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Considering the Community of Inquiry Framework in Online Engineering Education

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***Abstract*—This Research Full Paper presents a semi-systematic literature review of the application of the Community of Inquiry (CoI) framework in online engineering education. In a generally undertheorized field, the CoI framework has gained considerable attention as a theoretical and methodological means to understand and facilitate learning experiences in online learning environments. However, despite excellent contributions in both these areas, there is a concern about the effect of the disciplinary context and there are calls for more studies investigating disciplinary differences and blended learning environments. We observe that no study to date has tried to summarize and synthesize CoI's application in engineering education, making informed judgments about its potential for educational research and practice in this particular context difficult. This review aims to contribute to closing this gap. Based on the reviewed articles, we conclude 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. Due to the relatively limited number of CoI-based studies in online engineering education, we conclude that more research of CoI is needed in the field, especially in specific learning contexts. 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. We suggest several directions for improvement and further research both in order 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.**

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

I. INTRODUCTION

Engineering education – as 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 classroom 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 [1].

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 [2], the Community of Inquiry (CoI) framework [3] has gained considerable attention as a theoretical and methodological means to understand and facilitate learning experiences in online learning environments [4]. Rooted in a (social) constructivist view of learning through a sense-making process of learners' interactions in a social-cultural context [5], 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 [6].

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. are able to construct and validate meaning as result of critical and continuous thinking and communication [3], [7]. Specifically, this presence comprises an iterative or even cyclical move through four phases that are based on the practical inquiry model by John Dewey. 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) [8].

Social presence refers to the learners' ability to project their personal identity in the community, communicate purposefully in a trusting environment, and develop interpersonal relationships [9] and therefore consists of (a) emotional expression in relation to 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 [3].

Finally, teaching presence is the design, facilitation and direction of the learners' cognitive and social processes with the goal of achieving meaningful and worthwhile learning outcomes [3]. 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 mean 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 in relation to learner populations from (teacher) education and business disciplines [10], [11]. Its considerable popularity has resulted in a number of review studies and research syntheses over the years [8], [10]-[15]. As a process model CoI attempts to outline not only its three elements, but also the dynamics of an online educational experience through examining the relation of those presences to each other [13]. 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 [16]. 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 [11]. 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 presence of the three CoI dimensions was mainly identified through the occurrence of certain key words or phrases. The second decade was heavily influenced by development and validation of the 34-item CoI survey instrument [11], [15], [17]. 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 [13]. 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 [18].

In sum, promoters of CoI have concluded that the framework accounts for much of the complexity of the teaching and learning transaction [8] and provides guidance for both research in online teaching and practical design of learning experiences [11], [15]. 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 [15]. 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 in order 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?

II. 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 [19]. 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 I. 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 actually 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 [18], [20]-[40] were selected to be included in the detailed review.

TABLE I. 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)

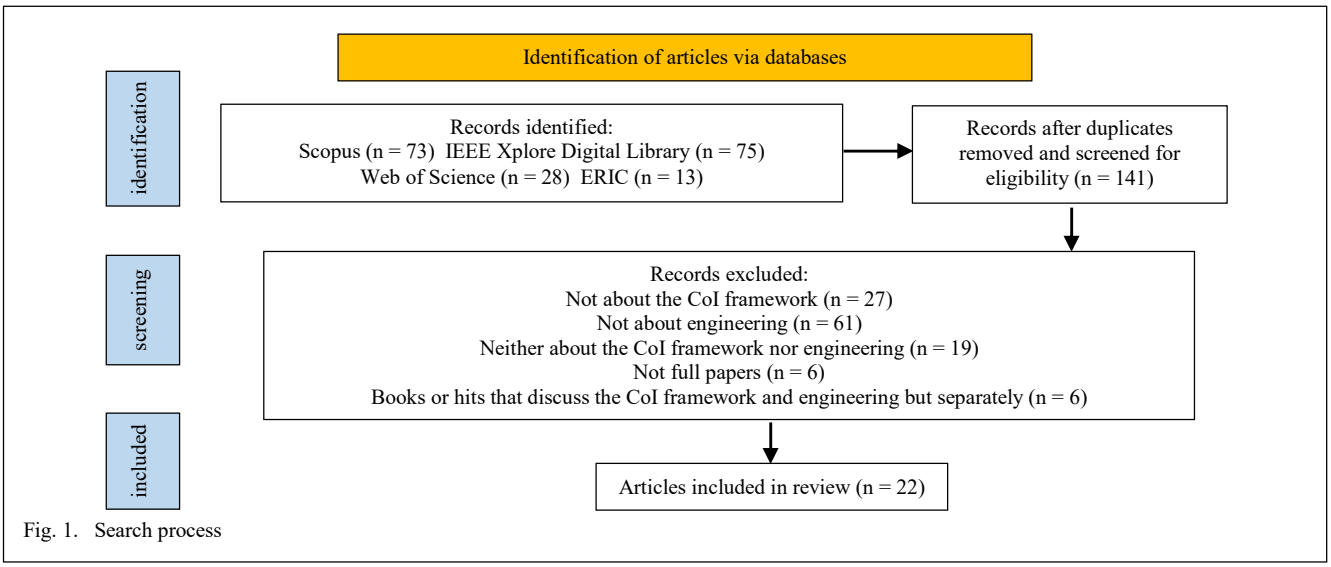

Fig. 1. Search process

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

III. RESULTS

A. 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 II.

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

1) *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 [21], [23], [25]-[27], [31], [33], [39] including five comparative case studies [28], [34], [36]-[38] and, to analyze the relationships between the different presences (social, teaching and cognitive) in the CoI framework [25], [27]. An evaluation of learning environments and experiences includes questions of student satisfaction, performance, and learning. The comparative case studies include examining differences between different levels of engineering courses [28], traditionally underrepresented students in the field of science, technology, engineering, and mathematics and students who are non-underrepresented [34], group discussion and class discussion as two types of online discussions [36], different disciplines [37], as well as text-based and audio feedback [38]. Through targeting the differences, reference [28] aims at identifying challenges of online learning and ways to support a successful online learning experience. Reference [34], and [36]-[37] examine how online learning behaviors affect learning outcomes. Reference [38] discusses 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 in relation to flipped classrooms [27]. Their relationships are also investigated to determine ways to strengthen cognitive, social, and teaching presence to promote collaboration and critical thinking [25].

Four articles employ the CoI framework as a design instrument. They use it for different purposes: to guide online instructional practices in courses [22]; to redesign courses (and evaluations) [20], [32]; and, to propose training design for specific parts of online courses [30].

Finally, reference [18], [24], [29], [35], and [40] use the CoI framework to both evaluate and design. Reference [24] identifies key components of student satisfaction and engagement and develops an equitable instructional design model. Reference [29] evaluates engineering student experiences of an emergent remote online teaching and learning environment and provides insights for the design of online teaching and learning environments. Reference [18] compares online laboratory experiences with what is already known about face-to-face learning and uses the CoI presences to establish an online environment. Reference [35] employs the CoI framework as an instructional approach to explore the effects of the presences on shaping online and face-to-face learning and teaching experiences. Reference [40] evaluates online discussion forums and recommends design principles.

2) *Methodologies*

Methodologically, the three CoI elements, cognitive, social, and teaching presence, are included in all articles but one [23]. Reference [27] and [29] also consider a fourth presence, learning presence, identified by [41]. Learning presence refers to self-directed learning skills. Reference [39]

also discusses another presence, emotional presence [42]. Reference [23] does not employ all three CoI elements and solely focuses on cognitive presence in order to assess critical thinking.

More than half of the articles that use the CoI framework as an evaluation tool employ the standardized CoI survey [17] as a method of quantitatively collecting and analyzing data [21], [25], [27], [31], [33], [36], [38], as do [24], [29], [35], and [40] that use the CoI framework to both evaluate and design. The articles apply the survey strictly or use it with minor modifications. Reference [39] utilizes the Relationship of Inquiry (RoI) [43] 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. Reference [24], [27], [29], [36], and [38] use open-ended questions in addition to the survey instrument. Reference [27] includes questions about what students like, dislike and recommend about the teaching method in order to gain additional qualitative insights into students' perceptions of a flipped learning experiences. The other four combine the survey instrument with open-ended discussion questions about students' experiences and challenges in online learning environments. Reference [40] adopts 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. Reference [28] employs a case study protocol to examine how different relationships change during the move to emergency remote teaching and how instructor decisions affect those relationships. Reference [26] designs a survey to measure students' perceptions of online learning and interprets the results from a CoI perspective with respect to 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

TABLE II. LIST OF INCLUDED ARTICLES

reference	author	year	title
[18]	N. I. Jaksic	2021	Pair-to-Pair Peer Learning: Comparative Analysis of Face-to-Face and Online Laboratory Experiences
[20]	J. C. Dunlap et al.	2016	Presence+Experience: A Framework for the Purposeful Design of Presence in Online Courses
[21]	Y. Y. Lau et al.	2021	COVID-19 Crisis: Exploring Community of Inquiry in Online Learning for Sub-Degree Students
[22]	D. Beneroso and J. Robinson	2022	Online project-based learning in engineering design: Supporting the acquisition of design skills
[23]	V. Kovanović et al.	2015	Analytics of communities of inquiry: Effects of learning technology use on cognitive presence in asynchronous online discussions
[24]	J. Chernosky et al.	2021	Students as Consumers: Retaining Engineering Students by Designing Learner-Centric Courses of Value
[25]	E. P. Purwandari et al.	2022	Exploring e-learning community of inquiry framework for engineering education
[26]	B. H. W. Guo et al.	2022	Civil engineering students' perceptions of emergency remote teaching: a case study in New Zealand
[27]	R. Nihlawi et al.	2018	Engineering students' perceptions of flipped learning: Benefits, challenges and recommendations
[28]	K. A. Douglas et al.	2022	How engineering instructors supported students during emergency remote instruction: A case comparison
[29]	T. Hattingh et al.	2020	Engineering student experiences of a remotely accessed, online learning environment
[30]	K. Junus et al.	2017	The Community of Inquiry Model Training for Beginners: Patterns of Interaction and Student Learning Strategies
[31]	H. Baytiyeh	2018	Progreen online engineering diploma in the Middle East: assessment of the educational experience
[32]	I. Cabrera et al.	2017	Blending Communities and Team-Based Learning in a Programming Course
[33]	N. Eteokleous and D. Ktoridou	2012	Community of inquiry developed through cloud computing for MIS courses
[34]	D. Williams-Dobosz et al.	2021	A Social Network Analysis of Online Engagement for College Students Traditionally Underrepresented in STEM
[35]	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?
[36]	T. S. N. Rachmawati et al.	2020	Comparison of online group discussion and class discussion learning for a soil mechanics class
[37]	J. Lim and J. C. Richardson	2022	Considering how disciplinary differences matter for successful online learning through the Community of Inquiry lens
[38]	E. Rutz and S. Ehrlich	2016	Increasing Learner Engagement in Online Learning through Use of Interactive Feedback: Results of a Pilot Study
[39]	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
[40]	P. Padayachee and A. L. Campbell	2022	Supporting a mathematics community of inquiry through online discussion forums: towards design principles

and challenges of online teaching and learning, and selection of the main factors that contribute to effective online teaching and learning respectively. Yet, reference [18] 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. Reference [23] measures the levels of cognitive presence through implementing the practical inquiry model [7] 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. Reference [34] uses social network analysis [44] and nested regression models to explore how different measures of forum engagement including total number of posts written, number of help-seeking posts written and replied to, and level of connectivity are related to performance gains. Reference [37] conducts 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 guidance when developing courses or parts of courses. They adopt the framework very differently. In [22] and [35], the CoI framework, based on the intersection of the three presences, is used to ensure deep and meaningful online learning. Three articles combine the CoI framework with other theoretical and pedagogical frameworks in redesigning courses. Reference [32] combines the CoI framework with Team-Based Learning [45] and Web community [46], and uses the combination as a basis for the redesign of a programming course. Reference [20] merges the CoI framework with experiential learning cycle [47] to guide the redesign of courses. Reference [30] uses 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.

3) Main findings

As stated in section 3.1, 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.

a) 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. Reference [31] identifies the importance of five factors of 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, reference [28] recognizes the importance of the access to relationships and support from people, which learners believe influence their success and persistence. Therefore, it recommends the establishment of informal conversations among students as well as between students and instructors. Reference [26] also identifies social presence, represented by student-lecturer interactions, as a supportive online environment, and student-student interactions, as a significant factor. Reference [27] echoes this view by observing that social presence has the highest level of student satisfaction in undergraduate classes. However, reference [34] disagrees by saying that one does not need to be well connected in a class network to achieve positive learning outcomes. Reference [37] comes to a similar conclusion that engineering students do not perceive the importance of social presence for achieving learning outcomes. Reference [36] finds that cognitive presence is dominant, while [37] stresses the importance of teaching presence. Reference [35] also emphasizes teaching presence as it reveals that the attainment of intended learning outcomes relies more on teaching presence than on social and cognitive presences. Reference [38] adds that teaching presence is improved due to audio feedback. Reference [39] acknowledges the role of teaching presence in question-and-answer sessions. Reference [40] concludes from a more comprehensive point of view and points out that discussion forums contribute to all the three CoI presences.

Reference [25] shows 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, in order to facilitate students learning, or more specifically, by providing facilitation and direction they will ensure students' progress through the phases of cognitive presence [13].

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, reference [21] finds out 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. Reference [28] focuses on cognitive presence and indicates that the availability of different tools in a learning environment is not enough for their successful use. Students also need to have adequate and meta-cognitive capabilities, skills, and motivation to use the available tools. Reference [24] has used the CoI framework to redesign courses as well as to evaluate and indicates 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.

b) As a design instrument

Some articles employ the CoI framework primarily as a design instrument. Reference [22] acknowledges the importance of social presence as it points out that the extent to which social presence alongside with cognitive presence are developed influences students' response to learning. It thus proposes to strengthen social presence that involves broader open communication and social cohesion. Reference [32] further proves the effectiveness of the CoI framework as a design tool. According to it, students who combine 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 of time due to increased participation rates. The value of the CoI framework is also presented in [20] where the integration of the CoI framework and experiential learning cycle is found to contribute to the creation of productive, meaningful, and flexible learning experiences. The integrated approach can both be used online through blog posts on students' reflections of 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, reference [29] reiterates the importance of self-directed learning skills and enhancing student engagement, not only with the content but also with other students and instructors. Reference [18] uses the CoI presences to establish an online environment. Teaching presence is attained through synchronous video conference meetings and through 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, reference [24] suggests different areas for enhancement including faculty interaction, authenticity, student-to-student engagement, feedback, multimedia, and homework. Reference [40] also proposes 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.

Reference [33] uses 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. Reference [30] observes that in its training design, social presence is the most dominant presence, followed by cognitive presence and teaching presence. It also notes 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.

IV. Discussion

This study is set 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 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 like [10] 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.

With regard to how CoI is used, the majority of studies either applies CoI to evaluate learning environments or student experiences in online engineering courses or as a design framework to develop or re-design online courses. In 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 in order 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 with the exception of [27], [29], and [39], 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 dimension such as learning presence [10], autonomy presence [48], emotional presence [42] and instructor social presence [49] (see for example [4] for an overview).

Methodologically, most of the papers are small sample case studies with quantitative surveys as data collection method. There is also a clear dominance of studies of pure online learning environments with the exception of two articles examining blended learning with online parts [27], [35]. In many ways these results echo the findings from other, more general review papers about CoI. However, whereas for example [10] 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 [27], [35] 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 [12] in their call for more mixed method

studies with CoI as a conceptual framework in order 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, with regard to student learning, the existing results indicate that CoI-based online learning can at least result in similar learning compared to campus teaching [18], [24], [32]. Nevertheless, the number of comparative studies is very limited, but some interesting tendencies can be discussed in the context of engineering education. For example, the result of [18] indicates 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. Other research confirms this interesting finding (e.g. [50]) 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 the social presence in online engineering education and suggest a conscious learning design effort to foster communication among learners as well as teachers and learners [26], [29]-[31], particularly in undergraduate classes [27] and also to create opportunity for informal conversation [28]. Nevertheless, these findings are not homogeneous and the importance of the 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 [25], [35], [36], [37] or that other factors such as technical infrastructure [21] and metacognitive skills [23], [29] have more explanatory power. These findings show the value of CoI but also reinforce the question if 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 developing online learning environments. However, the framework is often used in combination with other theoretical and pedagogical models, such as team-based learning [32] or Kolb's experiential learning cycle [20]. Noteworthy, the integrated approaches can be used both online and on campus without degradation of social, cognitive, or teaching presences.

Finally, a number of studies point at the differences between learner perceptions of online learning environments indicating that advanced students [26] and stronger students [24] benefit more from online learning than less advanced and new students with less experience. Also, they show more positive attitudes towards the benefits and challenges of online learning [26] and the more experienced students become, the less dependent on the guidance of the teacher [30]. 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 graduate level typically have developed those skills to a larger extent than newly enrolled learners. Similarly, stronger and 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 authors stressing the importance of communication and social activities particularly in early years of study [27]. The phenomenon, when discussed by using Transactional Distance Theory, is called the "polarization effect" of online learning [51].

V. 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 of CoI is needed in the field in order 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 in order 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 of quantitative nature 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 in order 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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References

[1] R. G. Hadgraft and A. Kolmos, "Emerging learning environments in engineering education," Australasian Journal of Engineering Education, vol. 25, no. 1, pp. 3–16, Jan. 2020, https://doi.org/10.1080/22054952.2020.1713522.

[2] K. F. Hew, M. Lan, Y. Tang, C. Jia, and C. K. Lo, "Where is the 'theory' within the field of educational technology research?," British Journal of Educational Technology, vol. 50, no. 3, pp. 956–971, May 2019, https://doi.org/10.1111/bjet.12770.

[3] D. R. Garrison, T. Anderson, and W. Archer, "Critical Inquiry in a Text-Based Environment: Computer Conferencing in Higher Education," The Internet and Higher

Education, vol. 2, no. 2, pp. 87–105, 1999, https://doi.org/10.1016/S1096-7516(00)00016-6.

[4] K. Kozan and S. Caskurlu, "On the Nth presence for the Community of Inquiry framework," Computers & Education, vol. 122, pp. 104–118, Jul. 2018, https://doi.org/10.1016/j.compedu.2018.03.010.

[5] L. Vygotsky, Mind in society: The development of higher psychological processes, Cambridge: Harvard University Press, 1078.

[6] Z. Akyol et al., "A Response to the Review of the Community of Inquiry Framework," International Journal of E-Learning & Distance Education / Revue internationale du e-learning et la formation à distance, vol. 23, no. 2, Art. no. 2, Jul. 2009.

[7] D. R. Garrison, T. Anderson, and W. Archer, "Critical thinking, cognitive presence, and computer conferencing in distance education," American Journal of Distance Education, vol. 15, no. 1, pp. 7–23, 2001, https://doi.org/10.1080/08923640109527071.

[8] D. R. Garrison and J. B. Arbaugh, "Researching the community of inquiry framework: Review, issues, and future directions," The Internet and Higher Education, vol. 10, no. 3, pp. 157–172, 2007, https://doi.org/10.1016/j.iheduc.2007.04.001.

[9] D. R. Garrisson, "Communities of Inquiry in Online Learning," in Encyclopedia of Distance Learning, vol II, P. L. Rogers, G. A. Berg, J. V. Boettcher, C. Howard, L. Justice and K. D. Schenk, Eds. Hershey, PA: IGI Global, 2009, pp. 352-355.

[10] M. Befus, "Conducting a Multivocal Thematic Synthesis on an Extensive Body of Literature," Canadian Journal of Learning and Technology / La revue canadienne de l'apprentissage et de la technologie, vol. 42, no. 2, 2016, Accessed: Apr. 07, 2022. [Online]. Available: https://www.learntechlib.org/p/178102/.

[11] Kim, G. & Gurvitch, R. (2020). Online Education Research Adopting the Community of Inquiry Framework: A Systematic Review, Quest, 72(4), 395-409

[12] S. Caskurlu, J. C. Richardson, Y. Maeda, and K. Kozan, "The qualitative evidence behind the factors impacting online learning experiences as informed by the community of inquiry framework: A thematic synthesis," Computers & Education, vol. 165, p. 104111, May 2021, https://doi.org/10.1016/j.compedu.2020.104111.

[13] D. R. Garrison, T. Anderson, and W. Archer, "The first decade of the community of inquiry framework: A retrospective," The Internet and Higher Education, vol. 13, no. 1, pp. 5–9, Jan. 2010, https://doi.org/10.1016/j.iheduc.2009.10.003.

[14] S. Stenbom, "A systematic review of the Community of Inquiry survey," The Internet and Higher Education, vol. 39, pp. 22–32, Oct. 2018, https://doi.org/10.1016/j.iheduc.2018.06.001.

[15] D. Castellanos-Reyes, "20 Years of the Community of Inquiry Framework," TechTrends, vol. 64, no. 4, pp. 557–560, Jul. 2020, https://doi.org/10.1007/s11528-020-00491-7.

[16] K. Kozan and J. C. Richardson, "Interrelationships between and among social, teaching, and cognitive presence," The Internet and Higher Education, vol. 21, pp. 68–73, Apr. 2014, https://doi.org/10.1016/j.iheduc.2013.10.007.

[17] J. B. Arbaugh et al., "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, pp. 133–136, Jan. 2008, https://doi.org/10.1016/j.iheduc.2008.06.003.

[18] N. I. Jaksic, "Pair-to-Pair Peer Learning: Comparative Analysis of Face-to-Face and Online Laboratory Experiences," 2021 ASEE Annual Conference, 2021.

[19] H. Snyder, "Literature review as a research methodology: An overview and guidelines," Journal of Business Research, vol. 104, pp. 333–339, 2019, https://doi.org/10.1016/j.jbusres.2019.07.039.

[20] J. C. Dunlap, G. Verma, and H. L. Johnson, "Presence+Experience: A Framework for the Purposeful Design of Presence in Online Courses," TechTrends, vol. 60, no. 2, pp. 145–151, Mar. 2016, https://doi.org/10.1007/s11528-016-0029-4.

[21] Y. Y. Lau, Y. M. Tang, K. Y. Chau, L. Vyas, A. Sandoval-Hernandez, and S. Wong, "COVID-19 Crisis: Exploring Community of Inquiry in Online Learning for Sub-Degree Students," Frontiers in Psychology, vol. 12, Jul. 2021, https://doi.org/10.3389/fpsyg.2021.679197.

[22] D. Beneroso and J. Robinson, "Online project-based learning in engineering design: Supporting the acquisition of design skills," Education for Chemical Engineers, vol. 38, pp. 38–47, Jan. 2022, https://doi.org/10.1016/j.ece.2021.09.002.

[23] V. Kovanović, D. Gašević, S. Joksimović, M. Hatala, and O. Adesope, "Analytics of communities of inquiry: Effects of learning technology use on cognitive presence in asynchronous online discussions," Internet and Higher Education, vol. 27, pp. 74–89, Jul. 2015, https://doi.org/10.1016/j.iheduc.2015.06.002.

[24] J. Chernosky, J. Ausburn, and R. Curtis, "Students as Consumers: Retaining Engineering Students by Designing Learner-Centric Courses of Value," Journal of Continuing Higher Education, vol. 69, no. 2, pp. 100–120, 2021, https://doi.org/10.1080/07377363.2020.1786342.

[25] E. P. Purwandari, K. Junus, and H. B. Santoso, "Exploring e-learning community of inquiry framework for engineering education," International Journal of Instruction, vol. 15, no. 1, pp. 619–632, Jan. 2022, https://doi.org/10.29333/iji.2022.15135a.

[26] B. H. W. Guo, M. Milke, and R. Jin, "Civil engineering students' perceptions of emergency remote teaching: a case study in New Zealand," European Journal of Engineering Education, 2022, https://doi.org/10.1080/03043797.2022.2031896.

[27] R. Nihlawi, H. El-Baz, and C. Gunn, "Engineering students' perceptions of flipped learning: Benefits, challenges and recommendations," in Advances in Science and Engineering Technology International Conferences, ASET 2018, Jun. 2018, pp. 1–6. https://doi.org/10.1109/ICASET.2018.8376920.

[28] K. A. Douglas, A. C. Johnston, J. P. Martin, T. Short, and R. A. Soto-Pérez, "How engineering instructors supported students during emergency remote instruction: A

case comparison," Computer Applications in Engineering Education, 2022, https://doi.org/10.1002/cae.22495.

[29] T. Hattingh, W. van Niekerk, H. Marais, and Y. Geldenhuys, "Engineering student experiences of a remotely accessed, online learning environment," Nov. 2020. https://doi.org/10.1109/WEEF-GEDC49885.2020.9293652.

[30] K. Junus, H. B. Santoso, L. Sadita, S. H. R-Suradijono, and H. Suhartanto, "The Community of Inquiry Model Training for Beginners: Patterns of Interaction and Student Learning Strategies," in 7th World Engineering Education Forum, 2017, pp. 343–348.

[31] H. Baytiyeh, "Progreen online engineering diploma in the Middle East: assessment of the educational experience," European Journal of Engineering Education, vol. 43, no. 2, pp. 264–277, Mar. 2018, https://doi.org/10.1080/03043797.2017.1359240.

[32] I. Cabrera, J. Villalon, and J. Chavez, "Blending Communities and Team-Based Learning in a Programming Course," IEEE Transactions on Education, vol. 60, no. 4, pp. 288–295, Nov. 2017, https://doi.org/10.1109/TE.2017.2698467.

[33] N. Eteokleous and D. Ktoridou, "Community of inquiry developed through cloud computing for MIS courses," 2012. https://doi.org/10.1109/EDUCON.2012.6201010.

[34] D. Williams-Dobosz et al., "A Social Network Analysis of Online Engagement for College Students Traditionally Underrepresented in STEM," in LAK21: 11th International Learning Analytics and Knowledge Conference, Irvine CA USA, Apr. 2021, pp. 207–215. https://doi.org/10.1145/3448139.3448159.

[35] E. Szeto, "Community of Inquiry as an instructional approach: What effects of teaching, social and cognitive presences are there in blended synchronous learning and teaching?," Comput. Educ., vol. 81, pp. 191–201, Feb. 2015, https://doi.org/10.1016/j.compedu.2014.10.015.

[36] T. S. N. Rachmawati et al., "Comparison of online group discussion and class discussion learning for a soil mechanics class," IOP Conf. Ser. Mater. Sci. Eng., vol. 830, no. 3, p. 032056, Apr. 2020, https://doi.org/10.1088/1757-899X/830/3/032056.

[37] J. Lim and J. C. Richardson, "Considering how disciplinary differences matter for successful online learning through the Community of Inquiry lens," Comput. Educ., vol. 187, p. 104551, Oct. 2022, https://doi.org/10.1016/j.compedu.2022.104551.

[38] E. Rutz and S. Ehrlich, "Increasing Learner Engagement in Online Learning through Use of Interactive Feedback: Results of a Pilot Study," in 2016 ASEE Annual Conference & Exposition Proceedings, New Orleans, Louisiana, Jun. 2016, p. 25672. https://doi.org/10.18260/p.25672.

[39] M. Jansson, S. Hrastinski, S. Stenbom, and F. Enoksson, "Online question and answer sessions: How students support their own and other students' processes of inquiry in a text-based learning environment," Internet High. Educ., vol. 51, p. 100817, Oct. 2021, https://doi.org/10.1016/j.iheduc.2021.100817.

[40] P. Padayachee and A. L. Campbell, "Supporting a mathematics community of inquiry through online discussion forums: towards design principles," Int. J. Math. Educ. Sci. Technol., vol. 53, no. 1, pp. 35–63, Jan. 2022, https://doi.org/10.1080/0020739X.2021.1985177.

[41] P. Shea and T. Bidjerano, "Learning presence as a moderator in the community of inquiry model," Computers & Education, vol. 59, no. 2, pp. 316–326, 2012, https://doi.org/10.1016/j.compedu.2012.01.011.

[42] S. Stenbom, S. Hrastinski, and M. Cleveland-Innes, "Emotional Presence in a Relationship of Inquiry: The Case of One-to-One Online Math Coaching," Online Learning, vol. 20, no. 1, pp. 41–56, 2016.

[43] S. Stenbom, S. Hrastinski, and M. Cleveland-Innes, "Student-student online coaching as a relationship of inquiry: An exploratory study from the coach perspective," vol. 16, no. 5, p. 12.

[44] S. Wasserman, K. Faust, and others, "Social network analysis: Methods and applications," 1994.

[45] L. K. Michaelsen and M. Sweet, "The essential elements of team-based learning," New Directions for Teaching and Learning, no. 116, pp. 7–27, 2008, https://doi.org/10.1002/tl.330.

[46] A. J. Kim, Community building on the web: Secret strategies for successful online communities. Peachpit press, 2006.

[47] D. A. Kolb, Experiential learning: Experience as the source of learning and development. FT press, 2014.

[48] J. Y. Lam, "Autonomy presence in the extended community of inquiry," International Journal of Continuing Education and Lifelong Learning, vol. 8, no. 1, pp. 39–61, https://doi.org/10.3316/informit.705821081676347.

[49] H. Pollard, M. Minor, A. Swanson, "Instructor social presence within the community of inquiry framework and its impact on classroom community and the learning environment," Online Journal of Distance Learning Administration, vol. 17, no. 2, 2014.

[50] V. Olesen, C. Stöhr, M. Enelund and J. Malmqvist, "Learning Mechatronics Using Digital Live Labs," Proceedings of the 18th International CDIO Conference, Reykjavík University, Reykjavík, Iceland, June, 2022.

[51] C. Stöhr, C. Demazière, and T. Adawi, "The polarizing effect of the online flipped classroom," Computers & Education, vol. 147, p. 103789, Apr. 2020, https://doi.org/10.1016/j.compedu.2019.103789.