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Literature review of students' perceptions of generic competence development in problem-based learning in engineering education

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ABSTRACT

The development of generic skills and competences has become a central component of contemporary engineering education due to increased societal and occupational complexity. Problem- and project-based learning (PBL) has been highlighted as one of the pedagogical approaches fostering generic skills and competences that are transferable between various contexts. However, the arguments linking PBL and generic competences have mostly been theoretically grounded or based on singular cases of teaching experience. The purpose of this literature review is therefore to present a comprehensive overview of the different types of generic competences documented in a PBL environment. The review includes 28 peer-reviewed articles that have documented engineering students' perceptions of generic skill and competence development. The results reveal either an emphasis in the studies on teamwork, typically combined with a couple of other types of generic competences, or, in a few cases, a narrow focus on problem-solving. The synthesis of generic competences perceived by engineering students in PBL environments furthermore unfolds a landscape of generic competences, which provides a frame of reference to discuss strategies to foster the broad set of generic competences needed for future engineers to deal with the complex societal challenges of our time.

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PBL; problem-based learning; generic competences

1. Introduction

Engineering has often been perceived as solitary problem-solving involving technical and disciplinary competences, with little emphasis placed on social dimensions (Trevelyan 2010). In 2004, visions for *The Engineer of 2020* were proposed by the National Academy of Engineering (2004). Although 2020 has passed, the core principles and subject matters still remain, and the challenges have become even more complex. This complexity unfolds by increasing societal interdependence, the extreme pace of emerging technologies, demands for accountability and stakeholder involvement, a high degree of uncertainty, and, lastly, a lifelong learning perspective to respond to continuous change. As a consequence, new competences are needed in relation to ingenuity, creativity, communication, management, leadership, agility, and resilience. These attributes are similar to those described in frameworks describing key, generic, or twenty-first-century skills and competences (e.g. Gonzáles and Wageneer 2003; Voogt and Roblin 2012; Young and Chapman 2010) and also to those found in reviews and analyses of engineering practice (e.g. Passow 2007; Woollacott 2009). Furthermore, they are competences that are transferable across vocational and contextual

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boundaries and that have gained traction in the globalised knowledge economy (Young and Chapman 2010).

1.1. Typologies of competence

According to Markowitsch and Plaimauer (2009), occupational classifications have failed to address the gap between the labour market and education, and competence classifications rather than occupational classifications are determining placement in the job market. The misalignment between formal education and the labour market has also been noted by Hennemann and Liefner (2010), who suggested transitioning from a content-oriented and cluttered curriculum to one consisting of projects dealing with authentic problems. For educational institutions, student-centred approaches, such as problem, inquiry, or challenge-based learning, have been promoted as viable methods to bridge this gap between education and vocation (Voogt and Roblin 2012).

The notion of bridge building between education and the labour market has also been a premise for problem-based learning (PBL) and approaches like Conceive-Design-Implement-Operate (CDIO), where the learning environment serves as a training ground emulating future vocational practice (Barrows and Tamblyn 1980; Crawley et al. 2014; Kjersdam and Enemark 1994). Previous research has indicated the effectiveness of PBL in preparing students for the labour market while promoting long-term knowledge retention acquired during education or training (Dochy et al. 2003; Strobel and van Barneveld 2009). Jonassen, Strobel, and Lee (2006) argued that practicing engineers deal with workplace problems that are less linear than those often encountered by students in classrooms, which involve both ill-structured problems with multiple solution paths and settings with unidentified constraints. The authors further argued that the most significant goal of engineering education is to stimulate workplace transfer and that one solution is to convert existing curricula to PBL. However, PBL alone does not entail a solution unless the environment is expanded to include a wide variety and kinds of problems, meaningful collaborations with important stakeholders, distributed knowledge construction, and support (Jonassen, Strobel, and Lee 2006).

PBL is not a single entity but an approach consisting of multiple variations and degrees of implementation, which range from course-based approaches to systematic integration throughout an entire curriculum (Kolmos 2017). Taking the point of departure in translation theory, Scholkmann (2020) also notes that implementations of PBL are socially and contextually influenced by diverse interpretations, resulting in new versions or variations catering to local aspirations limited by boundaries of social conformity. Chen, Kolmos, and Du (2020) performed a systematic review based on a conceptual framework of PBL constellations proposed by Savin-Baden (2014). The authors identified that most of the reviewed literature concerned course-based integration of PBL with various and overlapping configurations and strategies for modes of knowledge, activities, and problem scenarios. Rather than demarcating different modes of PBL, Savin-Baden (2014) suggested embracing them all while building on reasoned pedagogy. Kolmos and De Graaff (2003) made similar remarks and described fundamental elements in PBL: exemplary, authentic, and real-world problems, which serve as the starting point for a learning process in which students co-construct and negotiate a path towards viable problem-solving in collaboration with peers and stakeholders.

While there appears to be some consensus on the overall principles characterising PBL, competence and particularly the generic aspect have been contested with a wide range of typologies, parting in local interpretations and traditions (Le Deist and Winterton 2005; Markowitsch and Plaimauer 2009; Miranda et al. 2017). Sandberg (2000) critically remarked that the majority of interpretations of competence generally consist of decontextualised condensations obtained by observing or interrogating skilful or successful workers, which often misses embodied and tacit parts of performance, thus resulting in a reduction of activities and context. Further, Sandberg (2000) noted that competence is not a specific set of attributes but instead suggested that a worker's conception of work defines what competences are developed and thus performed. Following this line of thought, Raven (2001) argued that competence does not occur in humans but is a result of an

interaction between role requirement and personal abilities. How this relationship turns out is influenced by internal predispositions, motivations, and conceptions of tasks and activities. Performance can hence be qualified as a result of these internal attributes in action (Woollacott 2009). Though both Raven (2001) and Sandberg (2000) addressed competence at work, Sandberg (2000) emphasised Schön's reflective practicum found in education as a method to trigger stimulation and development of a worker's conception of work. From this, it follows that competences are to be understood by focusing on the individuals who develop and perform these competences.

While the typologies presented above conceptualise competence on a general level and contribute to conceptions of what constitutes competence, efforts aimed at mapping and contextualising generic engineering competences have been undertaken. Often these efforts have been based on stakeholders' aspirations for graduates or based on ratings supplied by practicing engineers, but despite great variations in methodologies applied in research, the themes appear to be consistent (Male 2010). This notion is also exemplified in Woollacott's (2009) development of a taxonomy of engineering competences, where the inclusion of multiple accreditation frameworks, previous reviews, or conceptual papers form the basis of a taxonomy including both specific and generic engineering competences. To cater to adaptability, described performances of abilities, dispositions, or understanding (see 288–291) are decontextualised. Male, Bush, and Chapman (2011) presented a relation between generic competences and engineering to capture the overarching technical and social aspects of engineering practice. Like Woollacott's taxonomy, Male, Bush, and Chapman (2011) emphasised that generic competences are those usable by engineers across all engineering disciplines. Based on practicing engineers' ratings of 64 generic competency items, Male, Bush, and Chapman (2011) found competences such as communication, teamwork, professionalism, self-management, and problem-solving to be highly important. However, integrating these as intended learning outcomes can prove difficult, and as shown by Passow (2007), not all outcomes are captured by accreditation frameworks. The gaps between the expected outcomes of an engineering education and the labour market, as addressed by Male (2010), Woollacott (2009), and Passow (2007), includes the view of practitioners but not students. While providing a context emulating professional practice, as suggested by the three authors, none acknowledged that practitioners have an interpretive framework or personal epistemologies different from that of students who are yet to enter practice (Chou and Chen 2016; Schommer 1994). Thereby, there is a need for more comprehensive descriptive studies including not only practicing engineers but also student perspectives.

To create a typology of competence, Le Deist and Winterton (2005) drew on different local interpretations that emphasised various aspects of the components constituting competence, which differ from vocational traits with respect to more personal and formative aspects. In their typology, they summarised competence using four dimensions: functional, cognitive, social, and meta-competences. Local interpretations of competence typologies have also emerged in higher education. Kallioinen (2010) described a future-oriented and adaptable competence-based curriculum at Laurea University of Applied Science in Finland, where educational programs share five overarching generic competences: ethical, globalisation, innovation, reflection, and networking. Each of these elements progresses through three levels, moving from personal to organisational and ending with social reform. Another example of a local interpretation is from Aalborg University where generic competences are dubbed PBL competences and consist of four dimensions with distinct orientations towards problems, interpersonal relations, structural and managerial aspects, and meta-cognitive abilities, such as reflection (Holgaard and Kolmos 2019). While these typologies propose structures for characterising different types of generic competences, there is notably little overview of research on the students' perceptions of generic competences.

The goal of our study is therefore to review empirical research documenting students' perceptions of generic competence development in engineering education. We focus specifically on generic competences developed in a PBL environment due to the above-mentioned prospects of this educational approach. The research question thus is as follows:

What landscape of generic competences unfolds by reviewing empirical research of student perceptions of generic competences in a PBL environment?

The purpose is to reveal particular emphases in students' perceptions of generic competences across institutions and to provide a baseline to qualify the discussion of how future engineering education can foster the generic competences needed to address the complex challenges of our societies.

A limitation of this study is that it is centred on students' subjective perceptions of their generic competence development. This is, however, a deliberate choice in order to supplement theoretically based conceptual frameworks and studies of employers' perspectives on the need for generic competences. We are aware, nevertheless, of the emancipative aspects of the results presented. Emancipation lies in letting students attribute qualities to objects based on how they experience them. This, however, implies a risk of students not attributing the qualities we anticipate, but this is a risk of engaging in education (Biesta 2006). Likewise, there is a risk that competences, which are tacit for the students themselves, are not revealed.

We are also well aware that the results highlighted in the literature review represent a rather fixed picture of students' perceptions of competence grounded in their particular epistemological beliefs. Epistemological beliefs are a personal understanding of the nature of knowledge and knowing, which, in theory, over time becomes more sophisticated, but Chou and Chen (2016) have stated that a linear progression cannot be expected, as new and more advanced courses and interactions with peers and teachers also condition development in epistemological beliefs. Still, as the purpose is to present as rich a landscape of perceptions of generic competences as possible, based on the evidence put forward in literature, variations of perceptions are considered a strength.

Finally, while we focus exclusively on PBL and PjBL in this article, it is worth noting that PBL is comparable to other student centred pedagogical approaches like Inquiry Based Learning (IBL) and design based learning (DBL) (Kolmos, Bøgelund, and Holgaard 2021). CDIO is another prominent example of such an approach where generic skills are part of the syllabus (Crawley et al. 2014). Studio-based environments, challenge-based learning, internships, and informal learning environments not confined to an educational sphere can also provide opportunities to engage in emulated or authentic as response to emerging educational trends in engineering practices, and potentially develop generic competences (Hadgraft and Kolmos 2020).

2. Methodology

The aim of this review is to synthesise what has been reported on engineering students' perceptions of generic competence development in a PBL environment. To this end, we conducted a literature review following the typical stages of the process: developing a review plan, searching for literature, selection, assessment of quality, extraction of data and key concepts, analysis, interpretation, synthesis, and drawing conclusions (Booth, Papaioannou, and Sutton 2012; Paré et al. 2016). Each of these steps will be elaborated as they appear chronologically in the review.

2.1. Search protocol

We started our process by conducting a number of minor scoping literature searches as a suitable method to identify research gaps (Booth, Papaioannou, and Sutton 2012). For this review, initial searches aimed at establishing an understanding, refining the conceptualisation of 'generic competences,' and exploring whether definitions included competence, skills, or both. The preliminary results indicated that skills, competence, and competencies were used indiscriminately in the literature to describe broad, personal, transversal abilities (Tahirsylaj and Sundberg 2020). Further, generic competences were also labelled with alternative terminologies, such as employability, key competence, or transferable competence (Gonzáles and Wageneer 2003; Young and Chapman 2010).

Consequently, this influenced the creation of the research protocol and the selection of keywords used in searching the selected databases (see Table 1).

The scoping searches also resulted in a substantial number of potential resources. To keep the review manageable, we decided to include only peer-reviewed articles and omit books and conference papers from our searches directly in the databases. The character of our literature review is selective (Paré et al. 2016) and consequently less comprehensive due to the exclusion of grey literature covering organisational reports and government papers, to name a few (Haddaway et al. 2015). While only a few articles in our synthesis referenced political papers and processes, a discussion to omit the political dimension was made, although the influence of external stakeholders by means of soft and hard governance is becoming more pervasive (Tan 2014; Zapp 2019).

Searches were supplemented with additional citation searches, when relevant, to snowball through background literature, as suggested by Booth, Papaioannou, and Sutton (2012). The context was engineering education in universities or higher education. The time frame for the initial searches was left open based on the notion that generic competences have been of particular interest in the last two decades due to increased globalisation and changes in competences recognised for success in the knowledge economy (Gonzáles and Wageneer 2003; Moulier Boutang 2011; Young and Chapman 2010). The searches were performed in the first week of July 2020 and reiterated in November 2021 and consisted of variations of the keywords presented in Table 1. Searches performed in EBSCOhost's included databases were performed simultaneously, and Scopus and Web of Science were selected to provide potential variety.

2.2. Screening process

In each of the selected databases, the results were limited to include only peer-reviewed articles as an initial first step before the results were downloaded as.bib files for further exclusion in Mendeley, based on title, keywords, journal, and further full-text screening. The inclusion and exclusion criteria are presented in Table 2. Given that the concept of 'generic competences' is relatively new according to Young and Chapman (2010), a time interval was not set.

Figure 1 displays a diagram of the flow of information. The searches yielded a total of 845 resources after the removal of 115 duplicates. The first phase of exclusion reduced the number of articles to 235 after screening the names of journals, titles, and keywords. Screening of the abstracts and full-text readings narrowed the corpus to 101 articles, excluding articles concerning neither engineering education, PBL, nor higher education. Articles with theoretical or conceptual papers were likewise excluded, as a general characteristic of these types of articles highlights theoretical or conceptual learning principles and activities attributed to the development of students' generic competences. The selection process was repeated two times to ensure that no relevant articles had been mistakenly excluded. Additional random sampling of excluded articles organised in Mendeley folders was performed before concluding the selection process, and 77 articles were deemed eligible for full-text reading.

Table 1. Keywords and search blocks used in databases.

SEARCH	KEYWORDS
BLOCK 1	PBL **OR** problem-based learning **OR** problem-orient* **OR** project-orient* **OR** PjBL **OR** 'project-based'
AND	
BLOCK 2	Engineering education
AND	
BLOCK 3	Universit* **OR** HE **OR** higher education
AND	
BLOCK 4	Generic **OR** key **OR** soft **OR** employability **OR** core **OR** trans*
AND	
BLOCK 5	Competenc* **OR** skill*

Table 2. Inclusion and exclusion criteria.

CRITERIA	INCLUSION	EXCLUSION
TOPIC	Peer-reviewed journal articles containing empirical research of students' perceptions of generic competence development in PBL in engineering education. Students' perceptions of competence development	Conference papers, books, sources not explicitly focused on generic competences in EE and problem-based learning. Political papers and reports. Non-empirical research. Conceptual papers. Theoretical papers
CONTEXT	Engineering education in higher education or university	Medicine, nursing, school sector, public schooling
DATE	Not set	2021
LOCATION	International literature	Sources not in English language

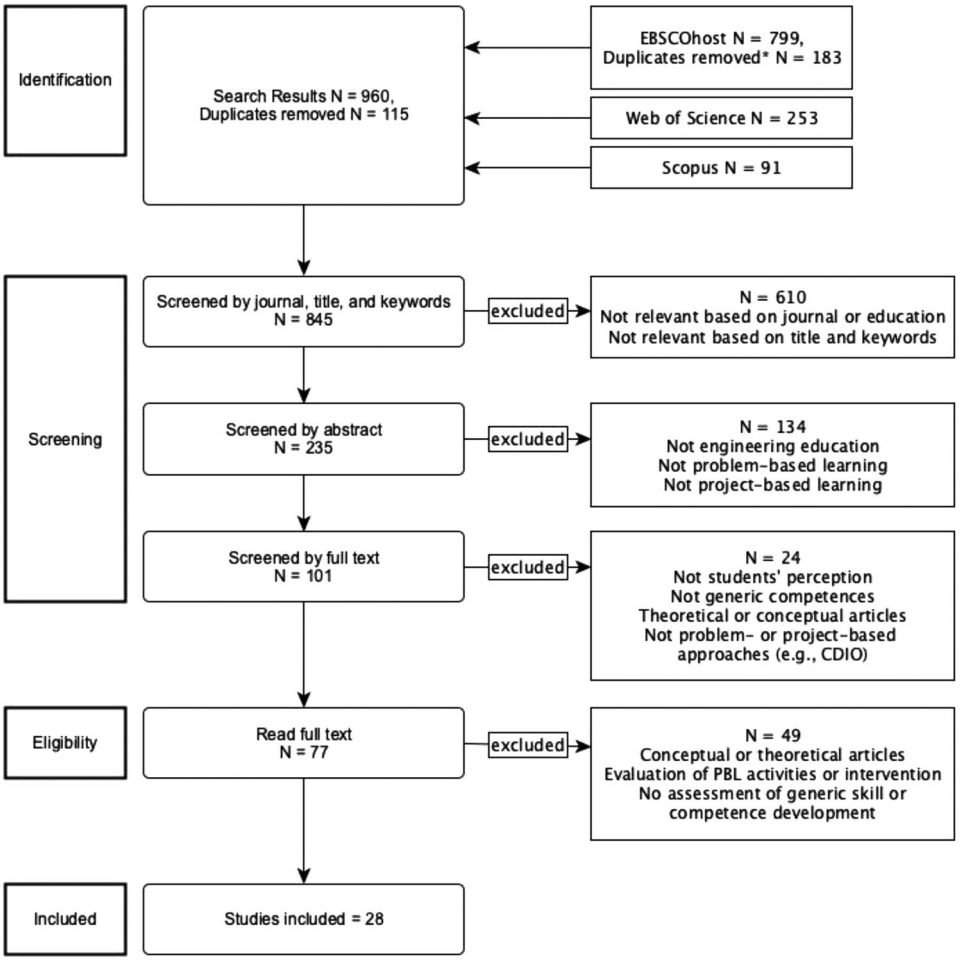

Figure 1. Flow of information.

Note: *799 results in EBSCOhost, 183 duplicates automatically removed when downloaded as .bib file from the database.

The full-text reading of the 77 articles found that less than half addressed students' perceptions of their generic competence development. Articles excluded from this final phase only superficially addressed the development of generic competences, either as a minor part of an evaluation of a PBL intervention in an existing practice or as secondhand experiences reported by teachers.

Evaluations often centred on students' satisfaction with their experience of PBL, at best assessing how much they had learned of the intended outcomes related to the disciplinary subject matter. Most excluded articles at this stage concerned research on the development of professional skills and competences, where generic competences were considered a positive side-effect of PBL, but there was no additional empirical evidence supplied by students. The process ended with 28 included articles. Furthermore, 7 sources were identified as background studies and used in the previous sections. The latter were used as background studies in the previous sections to provide theoretical perspectives on engineering, PBL, and generic competences.

2.3. Articles included for synthesis

The 28 articles meeting the inclusion criteria were published between 2003 and 2021 (Figure 2) in *Advances in Space Research* (1), *CBE, Life Sciences Education* (1), *Chemistry Education Research and Practice* (1), *Design and Technology Education* (1), *European Journal of Engineering Education* (5), *Innovations in Education & Teaching International* (1), *International Education Studies* (1), *International Journal of Engineering Education* (8), *International Journal of Engineering Pedagogy* (1), *International journal of Technology and Design Education (1), Journal of Information Technology Education: Innovations in Practice* (1), *Multicultural Education & Technology Journal* (1), *Multidisciplinary Journal for Education, Social and Technological Sciences* (1), *New Directions in the Teaching of Physical Sciences* (2), *TEM Journal* (1), and *Transportation Research Record* (1). The educational programs covered are electrical engineering, civil engineering, chemistry, computer engineering, and other subjects such as aerospace engineering and global business engineering.

The research comes from various countries, however, most prominently in Europe, with one-fourth of the articles coming from Spain. Articles concerns research conducted in *Australia* (1), *Canada* (1), *China* (1), *Croatia* (2), *Denmark* (1), *France* (1), *Ireland* (1), *Israel* (1), *Malaysia* (1), *Serbia* (1), *Slovenia* (1), *South Africa* (1), *Spain* (7), *Ukraine* (1), and the *United Kingdom* (2). Five articles do not explicitly address where the research presented is conducted. The educational level ranges from undergraduate students (12), including first-year students to final year bachelor students, to master students and senior students (5). Likewise, some articles do not explicitly address the study level limiting a classification to students from a particular educational program or faculty.

3. Findings

The included articles reaffirmed notions put forward by other authors, namely that PBL is implemented and practiced in a wide variety of modes. In the articles, PBL was primarily implemented as an intervention at course level or as activities hinging on an existing curriculum with limited change in overall curriculum structures. The articles presented various PBL activities

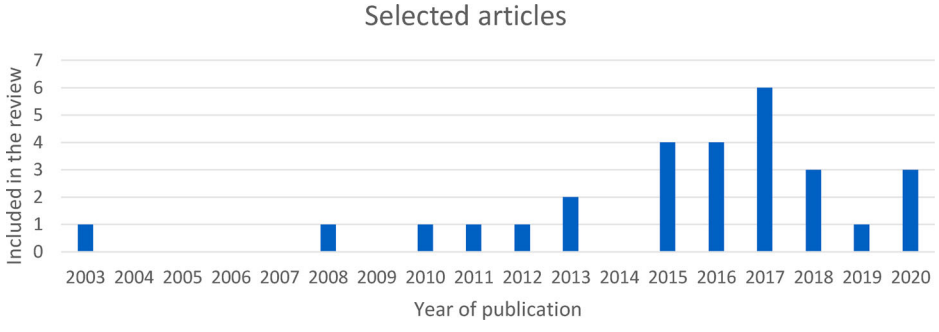

Figure 2. Year of publication and number of articles included.

and types of problems depending on project duration, core content, and what skills or competences students were anticipated to develop. The durations of projects in the selected literature ranged from a single week to a full semester, and different emphasis was given to professional and generic competence development.

The most addressed skills or competences were those centred on various aspects of teamwork, collaboration and communication, and self-directed learning and problem-solving. The research goals presented in the articles were diverse, and some concerned the effectiveness of PBL in promoting specific skills (e.g. Downing, Ning, and Shin 2011), exploration of exposure to PBL in relation to students' problem-solving skills (Kadir et al. 2016), or exploring how students' perceptions of teamwork competences change after working in teams (Beagon, Niall, and Ní Fhloinn 2019; Murzi et al. 2020).

Various terms were used in the articles to describe generic skills and competences related to PBL: sociotechnical skills (Beagon, Niall, and Ní Fhloinn 2019), generic skills (Downing, Ning, and Shin 2011), transferable skills (Williams and Handa 2016; Williams and Hin 2017), soft and transversal skills (Moliner et al. 2015), and generic competences (Božić et al. 2018; Lutsenko, 2018). Some research considered students sociotechnical skill development as part of a transition from secondary to tertiary education (Beagon, Niall, and Ní Fhloinn 2019), from an existing pedagogical approach to PBL (Božić et al. 2018; Lutsenko, 2018), or focused specifically on selected generic competence or skill development (Downing, Ning, and Shin 2011; Klegeris et al. 2017). While there was a consensus on the importance of competences or skills transcending those that are purely vocational, there was little consensus regarding the conceptualizations used.

3.1. Rationales for generic competence development

Although different terms were used to specify generic skills or competences related to PBL, there was a general recognition of the importance of competences traversing vocational spheres. A perceived mismatch between industry desires and aspirations and educational outcomes was the primary concern for developing generic skills or competences. The importance was framed in multiple ways: gaps between education and industry (Beagon, Niall, and Ní Fhloinn 2019; Božić et al. 2018; Kadir et al. 2016; Macho-Stadler and Jesús Elejalde-García 2013), rapid changes in technological development and economy (Fain, Wagner, and Vukasinovic 2016; Mekovec, Anicic, and Arbanas 2018; Mihić and Završki 2017), a need for fostering encouragement for lifetime employability rather than lifetime employment (Mihić and Završki 2017), and enhanced skills and competence in teamwork and interpersonal relations as a response to new types of interdependence between occupational domains (Riis et al. 2017). Generally, the conception of generic skills and competences presented in the articles were occupational in foci and oriented towards developing competences deemed necessary by third parties to participate in the labour market of an increasingly complex and globalised world.

3.2. Methods applied to study generic skill and competence development

Researching students' perceptions of development was undertaken by applying various research designs. The research approaches are summarised in Table 3.

The majority of articles employed surveys or questionnaires administered to students as pre- and posttests or after PBL interventions or activities as part of an evaluation, in which assessment of generic competence or skill development was included. Studies using surveys and questionnaires relied on students' abilities to self-assess their development of competences and skills. In other articles, questionnaires were used to compare educational programs or different cohorts in the same educational programs with various implementations of PBL (e.g. Klegeris et al. 2017; Mgangira 2003; Vidic 2008; Williams and Hin 2017).

Table 3. Summary of research methods.

Reference	Pre-/post surveys or questionnaires	Post surveys or questionnaires	Survey or questionnaire	Observation or monitoring	Qualitative interviews	Document analysis	Control groups or comparative studies	Reflective assignments
Beagon, Niall, and Ní Fhloinn (2019)	x					x		
Božić et al. (2018)	x							
Downing, Ning, and Shin (2011)	x						x	
Fain, Wagner, and Vukasinovic (2016)			x				x	
Fini and Mellat-Parast (2012)	x						x	
Helmi, Mohd-Yusof, and Phang (2016)	x							
Jacques (2017)						x		
Kadir et al. (2016)	x							
Klegeris et al. (2017)			x				x	
Lutsenko (2018)			x					
Macho-Stadler and Jesús Elejalde-García (2013)		x						
Mekovec, Anicic, and Arbanas (2018)		x						
Mgangira (2003)		x					x	
Mihić and Završki (2017)		x						
Moliner et al. (2015)			x					
Murzi et al. (2020)	x				x			
Necchi et al. (2020)	x				x			
Overton and Randles (2015)			x					
Perez-Martinez et al. (2010)	x							
Ragonis, Hazzan, and Har-Shai (2020)								x
Riis et al. (2017)	x				x			
Rodriguez et al. (2015)	x							
Rodríguez Montequín et al. (2013)				x				
Terrón-López et al. (2017)			x		x			
Vidic (2008)						x	x	
Williams and Handa (2016)			x					
Williams and Hin (2017)	x						x	
Zou and Mickleborough (2015)	x				x	x		

These approaches mostly employed Likert scales, but more encompassing frameworks were also found. Downing, Ning, and Shin (2011) used the Learning and Strategies Inventory (abbreviated LASSI) and a course experience questionnaire to examine differences in students' metacognitive development between educational programs. Klegeris et al. (2017) used questions designed by PISA to measure the development of general problem-solving skills, whereas Božić et al. (2018) based their selection of relevant generic competences on a list created as part of the TUNING process based on data obtained from questionnaires distributed to graduates and employers. Other studies included the collection of documents, such as logbooks (Jacques 2017), thematic coding of reflective writings (Beagon, Niall, and Ní Fhloinn 2019), and sequential and other mixed research approaches, including both qualitative and quantitative data (Murzi et al. 2020; Riis et al. 2017; Zou and Mickleborough 2015) as additional means of analysis while contributing statements from situated practice. Other articles contributed with comparative studies between educational programs or institutions (Downing, Ning, and Shin 2011; Fain, Wagner, and Vukasinovic 2016; Klegeris et al. 2017; Williams and Hin 2017). Ragonis, Hazzan, and Har-Shai's (2020) research stood out by taking the analysis of six reflective assignments in two courses where students explicitly reflected on their soft skills as the point of departure.

3.3. Generic skill or competence development

The articles addressed various generic competences and skills, as presented in Table 4. The most common themes mentioned were teamwork, communication, problem-solving, navigating ambiguity, and self-directed learning. Project management appeared in four articles, while time management appeared in three. We divided the articles based on whether they concerned the management of a group or individual structure and management. Creativity, critical thinking, and information literacy were each mentioned three times. The remaining themes appeared one or two times.

Some of these can be unpacked in constituent elements. One prudent example is teamwork, which in some articles concerned interpersonal relations and mature communicative actions needed to act competently in teams (i.e. Murzi et al. 2020; Ragonis, Hazzan, and Har-Shai 2020). To structure the literature review, the competences are reported on in the four categories: problem oriented, structural, interpersonal, and metacognitive. The categorisation is used for the sake of readability and is not as such included in the landscape of competences developed from this review. Likewise, for simplicity and analytical purposes, metacognition is a category by itself, but it must be acknowledged that metacognitive competences run across all other categories (Schraw 1998). Table 5 summarises the categories and subthemes.

3.3.1. Interpersonal relations

The social component is one of the central learning principles in PBL, and most activities in PBL take place in teams (Mihić and Završki 2017; Moliner et al. 2015). The majority of articles reported positive development of students' teamwork skills and competences in pre- and posttests across all variations in learning activities. In one study, students reported improvements in teamwork skills when compared to traditional lecturing (Macho-Stadler and Jesús Elejalde-García 2013). Comparison of cohorts of students engaging in PBL activities and lecture-based teaching also showed an increase in students' perceived competence development in teamwork (Rodriguez et al. 2015; Williams and Hin 2017). In one article, however, the authors found no statistically significant difference in students' perceived levels before and after the PBL course (Božić et al. 2018). Lutsenko (2018) found that students' satisfaction with group work decreases as group size increases and results in an amplified sense of uncertainty. In order to mitigate emerging impediments and raise awareness of mutual interdependence and attributes of working in teams, it has been argued that teamwork should be scaffolded in the beginning of a course (Murzi et al. 2020; Vidic 2008).

Table 4. Generic competences or skills assessed in the selected literature.

Reference	Communication	Creativity	Critical thinking	Information retrieval	Metacognition	Navigating ambiguity	Planning and time management	Project management	Problem-solving	Self-directed learning	Self-efficacy	Self-regulation	Systems thinking	Teamwork
Beagon, Niall, and Ní Fhloinn (2019)	x							x		x				x
Božić et al. (2018)	x	x				x			x				x	x
Downing, Ning, and Shin (2011)					x	x						x		x
Fain, Wagner, and Vukasinovic (2016)	x						x	x						x
Fini and Mellat-Parast (2012)	x										x			x
Helmi, Mohd-Yusof, and Phang (2016)					x				x					x
Jacques (2017)														x
Kadir et al. (2016)									x					
Klegeris et al. (2017)									x					
Lutsenko (2018)	x							x		x				x
Macho-Stadler and Jesús Elejalde-García (2013)	x													x
Mekovec, Anicic, and Arbanas (2018)	x	x	x	x		x	x	x	x	x	x	x		x
Mgangira (2003)			x											x
Mihić and Završki (2017)				x										x
Moliner et al. (2015)	x			x		x		x						x
Murzi et al. (2020)	x													x
Necchi et al. (2020)	x							x						x
Overton and Randles (2015)	x								x					x
Perez-Martinez et al. (2010)							x							x
Ragonis, Hazzan, and Har-Shai (2020)	x	x					x	x		x	x			x
Riis et al. (2017)										x				x

(*Continued*)

Table 4. Continued.

Reference	Communication	Creativity	Critical thinking	Information retrieval	Metacognition	Navigating ambiguity	Planning and time management	Project management	Problem-solving	Self-directed learning	Self-efficacy	Self-regulation	Systems thinking	Teamwork
Rodriguez et al. (2015)	x							x	x					x
Rodríguez Montequín et al. (2013)									x					x
Terrón-López et al. (2017)										x				x
Vidic (2008)						x			x					x
Williams and Handa (2016)	x			x			x	x						x
Williams and Hin (2017)	x													x
Zou and Mickleborough (2015)									x					x

Table 5. Categories and themes found in the literature.

Category	Included subthemes (skills or competence domains)
Interpersonal competences	Teamwork
	Communication
Problem-oriented competences	Problem-solving
	Information retrieval
	Critical thinking
	Creativity
	System thinking
Project-oriented competences	Project management
	Planning and time management
metacognitive competences	Metacognition
	Self-directed learning
	Self-regulation
	Navigating ambiguity

Across contexts, authors found positive effects of PBL for teamwork skills and competences, albeit with different emphasis on explaining the concepts used. Murzi et al. (2020) presented a teamwork model utilising seven attributes covering both professional and interpersonal dimensions that both influenced the internal effectivity of a team and the effectiveness in meeting external requirements: common purpose and main objective, clearly defined goals, interpersonal trust and mutual respect, clarity in roles and task assignments, mature communication, productive conflict resolution, and accountable interdependence between team members (276). Each of the attributes was promoted by different activities and supervision and part of the pre- and posttests of team assessment. This can be attributed to the research topic of Murzi et al. (2020), particularly the explicit goal of measuring the impact of teamwork model.

A teamwork model comprised of different elements was presented in Necchi et al. (2020), where each one of four dimensions – identity, communication, execution, and regulation – were coupled with suitable learning activities, components, and identified elements were evaluated using rubrics during a final design project using challenge based learning initiatives. Pre- and postevaluation of rubrics revealed a perceived improvement in execution, consisting of planning, decision-making, task performance, and follow-up. The authors found improvements across all four dimensions and that assessment measures and activities improved results and preparation for the labour market. Similar details were provided in items given by Fain, Wagner, and Vukasinovic (2016), where perceptions of teamwork consisted of active listening, appropriate behaviours among team members, displaying assertiveness when exchanging ideas with team members, and how teamwork contributes to the outcomes of a project (55). This was also reported in qualitative interviews with students where a student highlighted interpersonal accountability and communication as a means of keeping members updated and apace with the project (Terrón-López et al. 2017).

However, conceptions of teamwork are not always explicitly defined prior to an intervention. In the inductive approach by Beagon, Niall, and Ní Fhloinn (2019), no initial definition of teamwork was presented, but in students' reflective writings, communication, contributions by all members, creation of social bonds and perceived interdependence were elements contributing to a positive team and learning experience.

Communication is an overlapping topic and covers both written and oral presentations and mature communication to mitigate potential conflicts or solve emerging ones. As noted above, communication is an integral part of fruitful teamwork (Beagon, Niall, and Ní Fhloinn 2019; Murzi et al. 2020; Rodriguez et al. 2015). Students perceive an increase in their skills and competences in oral presentations (Beagon, Niall, and Ní Fhloinn 2019; Božić et al. 2018). Rodriguez et al. (2015) found a statistically significant difference in oral communication between PBL students and a control group but results in written communication showed no significant difference. However, in another study (Lutsenko, 2018), students reported increased levels of confidence in their writing after completing a course with PBL.

Conceptualizations of communication range from instrumental transmissions of results to laymen and professionals (Beagon, Niall, and Ní Fhloinn 2019; Jacques 2017; Lutsenko, 2018) to interpersonal perspectives of effective communication when working in teams (Lutsenko, 2018) and mature communication and conflict management (Murzi et al. 2020). While the term 'effectiveness' lacks qualification, mature communication refers to students' abilities to communicate reasoned ideas clearly and concisely and listen actively without interrupting. Furthermore, it is part of building and sustaining a psychological safety characterised by trust and mutual respect (Murzi et al. 2020). Conclusively, few articles defined examples of communicative utterances in situ and how this conceptualisation aligns with assessment strategies for measuring students' development.

3.3.2. Problem-oriented competences

Generic problem-solving skills or competences are considered yet another positive outcome of PBL. Problem-solving concerns both collaborative and critical aspects. The ability to identify and define suitable problems is central to variations of PBL and aligns with contemporary challenges faced by engineers (Zou and Mickleborough 2015). In a study comparing generic problem-solving skills across four educational programs, Klegeris et al. (2017) found improvements in scores for problem-solving skills for students enrolled in the only program practicing a mixture of traditional lectures and PBL activities. To measure potential differences, the authors used questions developed by PISA and intended to capture multiple aspects of problem-solving, such as design, troubleshooting, and system analysis (Klegeris et al. 2017, 75). Kadir et al. (2016) conducted a comparable study between two cohorts of PBL and non-PBL students and found the PBL practice to be more conducive to problem-solving. The development was measured by a pre- and posttest administered to students, and the accuracy and quality of solutions using rubrics determined the scores.

Emerging technologies and subsequent information sources have also resulted in an increase in available information, making the need for rote memorisation less prevalent. Rather, retrieval and application of information are important skills and competences (Mihić and Završki 2017; Moliner et al. 2015). Students also perceive information retrieval skills as important transferable skills (Williams and Handa 2016), and according to Mihić and Završki (2017), surveys have shown that students perceive that PBL fosters improvements in information retrieval. The same was reported by Moliner et al. (2015), who found that projects help students acquire skills in searching, managing, and summarising information. However, there was little reference to skilful or competent application of knowledge in practice.

Critical thinking is one of the distinctive characteristics of PBL, and according to Mihić and Završki (2017), it is one of the higher-order thinking skills that students must develop in order to identify, define, and solve a problem. In a survey conducted after PBL activities, students mostly agreed that the project helped them to develop critical thinking (Mihić and Završki 2017, 1745). Similar to previous sections, the conception of critical thinking and what is meant more practically is needed to apply this way of thinking to a problem-solving context.

Creativity is tightly connected to presenting and generating new ideas to solve challenging problems in a project setting. In tests conducted before and after a PBL course, students perceived PBL to be conducive to developing competences to generate new ideas when trying to find a solution to an ill-structured problem (Božić et al. 2018, 1586). Similar results were reported by Moliner et al. (2015), where a majority of students in a survey concerning cross-curricular skills agreed that they had developed their creative skills (131). While PBL seems to foster skills or competences to solve problems creatively, we again have found a lack of descriptions of the practical conditions surrounding the enactment of being creative.

While these themes can be differentiated from an analytical perspective, Helmi, Mohd-Yusof, and Phang (2016) argued that in collaborative environment problem-solving, teamwork and students' problem-solving assets are constituent parts of engineering problem-solving skills, and an enhancement of the latter will require improvements in all the former. They conducted their study during a collaborative PBL (CPBL) course in chemical engineering and found that students perceived

improvements in their problem-solving processes, problem-solving assets, and teamwork after the CPBL intervention. More prudently, Helmi, Mohd-Yusof, and Phang (2016) highlighted a holistic perspective of pivotal elements in collaborative problem-solving, buttressing the social dimension of engineering practice also emphasised by Trevelyan (2010), showcasing how social interactions influence potential outcomes of a problem-solving process.

3.3.3. Project management

Project management covers the collective effort by teams to manage time and tasks accordingly to meet a set of requirements. In the selected literature, two approaches to applying PBL for developing project management skills and competences were found: one concerned the use of PBL to scaffold other experiments not directly related to PBL (Moliner et al. 2015; Rodriguez et al. 2015), and the other revolved around the basic principle of project division in an authentic problem (Beagon, Niall, and Ní Fhloinn 2019; Lutsenko 2018; Williams and Handa 2016). Rodríguez Montequín et al. (2013) used PBL as a pedagogical approach in project management courses to scaffold other experiments to determine whether the Meyers-Briggs Type Indicator (MBTI) can be used to form groups and increase performance based on MBTI categories (Rodríguez Montequín et al. 2013). Lutsenko (2018) used PBL specifically to scaffold generic competence development in a management course, and PBL was found to be fruitful for developing competences in project management. Beagon, Niall, and Ní Fhloinn (2019) also found improvements in project management skills. However, due to a role assignment at the beginning of the project, only one team member was responsible for project management, thus limiting the direct development of skills.

Overton and Randles (2015) emphasised planning activities that act as challenges for students to mimic real-world problem-solving, where context and scope change over time. Beagon, Niall, and Ní Fhloinn (2019) also found an interdependence of various systems, where potential solutions to a given problem must meet requirements found in the social environment that sets the stage for the initial problem. According to Božić et al. (2018), systems thinking can be taken literally as the concept concerns an understanding of constituent parts of a whole electronic system. Few articles mentioned aspects that appear to be generic for problem-solving, such as being able to plan stages of problem-solving (Rodriguez et al. 2015), design, and systems thinking (Klegeris et al. 2017). In other studies, problem-solving was presented as primarily a professional endeavour (Kadir et al. 2016) to equip students with problem-solving skills that enable them to find a solution regardless of the specifics of a problem (Lutsenko, 2018).

Planning and management are described in terms of individual personal traits related to study behaviour. Perez-Martinez et al. (2010) expressed competences in planning and management of time as strategies relating to individual study behaviour rather than managing a team of peers. Comparing answers from two groups of students participating in collaborative learning (CL) and PBL, Perez-Martinez et al. (2010) found no difference between means reported at the beginning and at the end of the semester. Williams and Handa (2016) found that PBL fosters individual time management skills because of shared responsibility between team members.

3.3.4. Metacognition

According to Downing, Ning, and Shin (2011) metacognition is often characterised as thinking about thinking but included in this metathinking is also the ability to reflect and analyze thought and respond accordingly, and to transfer what is learned to practice. The authors argued that PBL in theory at least ought to foster metacognitive developments due to the experiential aspects activating prior knowledge and monitoring processes of collaborative problem-solving. Still, according Downing, Ning, and Shin (2011), metacognition is a less researched topic in PBL outside of medicine. The authors measured undergraduates' metacognitive development over a 15-month time span in three areas of strategic learning: skill, will, and self-regulation. They compared students in courses based on 'distinctly non-PBL' and PBL approaches (59) and found drastic changes between the entry scores and those from the interim test after 15 months. Students who experienced the PBL

curriculum scored significantly higher than their peers when assessing self-perceived metacognitive abilities (60).

Literature addressing self-directed learning (SDL) has mostly indicated a positive correlation between PBL and students' perceptions of the development of SDL skills and competences. According to Lutsenko (2018), SDL is the skill with the highest increase between the pre- and posttests. Students' answers in distributed surveys also showed that students perceived that PBL creates a learning environment conducive to fostering self-directed learning since they are responsible for sorting out their problems (Moliner et al. 2015). Similar to other themes found in this review, the conceptualisation and operationalisation of SDL have not been given further consideration. Self-efficacy is a term often coupled with SDL, and findings showed significant improvements in transport engineering students' self-efficacy compared to traditional lecturing by emotionally engaging them in real situations and emphasising personal responsibility for learning (Fini and Mellat-Parast. 2012).

Fostering tolerance for anxiety, ambiguity, and uncertainty is another aspect addressed in the literature. Ambiguity occurs when errors are shown in learning and application of knowledge. It applies to both instructors and students and concerns how students and instructors then skilfully overcome unforeseen issues (Božić et al. 2018) While these have been addressed in various forms and combinations, students' perceptions have been primarily positive. According to Božić et al. (2018), students perceived effects of PBL as positively developing their tolerance for ambiguity. Other authors found that students engaged in a PBL curriculum had lower levels of anxiety than peers in a non-PBL curriculum (Downing, Ning, and Shin 2011).

Moliner et al. (2015) used a different framework to capture students' perceived improvements in navigating ambiguity, particularly how students perceived their skills to adapt to new situations. The authors found PBL to be supportive in the development. While differences exists in the frameworks and terms used, little elaboration has been given to describe them in more detail. According to Downing, Ning, and Shin (2011), anxiety is part of a 'will' component related to motivation and attitude and is defined more broadly, in the LASSI framework used, as diligence, self-discipline, and willingness to successfully complete academic requirements. It is worth noting that between the two, motivation is oriented towards individual processes of learning and knowledge application, whereas attitude is inclined towards expected academic requirements. However, nurturing this development requires attentiveness to appropriate scaffolding and support within the PBL environment.

4. Conclusion

The literature review overwhelmingly portrays PBL as favouring a broad selection of generic competences based on students' perceptions of their competence development. The majority of studies included reported these results based on quantitative questionnaires or surveys pre- and postintervention in an existing practice (Figure 3).

Most articles assessed teamwork and communication in particular, while the rest by comparison was less researched. This is not surprising, as teamwork often characterises the social dimension of engineering practice (Jonassen, Strobel, and Lee 2006; Trevelyan 2010) and is a central organising principle in PBL (Hmelo-Silver 2004; Kolmos and De Graaff 2003). By the same token, it is not surprising to find that these topics are dominant. The social aspects of PBL and PjBL are perceived by students as fruitful for developing a variety of generic competences (Beagon, Niall, and Ní Fhloinn 2019; Fain, Wagner, and Vukasinovic 2016; Necchi et al. 2020).

Beagon, Niall, and Ní Fhloinn (2019) note that professional coordination requires abilities to influence and build relationships. Still, students judge their competences to do so too favourably before engaging in a project and more nuanced after. The practical experience can thus inform potential reflection relating to competence development. Following Biesta (2013), PBL and PjBL then afford events of subject-ness, situations in which uniqueness matters for the individual student, setting them slightly apart from their peers. Ragonis, Hazzan, and Har-Shai (2020)

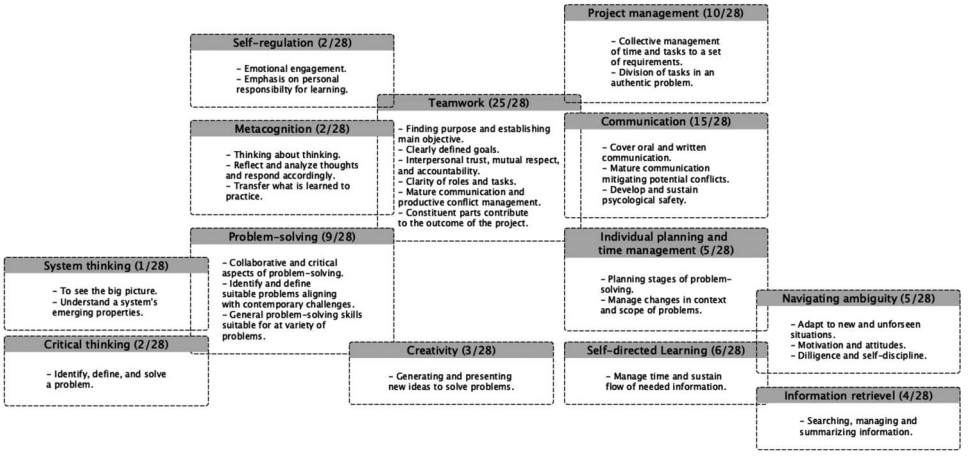

Figure 3. Themes and core aspects found in the reviewed literature.

provide a prudent example of team members adapting their positions when conducting project work (197). We hypothesise other pedagogical approaches of negotiated practices (Helmi, Mohd-Yusof, and Phang 2016) willing to risk events of subject-ness will support students' development of generic competences with the proper scaffolding, as suggested by Beagon, Niall, and Ní Fhloinn (2019).

Given the increased focus on lifelong learning as a remedy for disciplinary and societal change, it is remarkable to find critical thinking, metacognition, self-directed learning, self-efficacy, and self-regulation in so few articles. Furthermore, these competences have only received full attention in a few articles. One hypothesis is that concepts or terms are replaced over time, where conceptions of self-efficacy or self-regulation now are comparable to the personal traits found in the concept of phycological grit, which is also needed in a future of rapid technological changes. Practitioners thus need abilities to quickly adapt to evolving environments while still being able to solve emerging problems (Direito, Chance, and Malik 2021).

Generic skills and competences are seen as a remedy for an increasingly complex and interconnected world, but the movement towards including these is instrumental rather than critical and reflective. Nevertheless, even across the wide variety of PBL practices represented in this review, there appears to be a positive correlation between PBL and students' perceptions of generic competence development. Nonetheless, more research is needed.

5. Perspectives

The reports found in the selected literature predominantly depict positive perceptions by means of self-assessment across a variety of PBL activities and educational programs. While the findings are overwhelmingly in favour of PBL, there are caveats. This section discusses methodological considerations, our findings, and suggestions for further research.

The few results concerning metacognition may be attributed to the difficulty of measuring 'thinking about thinking' (Downing, Ning, and Shin 2011) and how metacognition can be represented as part of a learning process using semiotic resources as when assessing other skills or competences (Moon 1999). Research on students' perceptions of their competence development was mostly conducted with questionnaires, and consequently, the enactment of skills and competence in situ is missing. This results in a less detailed description of how students perceive and assess their own actions as skilful or competent. The inclusion of context-bound reflections of students' enactment could qualify how a subjective perception translates into action and informs action as part of an

experiential continuum (Dewey 2007). Here, the past, present, and future are intermeshed by past experience, enactment, and anticipation based on experience. Small interventions, such as those presented by Beagon, Niall, and Ní Fhloinn (2019) and Overton and Randles (2015), could provide disturbances to a habitual experiential continuum, allowing for fruitful variation within what could become a ritualised process.

Throughout the included articles, the relation between PBL and students' perceptions of generic skill and competence development was reported positively. This is unambiguous across all projects and problem types, even those where the PBL activities only comprised a minor part of an existing curriculum (Williams and Hin 2017). The add-on strategy thus proves a minor entry barrier for teaching staff aiming to develop variation in current teaching practices, and the findings thereby concur with other research (e.g. Chen, Kolmos, and Du 2020). However, it is not within the scope of this text to conclude that the same outcomes will be generated by PBL as an overarching pedagogical philosophy across all modes of organisation and practice. Rather, we hypothesise that distinct developments must be expected depending on the level of integration, from changes in existing courses to institution-wide and systematic approaches throughout an entire educational program (Chen, Kolmos, and Du 2020). This notion is buttressed by findings suggesting that educational context and subject matter to some extent determine which generic competences are developed. Fain, Wagner, and Vukasinovic (2016) compared engineering and marketing students and found differences regarding where emphasis is placed. Even though one might expect engineers to be mindful of an end user of a product, marketing students reported being more sensitive to specific target groups and more mindful of cultural considerations. Given the range of engineering education, it could be hypothesised that some divergence must be found in what kinds of generic competences are emphasised. Researching this aspect would require more attentiveness to descriptions of planned PBL interventions, subject matter, core aspects of a discipline, but also types of problems and pedagogical discourse (Bernstein 1996), and lastly local contexts.

Despite the mode of integration, research in generic skills or competence development is murky due to the mesh of conceptualisation depicting outcomes not confined to a specific discipline. This is also reflected in keywords used to search for and identify potential sources. This was noted in various articles, most prominently in a short review by Beagon, Niall, and Ní Fhloinn (2019, 852), who used various terms (skills, competence, and abilities, to name a few) before settling on technical skills. The murkiness is consistent with previous research results documenting the inconsistent use of terms and lack of a framework (Tahirsylaj and Sundberg 2020; Young and Chapman 2010).

The process of selecting relevant sources proved challenging when discerning articles evaluating PBL from those focused on generic skills or competence development. Often, the latter hinged on an evaluation of a PBL intervention in an existing practice. Few articles stood out in explicitly focusing on generic competences (Klegeris et al. 2017; Lutsenko, 2018; Murzi et al. 2020; Ragonis, Hazzan, and Har-Shai 2020), whereas others intertwined the generic aspect with socio-technical and professional skills and competences (Beagon, Niall, and Ní Fhloinn 2019; Božić et al. 2018). Research on generic skills and competences as the primary goals is needed to understand how activities and assessment in PBL can be aligned and scaffolded towards the intended learning outcomes. A critical point is if the results are caused by a novelty effect where students perceive improvements simply because they experience different activities than previously and are then directly asked about said changes. Longitudinal studies of generic competence development in engineering education practicing PBL could serve such a purpose.

5.1. Closing remarks

A central point to address is the lack of qualitative studies concerning students' articulation of their own competences. Ragonis, Hazzan, and Har-Shai (2020) stood out in this regard, with an emphasis on students' continued written reflections on their generic skill development.

In their review of definitions of competences for the twenty-first century, Tahirsylaj and Sundberg (2020) noted that the majority of sources are found in grey literature, particularly policy papers that are mostly left unquestioned as definitions find their way into academic research. The same is evident regarding the literature included in our review, where any discussion of including these generic competences in education is missing. One could question if such an inclusion becomes an imposition of values implicit in students who might aspire to what Giddens (1991) called ontological security rather than what is found in the project-based economy. It might also be argued that in order to study students' understanding of the competences they report on – to question the unquestioned – a shift in methodological approach is needed. Another issue is therefore to address the lack of qualitative studies found in this study. To paraphrase Polanyi (1972), developing a useful map of one's competences may require a more thorough and reflective articulation by students than what is possible in quantitative self-assessment.

Disclosure statement

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