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Cross-institutional collaboration in engineering education – a systematic review study

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ABSTRACT

To uncover and analyze conceptualizations of cross-institutional collaboration in engineering education, a systematic review study was conducted, identifying commonalities in frameworks, assessments and evaluations, and challenges across prior studies. 74 papers were reviewed, revealing *study descriptors*, *theoretically applied frameworks*, *outcomes of assessments and evaluations*, and *common challenges*. The findings indicate that the concept of cross-institutional collaboration in engineering education is region-specific, with papers most frequently originating from the US. The outcomes identified also highlight the difficulty in establishing clarity among outcomes based on assessments and evaluations, since the majority of the reviewed papers do not include empirical data gathered outside the collaborative activities. The structural and personal challenges and barriers found underline the need for more efforts to ensure successful collaboration with and across engineering education. Finally, designing, delivering, and sustaining collaboration require further attention from decision-makers in engineering education to address and facilitate collaboration between academic staff and students across institutions.

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Cross-institutional collaboration; engineering education; collaboration conception; assessment and evaluation in engineering education collaboration; curriculum design

1. Introduction

Collaboration in and across engineering education has been highlighted as an important necessity across global higher education institutions and has gradually been integrated into educational policies (UNESCO 2021; EUA 2023). When cross-institutional collaborations are attempted in engineering education, they are often found to adhere to standards set by external organisations, and there appears to be an absence of common perceptions of the commonalities among cross-institutional collaborations – what they produce, what is experienced, and what outcomes and challenges frequently emerge. Multiple institutions of higher education engaging in cross-institutional collaboration have made efforts to accommodate demands for the involvement of multiple stakeholders and disciplines (Blass and Hayward 2014; Hadgraft and Kolmos 2020; Lake et al. 2017). However, approaches concerned with research and innovation through collaboration across engineering institutions generally face difficulties in facilitating joint efforts, training staff and students, and disseminating outcomes to curious peers and curriculum designers. Arguments concerning the need for collaboration across sectors, disciplines, and institutions are abundant, indicating a political desire for engineering education, both internally and externally (The UN 2015; European Commission. Joint Research Centre 2016). However, for cross-institutional collaborations to occur more widely, commonalities and guiding principles must be explicated since former conceptualizations contain multiple orientations, potentially leading to inconsistencies and redundancies.

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Erasing former disciplinary silos and institutional structures also requires concrete theoretical considerations and commonly applied practices (Hay 2011; Weeks and Farmer 2017). Grand societal organisations, such as the EU or the US Department of Education, have directed attention toward institutional partnerships and collaborations as key elements for the development of student competencies in institutions of higher education (EPRS 2019; U.S.D.E 2021). Arguments link cross-institutional collaboration with the involvement of multiple disciplines and industry partners, although geographical differences exist. Additionally, theoretical frameworks are manifold yet dispersed across studies pertaining to cross-institutional collaboration in engineering education; thus, designing and sustaining initiatives in higher education requires aligning the perceived important theoretical proponents of collaborative processes across disciplinarities and institutional barriers. Unfolding the concept of cross-institutional collaboration involving engineers requires a systematic review approach to identify commonalities in prior studies of cross-institutional collaboration in engineering, producing a general, practical awareness of constituting conceptualizations from contemporary research. The intention in the discovery of indicators of commonalities in conceptualizations is to support the design of future cross-collaborative efforts in engineering education. These have received limited attention, often due to time restrictions, gaps in knowledge, and disciplinary differences, challenging both administrative processes and the intended learning experience (Hay 2011; Froyd, Wankat, and Smith 2012; EPRS 2019). This raises the question of what collaborations across and within engineering education provide if no common practices are applied in guiding their practical circumstances and if no prior challenges and lessons are incorporated into future collaboration designs.

This paper is a response to the seeming lack of cohesion characterising cross-institutional collaboration in engineering education, aiming to uncover and align prior and contemporary initiatives, as there appear to be gaps in the literature concerning different types of collaboration across engineering institutions. In addition, since it is essential to uncover how institutions embedded in collaborative elements regulate and adapt different norms and values in their curricular approaches, this paper aims to depict the challenges of cross-institutional collaboration from a structural perspective. Collaboration, as a process occurring in different contexts of engineering education and professional practice, can be found to exist in accrediting bodies, policymaking, and institutional strategies (Harris 2010; CFR 2021; EC 2022). However, the types of collaboration in engineering education that have been applied in practice and are conceptualised in the existing literature appear to be fragmented and ill-defined. As multiple national and global organisations have outlined the need for additional sets of generic competencies, the challenge is to identify key components and well-defined understandings, not only for educators and students in collaborative contexts in engineering education but also for policymakers and researchers involved in facilitating collaborative efforts across institutions and sectors. To support the abovementioned objectives, this systematic review of cases of cross-institutional collaboration in higher education across engineering disciplines is guided by the following research question:

> What are the commonalities and differences in the conceptualizations of cross-institutional collaboration in engineering education regarding applied formats, institutional or organizational practices, reported outcomes, and challenges?

A systematic literature review approach is appropriate here as it permits the exploration of commonalities across multiple relevant sources (Borrego, Foster, and Froyd 2014). Guiding the interpretations is LeFebvre's (2017) theory on conceptualizations to aggregate indicators that constitute prior and contemporary meanings of interest. Furthermore, Kirkpatrick's evaluation framework is applied to categorise and present common assessment and evaluation outcomes outlined in selected articles (Cahapay 2021; Steinert et al. 2006). Lastly, themes on common challenges are presented to emphasise what future engineering education collaborative efforts should be aware of to avoid complications in design, facilitation, and assessment.

2. Materials and methods

The research question guides this systematic review, which aims to create a general picture of the evidence related to a certain topic area while systematically extracting, appraising, and synthesising prior research evidence (Borrego, Foster, and Froyd 2014; Saunders-Smits and Cruz 2020). Thus, the methodological framework guiding this review can be said to have roots in understandings representing Borrego, Foster, and Froyd (2014) but concurrently adhering to Paré et al.'s (2016) concepts of systematicity and transparency, while acknowledging the dilemma presented by Saunders-Smits and Leandro Cruz (2020) concerning the lack of clear distinctions regarding content and understandings in different types of literature reviews of engineering education research.

Borrego, Foster, and Froyd (2014) suggest scoping topics to encircle what determines the research question and the areas of interest that need to be addressed systematically. To achieve a representative overview of current examples of cross-institutional collaboration in engineering education, searches were conducted in the *EBSCOhost, Scopus, ProQuest* (ERIC), *Web of Science*, and *Engineering Village* databases, which include, as prescribed by Borrego, Foster, and Froyd (2014), both general and non-general scientific fields. The selected databases represent coverage of papers originating from all geographical areas, and three (Scopus, Web of Science, and Engineering Village) of these involve predominantly engineering, science, and technology publications but also contain research from different disciplines (Aksnes and Sivertsen 2019).

Paré et al. (2016) argue that *systematicity* concerns how well organised, methodical, and orderly an inquiry has been, adding that trustworthiness is the ability to present the *process* as transparently as possible to avoid '*black boxing'* the review (Paré et al. 2016).

2.1. Searching and protocolizing

The search process for the final pool of evidence to be reviewed was initially developed by exploring peer-reviewed research conducted between 2002 and 2022, published as English-language conference papers or journal articles, across engineering education institutions. Keywords or search terms applied in the search string (Table 1) were checked for matching keywords found by snowballing test-sample articles and Google Scholar searches, combined with potential synonyms to avoid missing relevant results. The incorporation of *engineering education* and *engineering* was primarily intended to encircle the field of interest as research on collaboration in education is vast in information and less relevant for this systematic review. Similarly, examples of collaboration emerging from contexts outside higher education were also dismissed, although collaboration exists at the primary and high-school levels, often related to the field of STEM (Science, Technology, Engineering, Mathematics).

Search blocks were respectively applied in the abovementioned databases with the described filters and limiters, which included searches in the Abstract, Title, and Keyword (Abs-Title-Key) fields. To achieve what Borrego, Foster, and Froyd (2014) call *quality* in a systematic review, the review process must explicitly consider criteria of empirical quality. For this paper, the reviewing team internally discussed quality assurance, leading to concrete inclusion and exclusion criteria for extracted empirical evidence, which were applied in the different phases of developing the review synthesis (Table 3). This further addresses the trustworthiness of the review process and

Table 1. Final search string.

Block 1	Cross – or Inter-
Block 2	Institution* or Facult* or Organization* or Discipl*
Block 3	Collab* or Coop* or Teamwork or Team-work
Block 4	Engineering education or Engineering
Block 5	Higher Education or HE or Universit*
Block 6	Concept* or challenge* or experienc* or Curricul*

adherence to an iterative, reflective quality assessment and explicit reporting in each of the generic steps of systematic reviews (Paré et al. 2016). Both Borrego, Foster, and Froyd (2014) and Paré et al. (2016) hold that reliability is achievable through a collective, collaborative approach by the reviewing team in the critical appraisal step to avoid coding bias, inconsistencies in literature selection, and imprecise sample sizes (Borrego, Foster, and Froyd 2014; Paré et al. 2016).

For this systematic review, the process of searching, collecting, and reviewing literature produced 759 articles in total (Figure 1). To render the search process meaningful, additional inclusion and

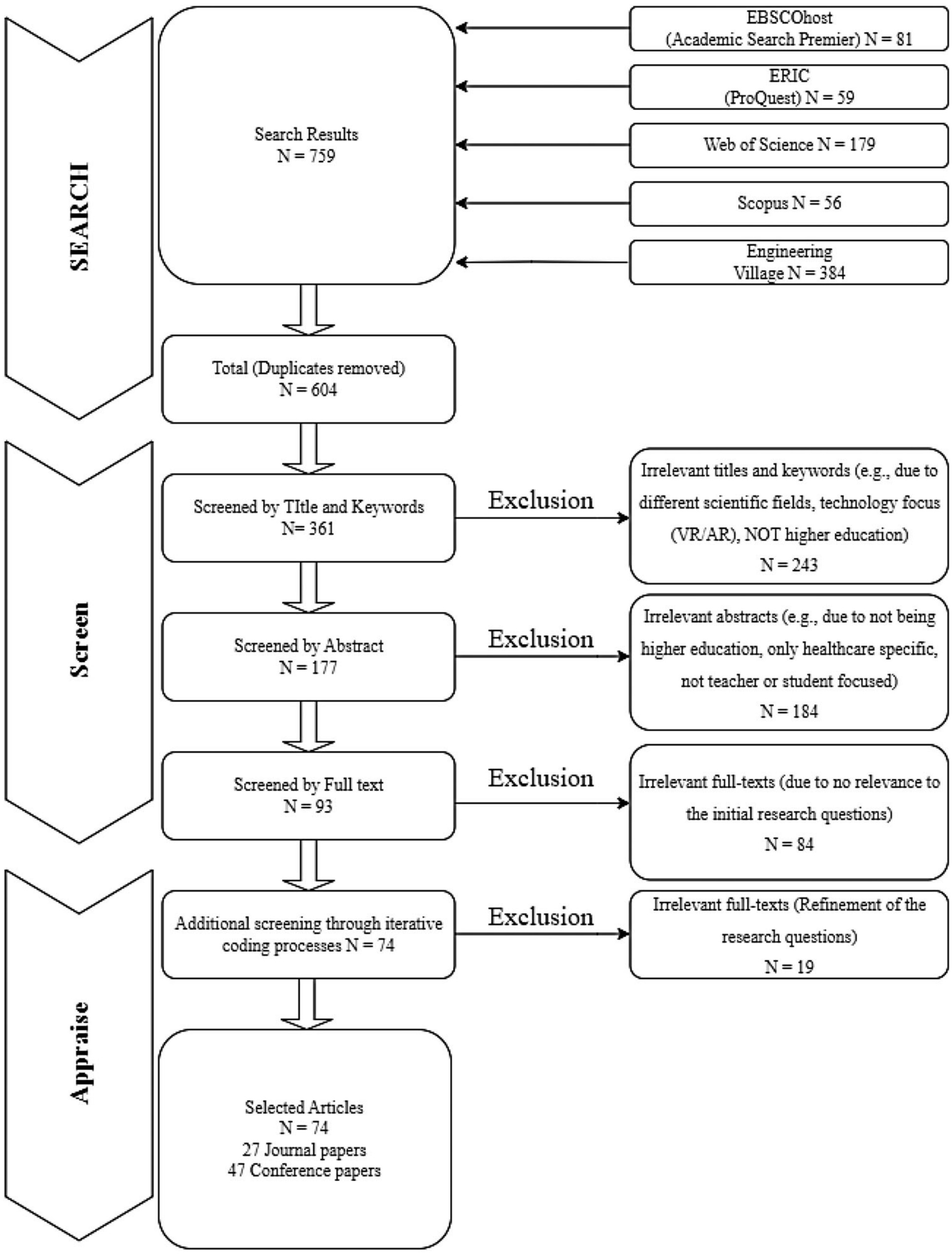

Figure 1. Flow chart of search and appraisal.

exclusion criteria for screening these 759 results were applied, some of which were established during the preliminary searches to correlate and select articles for the subsequent steps.

The initial phase of screening papers was influenced by various choices. A strict decision concerning what inclusion and exclusion criteria was to be guided by, was whether this review should capture both cross-institutional collaboration in research settings and student levels, or rather solely explore student collaborations. The latter was chosen, but it is acknowledged, that the final search still contained elements of research collaboration initiatives.

Inclusion criteria were streamlined throughout the screening, selection, and appraisal phases, primarily to incorporate research involving more than two disciplines; cross-cultural, cross-disciplinary, multi-disciplinary, or interdisciplinary student collaboration; partnerships with different industries involving multiple disciplines related to engineering education; faculty collaborations on the future direction of engineering education; collaborative educational design; collaborations within a higher education setting; collaboration between engineering programmes in different scientific fields; and reforms or transformations of an engineering curriculum. Exclusion parameters were differentiated depending on the stages of the review process. After removal of duplicates from the initial pool of 759 articles, a total of 604 articles remained. These were sorted to identify relevance based on the exclusion criteria, with the screening of *titles* and *keywords* resulting in the removal of articles that focused solely on healthcare or sports, used virtual or augmented reality as the main concepts, did not focus on cross-institutional collaboration (or something similar), focused on gender, approached collaboration through task-based teaching, only concerned collaboration in primary and/or high school, only studied art or management education, or focused on e-applications or remote learning concepts. This phase left 361 articles for *abstract* readings, wherein exclusion criteria for redundant articles were: not engineering-specific, not related to higher education, work-in-progress papers, only focusing on summer schools or competitions, only studying cross-cultural settings, only focusing on student clubs, having only a healthcare orientation, only involving hybrid or blended learning, and omitting the student or teacher perspective. After the abstract readings, 177 articles remained for full-text screening. In this phase, the main objectives were aligning the empirical data concerning the research question and seeking to uncover what conceptualises and defines cross-institutional collaboration, how outcomes are reported, and what challenges surface when attempting to facilitate collaboration across disciplines, departments, and curriculums. To record relevant findings, NVivo was used to index, structure, and sort extracted information. As an iterative approach for uncovering elements of interest *a priori* to the research question, open coding was used, characterised by '*not having pre-set codes, but developing and modifying the codes while working through the coding process*' (Maguire and Delahunt 2017). An additional objective was to limit the final pool of empirical evidence for the generation of themes and categories. This screening yielded a total of 93 articles. After several rounds of coding in an iterative and deductive manner, 74 articles were selected based on their relevance to the research question. Reviewing these produced the following *themes* of relevance: *theoretical indicators*, *assessment and evaluation indicators*, *common types of cross-institutional collaboration*, and *common challenges in cross-institutional collaboration in engineering,* which stems from the categorisation of codes into themes of relevance. To ensure validation throughout the reviewing process, 10 test samples for each generic review step were used as reference points, from which common codes, categories and themes were aligned, generally resulting in what Borrego, Foster, and Froyd (2014) prescribe for the collaborative reviewing procedures applied to be reliable.

Approaches chosen for the analysis involved both study descriptors and thematically inspired analysis (Braun and Clarke 2013), with tabulations as points of reference. Each of these was, in collaboration with the reviewing team, modified and discussed for the establishment of common ground and understanding. Critical for this review was discovering *empirical agreements* as described by LeFebvre (2017), resulting in conceptualizations of what is specified by the terminologies applied in the concept of cross-institutional collaboration in engineering education. The findings from the readings of papers in the final pool was established during two rounds of readings full texts. Codes were firstly done in an inductive manner (open coding) and the codes generated by the reviewers were discussed to align understandings of the given content. Second readings were done based on prior agreements reached, in a deductive manner. As mentioned, the 10 test samples for each reviewer meeting were matched for interrelating of codes. The main objective for each of the reviewer meetings was to reach at least 85% agreement in relation to the codes made. The interrater reliability was inspired by the concept of test-retestreliability (Belur et al., 2021), which was used to streamline the codes in the common codebook that pertained to each code. It does not, however, contain statistical representations of the agreements made. Themes were subsequently discussed according to the relevance of each code used, resulting in the overarching themes. These were divided into categories of clusters of codes, where a code could appear in different categories if found relevant by the reviewers. The final themes were constructed based on the clusters of categories constructed by the referring to the purpose of the research question (Braun and Clarke 2013). An example of a category made for *types of collaboration* is *methods or concepts for collaboration,* which have seven codes related (Assessment or evaluation, Recommendations for collaboration, accreditation, conceptualisation, Shared vocabularies, Dual degree, Accountability, Funding).

3. Results

The following sections systematically outline the results of analyzing the carefully selected evidence to present findings highlighting key recurring aspects of cross-institutional collaboration across universities and colleges. As a preliminary starting point, study descriptors containing information related to year of publication, countries of author origin, and conference and journal publications were constructed to showcase the observations made concerning affiliation and targeted audience while simultaneously highlighting the minor increase in research related to cross-institutional efforts.

3.1. Study descriptors

A numerical overview of the publications included in this review (Table 2) shows a pattern of limited focus on cross-institutional collaboration until 2011 (7 papers published). Thereafter, publication volume appears stable, with a peak in 2020 (11 papers published). No publications were found in 2022, but this is potentially due to publishing delays (e.g. peer-review processes).

An interesting observation relates to publication type and author affiliation (country or countries), indicating that certain geographical traditions influence how and where research is published.

Examining the geographical areas of author affiliation displayed in Table 3 shows most studies originating in the US ($N = 40$). While the UK and Germany are ranked second and third (both $N =$

Table 2. Number of papers by publication year.

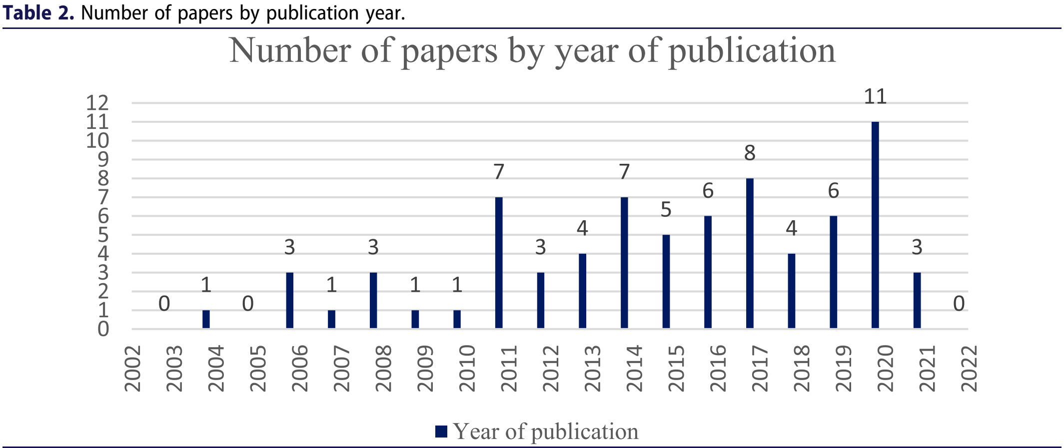

Table 3. Publications sorted by author-country affiliation.

Country (or countries)	Appearances (*N* =)
The US	40
Germany	5
The UK	5
Finland	3
Brazil	2
Egypt	2
India	2
Spain	2
Australia	1
Canada	1
Greece	1
Hong Kong	1
Hungary	1
Israel	1
Latvia	1
Malaysia	1
Myanmar	1
Romania	1
Norway	1
Portugal	1
Russia	1
Scotland	1
Shanghai	1
South Korea	1
Switzerland	1
Sultanate of Oman	1
Tajikistan	1
The Netherlands	1
The Philippines	1
Taiwan	1
Turkey	1
Venezuela	1
Not mentioned / Not available	10

5), the gap is rather significant. This could arguably be explained by the contextual differences between European and American research and between collaborative projects initiated between different engineering education institutions. US contexts have been influenced by the NSF and ABET accreditation requirements for much longer than their European-Union counterparts (Lucena and Schneider 2008; Harris 2010). Mapping where the papers were published also shows a noticeable difference in publishing in journals or as conference proceedings, as depicted in Table 4. Again, conference proceedings from *ASEE Annual Conference and Exposition* (*N* = *23*) outnumber those from its European counterpart, the *SEFI Annual Conference* (*N* = *8*), but overall, conference proceedings make up nearly half the papers in this review. As for journal publications, due to their position within the engineering education research field, it is less surprising that most appearances are linked to the *Journal of Engineering Education* (*N* = *4*) and the *European Journal of Engineering Education* (*N* = *3*). However, the difference between publications from conference proceedings and those reworked into journal publications is more peculiar and demonstrates the obstacles to transferring or expanding the research found in conference proceedings into journal papers.

3.2. Formats of cross-institutional collaboration in engineering education

Before presenting what prior research concerning cross-institutional collaboration contains, a common trait of *what* defines collaboration is outlined due to an existing repertoire of definitions on collaboration in engineering education. The offset guiding the following sections draw upon pre-existing characteristics, some of which derived from the final pool of papers. Anderson (2016) problematises the vague and multifaceted concept of collaboration by stating: '*There are numerous*

Table 4. List of publication types.

Journal	Number of papers	Conference	Number of papers
Journal of Engineering Education	4	ASEE Annual Conference and Exposition	23
European Journal of Engineering Education	3	SEFI Annual Conference	8
International Journal of Sustainability in Higher Education	2	International Conference on Engineering and Product Design Education	4
IEEE Transactions on Education	2	International Conference on Higher Education Advances	2
International Review of Research in Open and Distributed Learning	1	World Engineering Education Forum (WEEF)	2
International Journal of Sustainable Engineering	1	IEEE Global Engineering Education Conference (EDUCON)	2
Higher Education Pedagogies	1	International Scientific Conference on eLearning and Software for Education	1
Journal of College Science Teaching	1	IEEE International Conference on MOOCs, Innovation and Technology in Education	1
Journal of Mechanical Engineering Science	1	IEEE TALE	1
IEEE Access	1	IEEE Tsinghua International Design Management Symposium	1
Computing in Science & Engineering	1	International Design Engineering Technical Conferences & Computers and Information in Engineering Conference	1
International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship	1	Proceedings of the First European conference on Technology Enhanced Learning: Innovative Approaches for Learning and Knowledge Sharing	1
Journal of professional issues in engineering education & practice	1		
IEEE Transactions on Professional Communication	1		
Journal of Information Technology Education: Innovations in Practice	1		
Journal of STEM Education: Innovations and Research	1		
International Journal of Mechanical Engineering Education	1		
Australasian Journal of Educational Technology	1		
Journal of Engineering and Applied Science	1		
Sustainability	1		
TOTAL	27		47

theories of collaboration that span across disciplines and topic areas; political, organizational, economical, and strategic are but a few examples. There are also many nuanced definitions but there is no unified definition for collaboration. The consensus of the literature and common definitions explain that collaboration means to work together.'. When perceiving the element of *crossing*, Borrego and Newswander (2008) describes it as entailing collaboration across disciplines and classified it into two types of interaction: multidisciplinary collaboration and truly interdisciplinary approaches. The Engineering profession are defined by Ibrahim et al. (2017), as a profession that requires knowledge of mathematics and natural sciences gained through learning, experience, and practice. Crawley (2014) defines an engineer as one who has attained and continuously enhances technical, communications, and human relations knowledge, skills, and attitudes, and who contributes effectively to society by theorising, conceiving, developing, and producing reliable structures and machines of practical and economic value. Institutions can be defined as, perceived from an institutionalist approach, consisting of three types of elements: cultural cognitive, normative, and regulative. Cross-institutional collaboration examples from the pool of papers share these notions in different ways, but common for all is the role of interaction across study programmes, faculties, departments, other educational institutions, and across borders. Collaboration in higher education is undergoing constant exploration, but key definitions on collaboration between students often involve the

Table 5. Types of institutional collaborations found.

TYPE OF COLLABORATION	DESCRIPTION	ARTICLES (N =)
A	Collaboration within a single institution or faculty	24
B	Collaboration involving two or more institutions or faculties from the same university	13
C	Collaboration by more than two institutions from the same country	10
D	Collaboration by more than two institutions across countries	15
NO MENTION	No explicitly mentioned settings	7

process of teamwork (Andrews and Rapp 2015). Powell, Powell, and Council (2000) described collaboration prerequisites in teams in education as: '*Team members must have compatible and interactive work styles. Their individual knowledge needs to be complementary and yet the team members need to have sufficiently different perspectives and experiences so as to make their contributions diverse.*',

Interacting across disciplinary backgrounds and practicing cross-institutional collaboration with engineering students or staff potentially require more than just the involvement of a single faculty, despite this being the most common scenario (Table 5). Higher-education institutions often design, e.g. programmes or courses within their institutional boundaries, as these being more accessible. Whether collaboration involves a single faculty ($N = 24$) or multiple faculties or institutions ($N = 13$) at the same university, most cases found in this review are confined to intra-collaborative examples, although some do cross educational programmes and disciplines. A slightly rarer type of collaboration is found between different institutions from the same country ($N = 10$), indicating that cross-institutional collaboration among national institutions is, perhaps, more difficult to facilitate than collaboration within a single institution or faculty. Collaboration spanning and involving more than two institutions and countries is slightly more common ($N = 15$), possibly due to consortiums of higher-education institutions' establishing common research projects, collaborative courses, or innovative educational programmes (Graham 2018; Amoo et al. 2020).

Characterising common aspects of collaboration is as described multifaceted and without any solidified unity. What articles for this review suggests concerning collaborations to be qualified as a collaborative process, is the formation of joint developments or projects in groups of two or more to be present. This can either be collaboration during courses or collaboration in and across study programmes. To give an example, although not being the sole focus of this review, is the paper from Tronstad (2017) describing cross-institutional collaboration transpiring through the collaboration of different departments between Oslo and Akershus University in Norway for a doctoral programme consisting of engineering, arts, and design. Another example on the difference between collaboration with different study programmes and collaboration within a mono-disciplinary programme is described by Marcos-Jorquera et al. (2017), which compared students that were in interdisciplinary teams (multimedia engineering and teacher training students) facilitated during two different courses with engineering students that continued working within their own discipline. The constitution of collaborative dimensions is, to a large extent, dependent on common objectives, understandings, and motivation among the collaborators (Kimball et al. 2018). An interesting aspect is then, what does not count or characterise collaboration, which prior literature foretell pertains to e.g. competitiveness among participants, structural conditions not suited for collaborations, or when purposes are not settled or resistance for collaborating exist (Camarihna-Matos and Afsarmanesh 2008; de Man 2005; Guzdial et al. 2012). The different formats applied in examples from engineering education must therefore, for them to be qualified and characterised as collaborative, not only involve the dimension of crossing but also entail a framing on the actual element of collaboration, whether be across or within study programmes, courses, or departments.

The types of disciplinary collaboration mentioned throughout the papers examined (Table 6) are interesting, with the least common being cross-disciplinary ($N = 10$) and multi-disciplinary ($N = 16$)

Table 6. Types of disciplinarities in cross-institutional collaborations.

Type of disciplinarity	Volume (N =)	Articles
Cross-disciplinary	10	Breen and Durfee (2006), Karjalainen and Repokari (2007), Borrego and Newswander (2008), Pierrakos et al. (2012), Besterfield-Sacre et al. (2013), Fox, Kurtkouglu, and Meboldt (2014), Brewer et al. (2015), Othman et al. (2017), Tai and Ting (2020), Smallwood, Hart, and Polk (2021)
Multi-disciplinary	16	Warnick (2011), Hovsapian et al. (2011), Gnaur, Svidt, and Thygesen (2012), Taboada and Espiritu (2012), Badurdeen et al. (2014), Burian and Apul (2015), Buchholz and Stark (2016), Gupta, Jensen, and Shih (2016), Koch and Nyffeler (2016), Holloway et al. (2017), Ibrahim et al. (2017), Chui, So, and Khaing (2017), Tronstad (2017), Favaloro et al. (2018), Najem et al. (2019), Lemmens (2020)
Interdisciplinary	35	Andersen (2004), Tomkinson et al. (2008), Gordon, Carey, and Vakalis (2008), Richter and Paretti (2009), Borrego and Cutler (2010), Nuttall, Nelson, and Estes (2011), Biernacki and Wilson (2011), Mcnair et al. (2011), Jiji, Schonfeld, and Smith (2015), Yim et al. (2011), Pfluger et al. (2013), Simpson, Kisenwether, and Pierce (2013), Taajamaa et al. (2013), Bouwma-Gearhart, Perry, and Presley (2014), Adair and Jaeger (2014), Ejiwale (2014), Coops et al. (2015), Anderson (2016), Marcos-Jorquera et al. (2017), Reiter-Palmon and Leone (2019), Basu Ray and Maitra (2017), Davishahl et al. (2018), Vicente, Tan, and Yu (2018), Kovacevic et al. (2018), Mitchell et al. (2019), Mohsin et al. (2019), Ozkan, Mcnair, and Bairaktarova (2019), Abbonizio and Ho (2020), Van den Beemt et al. (2020), Homer et al. (2020), Steed and Gair (2020), Gast (2020), Lautamäki and Saarikoski (2020), Nguyen et al. (2021), Badawi and Abdullah (2021)
Transdisciplinary	1	Conner (2020)
No explicit mention	11	Harrer et al. (2006), Soibelman et al. (2011), Barberà, Layne, and Gunawardena (2014), Warnick et al. (2014), Streiner et al. (2015), Palomo and Cole (2015), Sutterer, Niezgoda, and Aidoo (2016), Schorr, Voigt, and Rose (2019), Dascalu et al. (2019), Raval et al. (2020), Bennedsen et al. (2020)

collaboration. Multiple variations and understanding exist concerning the different types of disciplinarity, but for the purpose of this review, definitions originated from the OECD showcase a general understanding of what differentiates multi, inter, and transdisciplinarity from each other (Chettiparamb 2007). Multi-disciplinarity is a '*juxtaposition of various disciplines, sometimes with no apparent connection between them, e.g. music + mathematics + history*', and interdisciplinarity is '*an adjective describing the interaction among two or more different disciplines. This interaction may range from simple communication of ideas to the mutual integration of organising concepts, methodologies, procedures, epistemologies, terminologies, data leading to an organisation of research and education in a fairly large field*'. Finally, transdisciplinarity is when *'establishing a common system of axioms for a set of disciplines.'* (ibid.).

The most mentioned type of collaboration is interdisciplinary ($N = 35$), but whether it is achieved is less certain as the purpose of this review is to conceptualise commonalities, leaving aside distinctions in feasibility among disciplinary approaches. For more on the difficulties of facilitating interdisciplinarity in engineering education, reference should be made to Van den Beemt (2020).

There seems to be a trend of promoting both interdisciplinarity and cross-institutional collaboration as a matter of course, indicating a transgression of disciplinary boundaries in course and programme design for engineering students. This ties well into former projections and demands presented by different governments and organisations embedded in educational policymaking (Graham 2018; National Research Foundation 2020; European Commission 2016; The UN 2015; US Department of Education and US Department of State, 2021). Accommodating political decisions for the crossing of disciplinarities can provide economic incentives in business contexts, concomitantly producing unique insight emerging from the works of multiple disciplinary voices – promoting inclusion rather than exclusion. Therefore, there is an urgent need for higher-education institutions, including engineering education, to ease former boundaries to collaboration across domains.

3.3. Common indicators for the conceptualisation of cross-institutional collaborations

To answer the research question concerning how cross-institutional collaboration is conceptualised in prior research, several indicators must be outlined and distinctions from similar concepts defined. Throughout the process of coding the pool of papers, commonalities emerged across the literature in theoretical understandings, meanings of specific terms, and the relationship between applied definitions – resemblances that, in this context, are relevant to a shared subjective representation of what cross-institutional collaborations entail. As LeFebvre (2017) states: '*Pre-existing conceptualizations affirmed by the field, extensively tested, and adopted across numerous studies have advantages; nevertheless, nuances can occur and often multiple conceptualizations exist in a variety of contexts*'.

To render the commonalities operationalizable and measurable, concepts are so described as to identify potential indicators of related conceptualizations. The following sections outline indicators through distinctions and observations regarding the final pool of articles made inductively and deductively through the coding and categorisation of the derived literature.

3.4. Commonly applied theoretical indicators

Arguably, theoretical descriptions that entail a specification or terminological representation of a certain common approach or process can serve as indicators to help conceptualise prior understandings of cross-institutional collaboration. In the context of cross-institutional collaboration, one way to identify and discuss a concrete commonality is by outlining how theory or theoretical distinctions have been applied, as in these examples from the final article pool.

Table 7 presents an overview of the explicitly mentioned theoretical approaches used to, e.g. facilitate a course, frame learning content, or assess a potential outcome. The indicators could, in this context, be said to be manifold, but certain perspectives also align because of overlaps in meaning. As an example, *lifelong learning* and *active learning* both refer to the same desired outcome of students' developing skills for future careers through either international collaboration or collaboration across faculties (Chui, So, and Khaing 2017; Palomo and Cole 2015). The same can be said of *multicultural teamwork* and *cross-cultural teamwork*, which both refer to collaboration across cultural differences (Karjalainen and Repokari 2007; Soibelman et al. 2011). The most frequently mentioned key theoretical indicators relate to *curriculum design* (*N* = *4*), *experiential learning* (*N* = *6*), and *problem – or project-based learning* (*N* = *14*).

Curriculum design theories involve theoretical dimensions stemming from multiple origins, and authors who explicitly mention these present various reasons. Borrego and Cutler (2010) establish a framework for curriculum designers based on 118 interdisciplinary graduate programmes (in a US context), where the collaborative processes included engineering education's active incorporation of other disciplines. Dascalu et al. (2019) apply prior concepts in their proposal of ontology-based curriculum design and argue that technological advances afford many possibilities thanks to digital tools for structuring learning organisations through curriculum management systems (CMS). A common indicator within this concept or theory is the coordination among educational managers, teachers, and students needed for cross-institutional collaborations to function, which Gordon, Carey, and Vakalis (2008) also highlight. This ties into Lemmens et al.'s (2020) description of TU Eindhoven's reform of its bachelor's programmes' curriculum structure. Lessons learned pertains to engineering students' capabilities and competencies in cross-disciplinary approaches and problem-solving for real-world challenges.

The papers' approaches to experiential learning differentiates. Davishahl et al. (2018), Nguyen et al. (2021), and Warnick et al. (2014) merely report the potential offered by exposing engineering students to collaboration between similar disciplines to produce a different kind of learning, without presenting theoretical background that defines experiential learning in engineering-education – related collaboration. In contrast, Brewer et al. (2015) build upon problem-based learning perspectives and David A. Kolb's learning philosophy; Buchholz and Stark (2016) mention the perspectives of

Table 7. Theoretical indicators.

Theoretical indicator mentioned	Authorship
Global citizen theory or global preparedness or global competencies	E. Besterfield-Sacre et al. (2013), Streiner et al. (2015), Warnick et al. (2014)
Holistic human development	E. Besterfield-Sacre et al. (2013)
PBL (problem-based learning or project-based learning)	Gnaur, Svidt, and Thygesen (2012), Tomkinson et al. (2008), Raval et al. (2020), Raval et al. (2020), Favaloro et al. (2018), Najem et al. (2019), Marcos-Jorquera et al. (2017), Pierrakos et al. (2012), Taajamaa et al. (2013), Buchholz and Stark (2016), Palomo and Cole (2015), Conner (2020), Lautamäki and Saarikoski (2020), Breen and Durfee (2006)
Cross-institution collaborative learning (CICL) or cross-disciplinary team learning (CDTL)	Burian and Apul (2015), Othman et al. (2017)
Learning community	Burian and Apul (2015)
Immersion theory	Homer et al. (2020)
Institutional theories of change, multiplicity, and interdisciplinarity	Koch and Nyffeler (2016)
Curriculum design	Borrego and Cutler (2010), Gordon, Carey, and Vakalis (2008), Adair and Jaeger (2014), Van den Beemt et al. (2020)
Design thinking	Favaloro et al. (2018), Taajamaa et al. (2013), Lautamäki and Saarikoski (2020)
Multicultural teamwork or cross-cultural teamwork	Soibelman et al. (2011), Karjalainen and Repokari (2007)
Instructional design	Barberà, Layne, and Gunawardena (2014)
C.*P*. Snow's identification of a conflict between two academic cultures: science and humanities	Tronstad (2017)
Collaborative design or collaborative course design	Kovacevic et al. (2018), Gast (2020)
Ontologies	Dascalu et al. (2019)
twenty-first-century graduate career development	Steed and Gair (2020)
Brokering	Bouwma-Gearhart, Perry, and Presley (2014)
Cross-institutional collaboration	Holloway et al. (2017)
Consortium-based collaboration	Holloway et al. (2017)
Experiential learning	Davishahl et al. (2018), Brewer et al. (2015), Nguyen et al. (2021), Buchholz and Stark (2016), Warnick et al. (2014), Chui, So, and Khaing (2017)
Collaborative networks	Davishahl et al. (2018)
Collaborative learning	Butterfield and Branch (2016)
Situated learning theory	Vicente, Tan, and Yu (2018)
Diversity theory	Vicente, Tan, and Yu (2018)
Lifelong learning or active learning	Basu Ray and Maitra (2017), Palomo and Cole (2015), Conner (2020), Chui, So, and Khaing (2017)
Systems thinking	Badurdeen et al. (2014)
Integrated education	Anderson (2016)
Distant collaboration	Harrer et al. (2006)
Truly interdisciplinary collaboration	Borrego and Newswander (2008)
Identity theory	Mcnair et al. (2011)
Social creativity	Tai and Ting (2020)
Boundary objects	Tai and Ting (2020)
Cultural dimension theory	Schorr, Voigt, and Rose (2019)
Communities of practice	Breen and Durfee (2006)
Reflective thinking	Ozkan, Mcnair, and Bairaktarova (2019)
Not specified or unclear	Smallwood, Hart, and Polk (2021), Taboada and Espiritu (2012), Mohsin et al. (2019), Hovsapian et al. (2011), Pfluger et al. (2013), Simpson, Kisenwether, and Pierce (2013), Yim et al. (2011), Fox, Kurtkouglu, and Meboldt (2014), Ejiwale (2014), Lemmens (2020), Richter and Paretti (2009), Sutterer, Niezgoda, and Aidoo (2016), Nuttall, Nelson, and Estes (2011), Biernacki and Wilson (2011), Jiji, Schonfeld, and Smith (2015), Andersen (2004), Badawi and Abdullah (2021), Abbonizio and Ho (2020), Ibrahim et al. (2017)

Brewer et al. in their theoretical approaches, and Kit Chui, So, and Khaing (2017) further align their theoretical approach with Kolb's.

The theoretical perspective most commonly applied as the basis for collaboration across institutions comprises variants of *problem-based learning* or *project-based learning* (PBL). This refers to engineering students' developing competencies aligned with industries' and companies' demands for certain skills, combined with working or collaborating on a concrete problem as a driver for solution-oriented knowledge. Certain PBL learning outcomes have also been found to support graduate students' careers (Marcos-Jorquera et al. 2017). Though arguments for the incorporation of aspects of PBL into engineering-related courses or programmes vary, common to most articles is the guiding vision of teamwork and multiple disciplinary backgrounds *coming together* in collaboration. Connections are often made between disciplinary collaboration (among various degree programmes), innovation, and the evolution of future engineers. This indicator presents a framework that formally and practically attempts to bridge collaborative interactions through, e.g. electives or extra-curricular events (Conner 2020; Gnaur, Svidt, and Thygesen 2012; Raval et al. 2020). Integrating PBL facilitation also tends to require a shift in mentality in both facilitators and students (Taajamaa et al. 2013; Tomkinson et al. 2008), which appears to require willingness and effort from the institutions involved. Despite being adapted and applied in numerous forms of engineering education, PBL is often referred to as a vessel for bridging disciplinary differences through the identification of common, complex problems. Favaloro et al. (2018) and Mitchell et al. (2019) both highlight the usefulness of PBL in designing courses entailing teamwork across disciplines, and pointing to the need for institutional structures to support adequate function of PBL strategies (Mitchell et al. 2019; Palomo and Cole 2015). A notable difference relates to whether the collaborations apply PBL to train specific competencies or as a stand-alone component (in incrementally designed learning experiences), such as problem statements in project work (Najem et al. 2019). Due to the intricate nature of PBL for framing collaboration and as a teamwork tool for use with engineering students, this indicator can be distinguished by whether PBL is used to *design* courses or learning content, as an overarching framework applied in relation to structural boundaries, or to revamp and transform existing barriers to collaboration across differences (disciplinary, practical, or technological). Pierrakos et al. (2012) describe their PBL approach as a design activity for open-ended problems, aimed at developing students' cognitive and non-cognitive knowledge and skills, whereas Breen and Durfee (2006) take it as a fundamental basis for a capstone course demanding complex problem-solving processes and peer interactions.

Rather peculiar is the absence in some papers found here ($N = 19$) of theoretically grounded descriptions regarding cross-institutional collaboration, which leaves the details open to conjecture. Theory, as an indicator in collaborations across faculties or departments, should indicate how certain processes have been designed and through what lenses to interpret a presented direction; it is also important to encompass a commonality of missing links to promote awareness concerning future experiments in cross-institutional collaboration depicted in research.

3.5. Evaluation and assessment indicators

To identify how the research papers assess the collaborations they respectively describe (e.g. courses, programmes, or curricular changes), a framing of their representations is processed through Donald Kirkpatrick's (1959) model for evaluation, with the modifications presented by Steinert et al. (2006). Originating from business contexts, this approach is used for evaluating training programme results to improve future practice (Praslova 2010; Reio Jr. et al. 2017). It should be noted that the concepts *assessment* and *evaluation* differ in meaning, as described by Yambi and Yambi (2020): '*Assessment and evaluation are two different concepts with a number of differences between them starting from the objectives and focus*'. Assessments can involve a search for either summative or formative knowledge, often through examinations or informal or formal feedback. Evaluation can be regarded as scientific in nature since it concerns the validity and reliability of a given measurement. Assessments entail a focus on *how to improve*, while evaluations seek to judge a predetermined object of focus and *whether outcomes were as intended* (ibid.). Still, this study treats the two terms interchangeably as their differences have little impact on representations of cross-institutional collaboration in engineering education, and papers often address either or both (e.g. the effectiveness of collaboration, the development of competencies, or teachers' perspectives or student feedback on learning experiences).

The characteristics of which type of methodological approaches the papers have applied can be divided into four types, which are indicating a predominant tendency, concerning methodological framings being left out of the papers (N = 42). The appearances of qualitative framed studies are the second most frequent (N = 13). The third most frequent methodological framing is concerning mixed methods approaches (N = 12), with the fewest framings appearing in connection with quantitative approaches (N = 7). This can arguably be of importance concerning the scientific quality assurance of papers, and since the largest sum of papers do not entail specific methodological framings, doubt can occur whether the outcomes are based on scientific research methodologies or mere reporting of events occurred.

The assessment and evaluation of the reported collaborative initiatives are necessary components, both for the sake of the collaboration that transpired and for researchers or programme designers initiating similar processes (Praslova 2010). Kirkpatrick's evaluation model, which has been applied as a framework for assessing programmes or education, divides assessment and evaluation outcomes into four levels; *1) Reaction, 2) Learning, 3) Behavior,* and *4) Results* (Cahapay 2021; Steinert et al. 2006). An important distinction must be noted by referring to Levels 1 and 2 as *internal* and Levels 3 and 4 as *external*. According to critics, prior studies applying Kirkpatrick's model potentially lack this distinction as internal evaluation is often possible in educational programmes, yet external evaluation requires empirical knowledge that emerges *after* or *outside* the described programme or educational process (Praslova 2010). The application of Kirkpatrick's evaluation model in the following sections shares the same tendencies, although it should be stressed that educational programmes involving cross-institutional collaboration are dynamic entities that most often, due to the difficulties of gathering data after students graduate, merely report on Levels 1 and 2 (Cahapay 2021; Praslova 2010). The findings are summarised in Table 8, but to reiterate, numerous papers do not include empirical evidence on the outcomes based on evaluations and assessments, and therefore papers are only mapped if they contain explicit empirical data. However, the same paper can appear on more than one level if it contains empirical evidence traversing multiple levels.

3.5.1. Level 1 – reaction

Level 1 concerns participants' immediate views on the learning experience, presentations, teaching content, or teaching methods (Table 9). The most common practices found are evaluations of cross-institutional collaboration programmes, courses, or extracurricular activities assessed either solely on the basis of questionnaires and descriptive comments or by means of statistical evidence, interviews, and/or observations. Distinctions within this level were found to relate to authors' reporting on the learning experience (*N = 18*) or on positive reactions to the content (*N = 26*).

Each article involving some description of the feedback received before, during, or after a reported collaborative initiative contains partial information concerning the participants' views on the learning experience. This category should be regarded as entailing *what is explicitly mentioned* by authors, although various reasons can explain why certain empirical elements are omitted.

Gnaur, Svidt, and Thygesen (2012) and Holloway et al. (2017) both describe ongoing research transpiring in multiple stages and therefore confine the outcomes reported by participants to

Table 8. Summary of findings using Kirkpatrick's model of evaluating educational outcomes (based on the modification presented by Steinert et al. (2006)).

LEVELS	DESCRIPTION	ARTICLES (N =)
LEVEL 1 – REACTION	Participants' views on the learning experience, presentation, content, or teaching methods	45
LEVEL 2 – LEARNING	Changes in attitudes and perceptions among participants or the acquisition of concepts, procedures, or problem-solving/thinking skills	21
LEVEL 3 – BEHAVIOR	Documentation of the transfer of, or willingness to learn and apply, new knowledge in practice	5
LEVEL 4 – RESULTS	Documentation of wider changes or improvements in students as a result of an educational intervention	0

Table 9. Findings on reactions for Level 1.

Level 1 – Reaction	Appearances (N =)	Contents
Contains participants' reactions regarding evaluation or assessment	18	**Reporting views on the learning experience:** Harrer et al. (2006), Karjalainen and Repokari (2007), Richter and Paretti (2009), Biernacki and Wilson (2011), Soibelman et al. (2011), Gnaur, Svidt, and Thygesen (2012), Burian and Apul (2015), Brewer et al. (2015), Streiner et al. (2015), Gupta, Jensen, and Shih (2016), Sutterer, Niezgoda, and Aidoo (2016), Holloway et al. (2017), Mohsin et al. (2019), Basu Ray and Maitra (2017), Favaloro et al. (2018), Kovacevic et al. (2018), Lemmens (2020), Lautamäki and Saarikoski (2020)
	14	**Reporting positive reactions to the content, the methods applied, or the quality of teaching (curriculum-related):** Andersen (2004), Tomkinson et al. (2008), Borrego and Newswander (2008), Warnick (2011), Mcnair et al. (2011), Pierrakos et al. (2012), Pfluger et al. (2013), Taajamaa et al. (2013), Jiji, Schonfeld, and Smith (2015), Adair and Jaeger (2014), Coops et al. (2015), Bouwma-Gearhart, Perry, and Presley (2014), Burian and Apul (2015), Palomo and Cole (2015), Butterfield and Branch (2016), Chui, So, and Khaing (2017), Marcos-Jorquera et al. (2017), Davishahl et al. (2018), Vicente, Tan, and Yu (2018), Najem et al. (2019), Schorr, Voigt, and Rose (2019), Abbonizio and Ho (2020), Raval et al. (2020), Steed and Gair (2020), Nguyen et al. (2021), Badawi and Abdullah (2021)

specific extracts obtained. Kovacevic et al. (2018) report their findings from assessments using both survey results and observations, but these can appear anecdotal since no empirical data is presented. Ali Mohsin et al. (2019) evaluate and assess their inter-institutional and interdisciplinary experiment through collegial talks mediated by digital applications. However, most of the reporting on outcomes through assessing and evaluating participants' views of a given learning experience contains both quantitative survey results and student or teacher statements as indicators. Soibelman et al. (2011), Biernacki and Wilson (2011), Gupta, Jensen, and Shih (2016), and Besterfield-Sacre et al. (2016) all include – to varying degrees – both survey data and qualitative statements, often pertaining to positive feedback on student learning outcomes.

Curriculum-related content also contains differences related to whether the students or staff involved in a cross-institutional collaboration experienced it as meaningful and whether participants considered the resources sufficient or perceived their common sharing positively. Davishahl et al. (2018) describe how faculty members saw an opportunity to establish new partnerships with industry partners and engineering education institutions and how students were satisfied with the interactions initiated by these projects. The same holds for Tomkinson et al. (2008), but their methodological approach differs through their use of *monitoring*, involving observations of both senior representatives and student reflections concerning the usefulness of a common 'topical thread' in their pilot module for engineering and science undergraduates. More curriculum-focused empirical evidence is found in Palomo and Cole (2015), who report students' responses to specific survey questions on how cross-collaborative elements in common curriculum models can be accommodated and facilitated based on experiences from students and staff. Borrego and Newswander (2008) describe interviews by multiple authors related to cross-disciplinary collaboration, examining how engineering professions can benefit from integrating awareness of diversity through collaborating with other cultures.

When descriptions emerge concerning assessing and evaluating specific methods applied, e.g. supportive teaching tools or frameworks, the representations of reactions also vary in context and form. As some authors demonstrate an interest in their participants' views on, e.g. approaches involving teamwork across different institutions or countries (Burian and Apul 2015; Raval et al. 2020), depictions of survey results tend to focus on prior expectations of participants correlated with detailed programme processes and measurements of outcome-based empirical data.

However, the authors' subjectivity also leads to their reporting assessments and evaluations from different angles. For example, Warnick (2011) includes reflections from subject experts to identify the usefulness of a particular international collaboration between engineering professions and whether the facilitation methods can be considered effective. Observations that aim to correlate outcomes of assessing the methods used can be found to entail an emphasis on a constant presence over a longer duration (Badawi and Abdullah 2021; Vicente, Tan, and Yu 2018) but simultaneously highlight insights pointing to differences in the object of focus (e.g. disciplinary differences). Notably, there appear to be unrelated understandings and inconsistencies when authors describe the results of a concrete method of choice; hence, some authors attempt to include distinctions concerning the quality of the delivery of teachings related to participants' reactions. These do require teacher reflections, as presented by Coops et al. (2015) or Bouwma-Gearhart, Perry, and Presley (2014), to understand both how the students experienced a certain teaching method or style and how the instructors performed, as well as to gauge their potential collaboration across faculties and how things were handled before, during, and after a course or semester collaboration.

3.5.2. Level 2 – learning

The findings related to Level 2 pertain specifically to mentioned changes in participants' attitudes or modifications of skills (Table 10). They are based on evaluations or assessments of changes in attitudes towards learning outcomes ($N = 6$), changes in self-belief ($N = 4$), modifications of skills and competencies related or desired prior to the cross-institutional collaboration, depicted as problem-solving skills ($N = 3$), or modifications of disciplinary skills and competencies related to collaboration across disciplines ($N = 7$).

Categories related to described changes or modifications often entail the use of concrete tools for measuring a certain alteration of mental or cognitive understanding, but differences exist as to whether this measurement compares results before and after a collaborative initiative. Soibelman et al. (2011) and Burian and Apul (2015) both apply student and instructor surveys or reflections to encapsulate the mental changes from collaborating across faculties without characterising their students' pre-collaboration perceptions. Holloway et al. (2017) align the findings of their cross-institutional efforts with industry partners' intentions for participation in concrete course activities. Smallwood, Hart, and Polk (2021) apply strictly quantitative measurements of the outcomes of collaborative experiments to determine whether their attempts to increase business and engineering students' communication and teamwork skills were successful. A similar approach is found in

Table 10. Findings for learning for Level 2.

Level 2 – Learning	Appearances (N =)	Contents
Contains information on changes in participants' attitudes or modification of skills	6	**Changes in attitude or perception among participants toward learning outcomes:** Soibelman et al. (2011), Nuttall, Nelson, and Estes (2011), Burian and Apul (2015), Marcos-Jorquera et al. (2017), Holloway et al. (2017), Smallwood, Hart, and Polk (2021), Tai and Ting (2020)
	4	**Changes in self-belief related to specific competencies:** Warnick (2011), Coops et al. (2015), Favaloro et al. (2018), Badawi and Abdullah (2021)
	3	**Modification of skills and competencies related to participants' way of thinking (e.g. problem-solving or social skills):** Pierrakos et al. (2012), Butterfield and Branch (2016), Steed and Gair (2020)
	7	**Modification of skills and competencies related to collaboration across disciplines (e.g. cross – multi – or interdisciplinary):** Mcnair et al. (2011), Gnaur, Svidt, and Thygesen (2012), Taajamaa et al. (2013), Davishahl et al. (2018), Vicente, Tan, and Yu (2018), Najem et al. (2019), Abbonizio and Ho (2020)

Marcos-Jorquera et al.'s (2017) measurement of change through pre – and post-survey results depicting interdisciplinary course alignments of multimedia engineering students involved in interdisciplinary teams. They do, however, acknowledge time constraints as a factor in not conducting interviews with which to compare their statistical conclusions.

Self-belief development is reflected in participants' reflections, offering specific evidence of a concrete shift from previous inclinations. Often, these can be seen as related to collaboration across disciplinary backgrounds, as demonstrated by Favaloro et al.'s (2018) summary of the experiences obtained throughout a multi-disciplinary senior design course and by Badawi and Abdullah's (2021) qualitative alignment between intended learning outcomes and student feedback. Warnick (2011) links the changes found to cultural and contextual differences among engineering students, whose attempts to break down barriers in cross-cultural and cross-disciplinary structures led to recognition of others (whether in national, professional, or disciplinary contexts). Coops et al. (2015) align changes in self-belief with measurements and statements of personal attributes in students collaborating across faculty affiliations with sustainability as the common ground.

Modifications are regarded as indicators of changes in skill sets or competencies following a collaborative activity involving engineering disciplines. Steed and Gair (2020) use graduate employment statements as their basis for depicting a transfer of skills modified to meet company needs. More detailed descriptions can be found in Pierrakos et al.'s (2012) description of how their non-discipline-specific educational programme has been progressing over several years, including how their students perceived the evolution of the programme but also presenting a measurement of freshmen and juniors' perceptions and skills to differentiate and compare their efforts. Butterfield and Branch (2016) argue that their collaborative project involving chemical engineers, wherein seniors mentored freshmen, produced changes in skills for both parties. The commonality in this category can also be said to involve generic skill development as concepts related to, e.g. problem-solving, communication, or teamwork are emphasised in each paper mentioned above. However, most authors addressing Level 2 seem to examine collaboration across disciplines. Both Gnaur, Svidt, and Thygesen (2012) and Vicente, Tan, and Yu (2018) offer insights into extra-curricular activities concerning cross – or interdisciplinary collaborations and find that awareness of others' perspectives has positive impacts on participants' mindsets. Identity as a concept is also linked to this category, with Mcnair et al. (2011), Najem et al. (2019), and Abbonizio and Ho (2020) describing their outcomes as components for developing and sustaining an interest in crossing disciplinary differences through innovative processes. While Davishahl et al. (2018) argue that collaborative dimensions benefit companies by preparing students for real-life settings, they also point out that the faculties and partners involved must establish collaborative networks to sustain future progress.

3.5.3. Level 3 – behavior

Level 3 does not involve new papers as compared to Levels 1 and 2 (Table 11). Instead, overlaps occur as the papers related to this level of inclusion of assessments and evaluations go beyond mere informal representations by involving elements of external character. Level 3 pertains to the actual documentation of a transfer of knowledge for the involved participants (*N* = *2*) or the willingness to apply new skills learned (*N* = *3*).

Table 11. Findings for behaviour for Level 3.

Level 3 – Behavior	Appearances (N =)	Contents
Documents the actual transfer of knowledge for the participants or a willingness to apply new skills	2	Provides evidence for a transfer of knowledge that has affected their abilities in their workplace: Steed and Gair (2020), Warnick (2011)
	3	Provides evidence for a shift towards a change in their ability to apply new-found knowledge: Favaloro et al. (2018), Davishahl et al. (2018), Vicente, Tan, and Yu (2018)

Steed and Gair (2020) document the transfer of knowledge through their Knowledge Transfer Partnership with a Scottish textile manufacturer; both a student and the company acknowledged the importance of their collaboration and their willingness to continue in line with the achieved outcomes. Equivalently, Warnick (2011) reports on the correlation found between mechanical engineers' competencies and skills and company hiring strategies, which points to the importance of presenting engineers with opportunities to experience real-world settings in their graduate preparations. To document shifts in abilities and motivation for applying new-found knowledge, Favaloro et al. (2018) report on the 20-year progression of their capstone course involving both company-sponsored projects and academic and entrepreneurial alignments of curricular content. They provide both exit interviews from graduate students and informal feedback from instructors in their continuous assessments and evaluations, where the importance of participating in teams and learning from mistakes is highlighted as valuable. Davishahl et al. (2018) rely on interview data to report on students' willingness to apply new knowledge; their study entails collaboration across faculties in combination with company partners. More detailed representations of their findings are offered by Vicente, Tan, and Yu (2018), who frequently assess the impact of their interdisciplinary course collaboration, indicating that the element of active learning is a cornerstone of the development of interdisciplinary approaches in cross-institutional collaborations for engineering students.

3.6. Common challenges in cross-institutional collaborations

Indicators for conceptualisation furthermore relate to common challenges and different types of faculty or institutional collaborations in engineering education. However, these do not clearly constitute concepts but instead hold significant information for course designers, facilitators, teachers, leaders, policymakers and administrators of engineering institutions interested in establishing or understanding commonalities in reported challenges and benefits.

Though, as noted above, the fruits of collaborative labour produced in engineering education are reflected in both subjective reporting and quantitively summarised findings of evaluations, evidence concerning the challenges emerging before, during, or after a described cross-institutional collaborative effort can also support similar forthcoming designs or experiments. These challenges can be divided into five overarching themes for the sake of, e.g. potential curriculum or course designers, students and staff, and institutional leaders, although categorisation depends on explicit mention in relation to empirical findings. The five themes are *institutional barriers*, *conflicts of interest or priorities*, *curriculum-related issues*, *obstacles and inconsistencies in communication and logistics*, and *disciplinary challenges* (Table 12).

Institutional barriers are associated with challenges, appearing on multiple levels within or across faculty boundaries, to creating new content that conceives new ideas as a counterbalance to former practices. These challenges emerge amid organisational turmoil, as Burian and Apul (2015) point out,

Table 12. Main themes among challenges facing cross-institutional collaborations in engineering education.

Main themes of challenges	Articles included
Institutional barriers	Mcnair et al. (2011), Burian and Apul (2015), Holloway et al. (2017), Ozkan, Mcnair, and Bairaktarova (2019)
Conflicts of interest or priorities	Nuttall, Nelson, and Estes (2011), Mcnair et al. (2011), Badurdeen et al. (2014), Othman et al. (2017)
Curriculum-related issues	Gordon, Carey, and Vakalis (2008), Warnick (2011), Pfluger et al. (2013), Mitchell et al. (2019), Homer et al. (2020)
Obstacles and inconsistencies in communication and logistics	Karjalainen and Repokari (2007), Warnick (2011), Yim et al. (2011), Badurdeen et al. (2014), Warnick et al. (2014), Coops et al. (2015), Sutterer, Niezgoda, and Aidoo (2016), Chui, So, and Khaing (2017), Holloway et al. (2017), Davishahl et al. (2018), Mohsin et al. (2019)
Disciplinary challenges	Borrego and Newswander (2008), Richter and Paretti (2009), Biernacki and Wilson (2011), Yim et al. (2011), Gnaur, Svidt, and Thygesen (2012), Taajamaa et al. (2013), Tronstad (2017), Othman et al. (2017), Kovacevic et al. (2018), Abbonizio and Ho (2020)

when there are attempts to integrate knowledge beyond, e.g. engineering-related disciplines – complicating matters for instructors. Ozkan, Mcnair, and Bairaktarova (2019) report that educators involved in interdisciplinary collaborative education designs are becoming redundant due to deviation of their former disciplinary expertise and are attracting fewer promotions. Holloway et al. (2017) emphasise differences in institutional cultures and norms, problematising the act of collaboration by multiple institutions on blended courses with both digital and physical teaching elements. Similarly, Mcnair et al. (2011) indicate that the alignment of departments, budgets, promotion, and tenure is challenging interdisciplinary actions, while time management and course content also face resistance due to structural and personal barriers. Ozkan, Mcnair, and Bairaktarova (2019) find identical challenges from tenure and promotion plus seemingly rigid structures governing departmental and organisational routines.

Conflicts of interest or priorities concern differences in values, disregard for others' expertise, and a lack of dedication to collaborative work. Personal behaviour and preferences tend to complicate cross-institutional collaboration, as described by Badurdeen et al. (2014), when there is limited familiarity and commitment to engaging with other disciplines. They surmise that both students and staff, when facing disciplinary differences (such as engineering majors' and architectural students' inability to understand each other), can become disincentivized regarding collaboration. Nuttall, Nelson, and Estes (2011) describes how cross-disciplinary collaboration between courses must be supported by the heads of the departments involved to sustain longer trial periods and broker solutions to challenges. As outlined by Othman et al. (2017), collaboration between engineers and non-engineers should feature concrete efforts to share and learn from each other, which in project work are linked to team formation and cohesion.

Curriculum-related issues are often associated with differences between institutional curriculums. Challenges related to this arise with collaboration between two or more institutions, which Warnick (2011) links to collaboration between countries. Both educators and students must adhere to different sets of curricular content, which are rarely designed to accommodate cross-institutional collaborative initiatives, or the students may be at different stages in their education. Mitchell et al. (2019) and Pfluger et al. (2013) both find a concern related to unchangeable syllabus content, when curriculum designers do not follow emerging trends in engineering programmes or experience difficulties in synchronising concurrent courses. Correspondingly, Homer et al. (2020) report the challenge of students' being required by interdepartmental collaboration to follow two different syllabi. To avoid similar issues, they advocate for accreditation boards to emphasise common values and goals in the development of collaborative projects or programmes.

Obstacles and inconsistencies in communication and logistics receive considerable mention in the articles, generally in relation to constraining processes that prevent stability in collaborative efforts. Numerous papers report similar challenges surfacing in their collaborative descriptions. For example, Warnick et al. (2014) and Coops et al. (2015) find that communication among faculty members was lackluster, and gaps in scheduling and assignments not only influenced preparation and teaching but also created an uncertain structure for faculty administrators. These findings are also noted by Badurdeen et al. (2014), and Holloway et al. (2017) who present examples of multiple instructors' collaborating to deliver content while experiencing clashes of institutional cultures and internalised practices. Engineers' preferences can, in some cases, clash with those of non-engineering disciplines, giving rise to conflicts. Ali Mohsin et al. (2019) identify time management as the greatest barrier to their inter-institutional collaboration. Davishahl et al. (2018) note similar complications in planning and implementing cross-institutional project work. They further find it critical to facilitate and structure student communication (for which they recommend digital tools), both within project groups and with other faculties and industry partners. Logistics are essential in cross-country collaboration due to potential differences in time zones and languages. Karjalainen and Repokari (2007) indicate that their cross-Atlantic project collaboration suffered from the Stanford-campus venue for most courses, which prevented the Finnish students from participating. In addition, the online collaborative dimension faced technical obstacles. Furthermore, Yim et al. (2011) report cultural obstacles – both personal and professional – to collaboration between Korean and German industrial design and engineering students. Similarly, Kit Chui, So, and Khaing (2017) describe language as a barrier in cross-institutional collaboration across countries.

Disciplinary challenges are the most profound obstacle to cross-institutional collaboration, with numerous challenges mentioned concerning cross-, multi-, or interdisciplinarity. Borrego and Newswander (2008) examine the complex processes of facilitating interdisciplinary engineering education from the facilitators' point of view, indicating that differences in epistemology and institutional structures often challenged efforts. They further point to the absence of frameworks for cross-disciplinary collaboration, a finding echoed by Gnaur, Svidt, and Thygesen (2012), who also note that higher-education institutions favour 'traditional' disciplinary paradigms. Othman et al. (2017) emphasise that students involved in cross-disciplinary collaborations can struggle with recognising relationships between their own discipline and others. Non-engineers also express difficulty grasping how engineers work, as described by Taajamaa et al. (2013), suggesting that project or learning content should be explicit for all students involved. When problems are guiding beacons for a collaborative effort, similar challenges appear, which Richter and Paretti (2009) attribute to epistemological differences (even between similar branches of engineering), work habits, and a rejection of the unfamiliar. A necessary component for engineering students seems to be a concrete shift from familiar processes to seeking involvement and knowledge from other disciplines, a shift that Biernacki and Wilson (2011) find it necessary for facilitators of interdisciplinary collaborations to instil in students' minds and practices. In their report on the challenges students face when collaborating across disciplines, Abbonizio and Ho (2020) point to distinguishing relevant from redundant information, a difficulty Kovacevic et al. (2018) attribute to vocabulary differences.

4. Limitations, practical implications of interest, and concluding remarks

As no gold standard has been promoted for precisely this type of systematic literature review, especially in EER (Saunders-Smits and Cruz 2020), various ways of pointing out methodological differences may apply. As this review also attempts at a coherent conceptualisation of *what is common* across varieties of cross-collaborative experiments in engineering education, a limitation is whether generalisations and deductions invite uncertainty rather than consistency. Another limitation of this systematic review is the exclusion of 'grey literature', meaning the potential neglect of, e.g. relevant governmental documents, non-peer-reviewed books, and white papers. Nonetheless, as this paper explores reports of collaboration in engineering education across higher-education institutions, the presumption behind the deselection is that to limit 'noise' and irrelevant information, the absence of external assessment (such as peer review) of collaborative efforts should count as an exclusion criterion in the final search. Furthermore, the question of literature reviews' validity and reliability deserves consideration as differences are bound to occur depending on the researchers' focus. For example, this study does not entail further categorisation of types of collaborations besides the differences in disciplinarity constellations, which could have further discovered, in more details, how a multi, or interdisciplinary cross-institutional collaboration involves students at different stages in their education.

For this study, a review team of three researchers conducted iterative dialogues on contextual and content-specific understandings. Though the need to align coding can produce discussions regarding discrepancies, this should be accepted as a fruitful venue for discovering commonalities and dismissing irrelevance. The indicators found in this study, to guide the identification of common understandings as starting points for cross-institutional collaborations, are components in a grander scheme of constructing consistent, measurable meanings of variable conceptualizations. However, this systematic review arguably deviates from prior conceptualizations by other researchers (LeFebvre 2017). Therefore, to limit inconsistencies in future related studies, interpretations should preferably contain the unfoldment of predetermined interrelated indicators of interest to determine commonalities constituting a single variable for conceptualisation.

A mention towards the limitations concerning the geographical areas mostly included for this review is also needed, as deliberate choices do affect the general characterisation of cross-institutional collaboration in engineering education (Aksnes and Sivertsen 2019). For instance, papers were only included if written in English but papers originating from European authors also are found written in many other languages. Asian countries also publish in their native language, which again makes a deselection of other languages a potential pitfall for important research to be found. Merely citing authors publishing in English or by favouring a certain geographical region, publication colonialism (Tennant 2020) is a risk authors face when not entailing reasons for the respective selections and deselections of papers, which is acknowledged can be applied to this review – although, considerations and choices are all rooted in concrete underlying choices of the selected papers.

4.1. Implications for future practice

An important consideration is the seemingly opaque nature of cross-institutional collaboration initiatives, which often conform to either accreditation standards, simple curiosity, or company and industry demands. Despite these influences, the actions needed for sustainable cross-institutional collaboration involving engineering students arguably lack a distinctive common objective, although exploring interdisciplinarity can in itself promote relevant collaborative competencies.

To guide future experiments and curricular design, the findings stemming from this study can contribute to the general understanding of the common experiences associated with crossing institutional barriers in engineering education. Recommendations involve 1) *distinguishing different formats, contextual and regional differences, and institutional or organizational interests*, 2) *aligning curricula and theoretical frameworks*, 3) *increasing shared commitment and overcoming structural or practical barriers*, and 4) *aligning common assessment and evaluation approaches for collaborative processes and outcomes.*

1. The dissimilarities found in cross-institutional collaborations can be overcome through several actions. The formats applied most often aim for the creation of interdisciplinary processes, although findings point to overlapping meanings of disciplinarities in instances of cross-institutional collaboration. This demands the attention of institutional leaders since collaboration as an integral part of engineering education requires support that simultaneously adheres to external policies and is institutionally sustained by internal efforts and contributions. Common boundaries are suggested here regarding shared curriculum models to facilitate future collaboration. If cross-institutional collaboration is to transpire across nations, overcoming the substantial vocabulary differences between engineers and non-engineers will also require further research. Engaging in cross-institutional collaboration research with explicit, concrete objectives, where common boundaries imply a sense of urgency for establishing common ground, will require effort from both staff and students. A possible approach to achieving this is to emphasise and make these recommendations explicit as phrased and definite goals of future collaboration across institutions involving engineering education. Sustaining these practices can bring familiarity and continuous learning experiences not only for engineering students and staff but also for institutional leaders who are willing to transform prior structures.
2. Common structures for curriculum design are also recommended to achieve a sense of constructively aligned goals that are clear for all involved in a cross-institutional collaboration. These will benefit from the practical use of theory for evaluating or assessing the sufficiency of collaborative intentions in a curriculum model or course design. Guiding principles aligned with concrete intentions for learning can be found in different theoretical models, and a recommendation is to streamline similar representations or explore the effectiveness of collaborative processes through commonly described theoretical directions in future curricular design involving cross-institutional collaboration in engineering education.
3. Greater rewards for attempting a bridging of disciplines in practice are highly recommended as findings in this study foretell complications for educators who are intrinsically motivated or have

been involved in such activities. The training of collaborative facilitators may help resolve obstacles concerning limited experience. Additionally, establishing and nurturing processes related to communities of practice has the potential to support the processes occurring before, during, and after a cross-institutional collaboration and to guide future decisions and reforms. Tightly packed schedules risk hindering progress, leaving minimal space for efforts outside the institutions' respective curriculum models. Administrators and leaders of engineering education programmes must address time constraints if the delivery of collaborative elements is to become a reality.

4. Achieving certainty regarding the outcomes of collaborations across disciplines and institutions may benefit from using a research-based approach to ensure the quality of programmes, courses, or projects. Empirical evidence is crucial for learning transfer between similar experiments, and perhaps more importantly, for facilitating the sustainable development of engineering students' competencies for a complex and intertwined world. Efforts should not be confined to solitary approaches; on the contrary, diverse approaches are suggested to develop innovative ways of collaborating, assess the results, and propose improvements and solutions to challenges. Nevertheless, it must be stressed that upcoming curricular designs should preferably align in the inspiration and knowledge with which they ground common evaluation and assessment criteria for ongoing cross-institutional collaborations involving engineering institutions.

4.2. Concluding remarks and next steps

By exploring commonalities, differences and potential indicators for cross-institutional collaboration conceptualizations, an outcome is a collective understanding of the constituting approaches in examples from EER. The review has led to the discovery of potential types and formats of cross-institutional collaboration in engineering education, but it also demonstrates the distinct lack of methodological representations and evaluations and assessments of the actual transferability of results. Combined with the notion of theoretical representations being neglected in many cases, a further advocating for including all these aspects in future research will support the scientific validity of the research enacted.

This systematic review has uncovered only a few examples of additional aims, e.g. generic skill development, appreciating cultural differences, industry preparedness, and problem-solving competencies, which leaves open the question of what engineering education should strive to achieve. Romero et al. (2020) conducted a systematic review of the 2030 agenda implementation and its deployment at engineering schools around the world. Their recommendations concerning collaborative efforts for engineering education are quite significant, pertaining to a lack of teacher training to ensure the necessary competencies and prerequisites to transform and transfer knowledge into learning processes (Romero et al. 2020). In addition, they found scarce information related to university administrators and leaders' following up on the UN Sustainability Goals (SDGs). Even though reforms are found to have been initiated across multiple engineering schools and higher education institutions worldwide, curricular content, assessment strategies, and collaborative institutional structures appear lackluster (ibid.). Although this is not the focal point here, it is also confirmed in this study through evidence related to cross-institutional collaboration. Only one (Abbonizio and Ho 2020) of the 74 papers chosen for this study is oriented towards SDGs as a boundary object around which collaboration can revolve. Although this result may be due to the absence of SDGs or synonymous words in the search string, further attention to this concern is recommended.

Central to the discussion of emerging potentials for collaborative efforts is how a sustainable, innovative, and democratic praxis can be achieved. Cross-institutional collaborations involving multiple disciplinary voices, including engineering, offer the prospect of social innovation and economic benefit. Yet, underlying processes related to competition and status seem to hinder the overarching collaborative purposes. Universities play an important role in developing students into beneficial contributors to society and are, as Blass and Hayward observe, privileged entities that should challenge prior political agendas and promote inclusion and diversity (Blass and Hayward 2014). Thus, to transgress boundaries, theoretically considered designs and initiatives should attempt to align commonalities in assessment and frameworks and draw upon empirical evidence that appears after the collaboration has ended. A notion of the role and inclusion of employers of graduate students is therefore important for future initiatives – potentially with the SDGs as the common denominator (The UN 2015). This should serve as a recommendation for universities to join forces in supporting activities that can train both students and staff through potential *mission-driven* projects or programmes, both connecting national institutions and crossing borders and sectors (Mazzucato 2018).

Disclosure statement

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