version of the CoI framework with the three presences. Thus, we think that online engineering education would benefit from a more careful consideration of theoretical work on CoI than has been done including suggested revisions and additions to the original three dimensions such as learning presence (Befus, 2016), autonomy presence (Lam, 2015), emotional presence (Stenbom et al., 2016) and instructor social presence (Minor & Swanson, 2014; see Kozan & Caskurlu, 2018 for an overview).

Methodologically, most of the papers are small sample case studies with quantitative surveys as the data collection method. There is also a clear dominance of studies of purely online learning environments except for two articles examining blended learning with online parts (Nihlawi et al., 2018; Szeto, 2015). In many ways, these results echo the findings from other, more general review papers about CoI. However, whereas for example, Befus (2016) reports a dominance of studies placed in the US, we notice a broader geographical distribution of the research settings within engineering education. While this is a positive result, a consequence of the small total number of contributions is a need for further empirical studies in the different geographical contexts to increase the transferability of results through cumulative case study research. Similarly, even though during the pandemic much education in engineering education was conducted at a distance, post-pandemic there seems to be a shift back toward university campuses. It is therefore prudent not to limit research on the digitalization of engineering education to pure online learning environments but to also consider blended learning environments and approaches. While the CoI framework was developed for online learning environments, it has already demonstrated its usefulness for the analysis of blended learning environments (Nihlawi et al., 2018; Szeto, 2015) and we encourage engineering education researchers to explore this path further.

Both quantitative and qualitative research have their place in engineering education research and several of the reviewed articles approach CoI from a qualitative perspective. As both methodological traditions result in distinct types of knowledge, we join Caskurlu et al. (2021) in their call for more mixed-method studies with CoI as a conceptual framework to gain a more holistic picture of the observed phenomenon.

Lastly, we will discuss some of the key results that emerged during the review. Firstly, about student learning, the existing results indicate that CoI-based online learning can at least result in similar learning compared to campus teaching (Cabrera et al., 2017; Chernosky et al., 2021; Jaksic, 2021). Nevertheless, the number of comparative studies is very limited, but some interesting tendencies can be discussed in the context of engineering education. For example, it is indicated that laboratory work, a core engineering education activity that is traditionally placed in physical labs, can be conducted online with similar learning outcomes as traditional laboratories (Jaksic, 2021). Other research confirms this interesting finding (Olesen et al., 2022) and CoI appears to provide a suitable perspective to better understand the conditions and contexts in which online laboratories can provide students with a rich learning experience.

Further, a significant proportion of the reviewed studies stress the importance of social presence in online engineering education and suggest a conscious learning design effort to foster communication among learners as well as teachers and learners (Baytiyeh, 2018; Guo et al., 2022; Hattingh et al., 2020; Junus et al., 2017), particularly in undergraduate classes (Nihlawi et al., 2018) and also to create opportunity for informal conversation (Douglas et al., 2022). Nevertheless, these findings are not homogeneous and the importance of social presence is questioned. Several studies come to different conclusions, be it that the relative importance of teaching and cognitive presence is higher than that of social presence (Lim & Richardson, 2022; Purwandari et al., 2022; Rachmawati et al., 2020; Szeto, 2015) or that other factors such as technical infrastructure (Lau et al., 2021) and metacognitive skills (Hattingh et al., 2020; Kovanović et al., 2015) have more explanatory power. These findings show the value of CoI but also reinforce the

question of CoI as a theoretical framework covers the key factors for online learning success in engineering education.

Some articles present case studies that utilize CoI as a valuable and effective design tool. This illustrates the framework's strength in guiding the development of online learning environments. However, the framework is often used in combination with other theoretical and pedagogical models, such as team-based learning (Cabrera et al., 2017) or Kolb's experiential learning cycle (Dunlap et al., 2016). Noteworthy, the integrated approaches can be used both online and on-campus without degradation of social, cognitive, or teaching presences.

Finally, several studies point to the differences between learner perceptions of online learning environments indicating that advanced students (Guo et al., 2022) and stronger students (Chernosky et al., 2021) benefit more from online learning than less advanced and new students with less experience. Also, they show more positive attitudes toward the benefits and challenges of online learning (Guo et al., 2022) and the more experienced students become, the less dependent on the guidance of the teacher (Junus et al., 2017). This effect can be linked to students' self-regulated learning abilities that typically are more demanding in online learning than in traditional classroom environments. Students at the graduate level typically have developed those skills to a larger extent than newly enrolled learners. Similarly, stronger and more motivated students tend to benefit from the increased flexibility of online learning environments while low-performing students might be struggling even more. This also fits the authors stressing the importance of communication and social activities, particularly in the early years of the study (Nihlawi et al., 2018). The phenomenon, when discussed by using Transactional Distance Theory, is called the "polarization effect" of online learning (Stöhr et al., 2020).

CONCLUSION

This paper explores the application of the CoI framework in engineering education in 22 articles. We conclude that CoI is a promising framework not only as an evaluation tool for online learning environments including blended ones in engineering education but also for the design of online engineering courses that want to build their learning design on a collaborative constructivist view of learning. Given the success of CoI in other fields, the relatively limited number of CoI-based studies in online engineering education lets us conclude that more research on CoI is needed in the field to make more informed and potentially critical statements about its usefulness as a design and evaluation framework guiding the digitalization of engineering education. So far, the utilization of CoI in engineering education is still very new and appears still to be in a junior state. We suggest several directions for improvement and further research both to foster CoI's theoretical development as well as to provide practical guidance for the design of engineering-specific learning environments based on reliable and valid research.

Methodologically, most research is quantitative using the standard version of the CoI survey to gather empirical data about participants' perceptions of learning experiences. Qualitative methods with semi-structured and open-ended questions and explanatory follow-up analysis, though often provide inspiring insight, are not as often applied. We, therefore, conclude that the field would benefit from more explicit and rigorous mixed-methods research designs to strengthen the results of quantitative correlational analyses with in-depth information about the underlying mechanisms that cause the effect of the different presences on the learning experiences.

Finally, we want to stress the importance of self-regulated learning skills that several articles identify as crucial in online learning environments. Further work is necessary to link CoI-based studies in engineering education to the body of literature that theorizes and empirically studies self-regulation in online learning contexts.

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