International Journal of Engineering Education Vol. 38, No. 2, pp. 525–542, 2022
Printed in Great Britain

0949-149X/91 $3.00+0.00

Students' Views on Sources of Engineering Identity Development in a Collaborative PBL Environment*

JUEBEI CHEN
UCPBL in Engineering Science and Sustainability, Aalborg University, Aalborg, Denmark. E-mail: juebei@plan.aau.dk

XIANGYUN DU
UCPBL in Engineering Science and Sustainability, Aalborg University, Aalborg, Denmark. E-mail: xiangyun@qu.edu.qa

ANETTE KOLMOS
UCPBL in Engineering Science and Sustainability, Aalborg University, Aalborg, Denmark. E-mail: ak@plan.aau.dk

This study examines the interplay between individuals' subjective actions and interactions with the collaborative PBL (Project/problem-Based Learning) environment for engineering identity development in order to capture engineering students' perception of what is important for their professional identity development in a PBL curriculum. A conceptual understanding of sources from internal and external domains was reported. Internal sources included students' interest in specific engineering topics and interdisciplinary projects, intention to promote changes in society, and belief in their engineering competences. External sources in the PBL included opportunities to work on real-life problems and gain work-related experience, allowing them to explore how engineers work, understand engineers' responsibilities, and interact with members from engineering communities. The outcomes of this study highlight the ongoing interplay between internal and external sources, indicating that internal sources offer support for individual choices of professional socialization experience, which are also related to relational sources, contextual sources, and other external sources. Suggestions for future PBL curriculum design propose that engineering educators provide a learning environment that supports students' better use of multiple sources for development of their engineering identity.

Keywords: engineering identity; teamwork; project-based learning; internal sources; external sources

1. Introduction

Global advances in engineering are increasing the demand for professional engineers, and by extension the need for higher education institutions to produce engineering graduates who are highly qualified and career ready. Accordingly, tremendous efforts are being made by engineering programmes in many countries to improve the quality of learning and teaching they offer and to help students better prepare for future engineering jobs. In this context, engineering education scholarship has increasingly engaged with the importance of engineering identity, recent research results recognizing that students who see themselves as future engineers, and who are recognized as engineers by others, tend to have a better chance of succeeding upon entering the profession [1–3]. An engineering identity involving the subjectivity of individual values can be developed from interactions, negotiations, and involvement in engineering communities during professional socialization processes [4–6].

Existing scholarship has used a range of theoretical perspectives to examine diverse aspects of engineering identity, including the components of engineering identity [7, 8], the relationship between engineering identity and agentic choices [9], and the measurement of engineering identity [9, 11], which could be used to predict students' persistence in engineering fields [12]. Several studies have aimed to identify factors promoting students' engineering identity development, in particular the influence of the learning experience in universities, which is a significant component of the professional socialization process [13]. According to subject-centred sociocultural theory, engineering identity development is a dynamic process which influences and is influenced by the sociocultural and institutional contexts in which students are situated [14]. Thus, for further insight into the factors associated with engineering identity development in diverse learning contexts, it is important to explore how individual students make sense of their own learning experiences in terms of engineering identity development in a range of specific contexts. In this study, we focus on a d (Project/problem Based Learning) environment, in which students are exposed to real-world and complex problems and learn to work collaboratively as real engineers [2, 15]. In this context, this study aims to explore which sources are considered important by students in development their engineering identity in a PBL environment.

* Accepted 24 November 2021.

2. Literature Review

2.1 Conceptualizing Engineering Identity

Identity, as a complex entity, has been explored for over 60 years and has inspired many theories and models from diverse perspectives to understand what identity means and how identity is shaped [16–18]. According to the developmental psychological theory, identity is defined as "psychological manifestations of a category" [19, p. 247]. In social learning theory, identity is the sense of belonging and an experience of multi-membership in social communities [18, 20]. According to Markus and Wurf [21], identity is a self-related concept and a self-focused construct related to one's own unique background and experience. It is a combination of various identifications and developed through interactions with members of specific communities [20], among which professional identity is an important component. Professional identity has been defined as a "self-image which permits feelings of personal adequacy and satisfaction in the performance of the expected role" [22, p. 85]. Professional identity construction is the process through which individuals preparing to enter a profession develop their "attitudes, beliefs and standards which support the practitioner role" and identify themselves as members of the profession with a clear understanding of their professional responsibilities [23, p. 10]. In the field of engineering education, students' professional identity as engineers, or their engineering identity [24, p. 1241], is more than just their awareness of their professional engineering competences: it also incorporates their discourses towards identifying and developing as future engineers in practice [1, 10].

Engineering identity development has increasingly received research attention, taking theoretical frameworks from diverse interrelated social science research approaches [25–31]. Socialization theories, underlining engineering identity as "a feeling of fitting with the engineering group" [31, p. 7], highlight students' social and academic integration and participation in communities of practice through interactions with peers, instructors, and professionals [13]. In the process of professional socialization, individuals learn the values, norms, and expected behaviours that enable participation as an effective member of the profession [6]. They also adopt professional roles, referring to how individuals view and imagine themselves based on their interpretation of their position according to the expectations from the society and work environment [32]. From a sociocultural perspective, engineering identity development is also a process of interaction and negotiation between the social expectations regarding a specific professional role and the individual aptitudes needed to engage in this role [4]. In this regard, critical theories have also been adopted by scholars, taking into consideration students' diverse backgrounds – including gender, ethnicity, prior experiences, and social capital – in their engineering identity developing process [33, 34]. This theoretical approach suggests that engineering identity development is not only the reproduction of a certain engineering professional role, but also a sociocultural production process involving individual autonomy and social agency [3].

Following the subject-centred sociocultural approach to identity development [5], in the present study, we conceptualize engineering identity in a way that incorporates the subjectivity of individual values (including motivation, interest, efficacy, self-belief, etc.) and sociocultural sources (including interpersonal relations, environmental and institutional aspects). Consequently, engineering identity development is a process of agentic actions (through which students participate in achieving their identities) and interactions with social, cultural, and historical contexts. Such a process is dynamic, temporal, and context-bound, relating to social-cultural and environmental factors [3]. In particular, students' prior experiences and prevailing beliefs about learning to become an engineer can be core to their awareness of engineering identity development, in addition to their present participation in and future anticipation of the practices related to engineering. Taking such a conceptual perspective allows us to acknowledge and integrate the values of other theoretical perspectives in the examination of engineering identity development; for example, for students, the study of engineering is a process of developing an engineering identity in stages [27], not only through the mastery of content knowledge but also by having an active association with "doing" engineering to "become" engineers [35] by participating in the community of practice and professional socialization [26, 36]. Furthermore, engineering students negotiate multiple identities, and position their identity as engineers among other personal, professional, and social identities [25, 37].

2.2 Sources of Engineering Identity Development

A large body of literature has examined how engineering identity is conceptualized and constituted [2, 8, 38] and how it can be measured [9–11]. Recent literature has also reported a relationship between students' developing sense of identity as engineers and their agentic choices in engineering studies [39]; the connection between students' sense of engineering roles, their metacognitive beliefs, and their motivation in learning engineering [33]; and the prediction of students' persistence in engineering study through measurement of the strength of their role identities [12, 40]. Previous studies have also identified factors and sources influencing engineering identity development. Using developmental theory, Meyers et al. [27] examine how engineering students' sense of professional identity increases with the number of study years and suggest that career plans and recognition by others play a supportive role in their persistence. Direct or indirect exposure to professional engineering practices during the programme also provides crucial support for engineering identity development, as noted by several systematic reviews of engineering identity research [24, 35, 41]. In general, these review works agree that few published works identify factors influencing and shaping engineering identity development as the core of their study, and there is a need for future research in the field to further explore the complexity of engineering identity development in diverse social and cultural contexts and to report on the various relevant factors associated with engineering identity development that may create unique experiences. Several studies have also suggested the crucial role of the learning context in experiences of engineering identity development [35, 41]. In their systematic review, Rodriguez, Lu, and Bartlett [41] suggest that more scholarly attention is needed to understand identity from a student development perspective, to better grasp the dynamic nature of identity development within changing contexts, and to show how identity development may be value-driven and bounded by the "held identities and contexts in which students find themselves" (p. 261).

Previous literature has agreed on the significance of the university's role in connecting curriculum and work to support professional identity development [3, 26, 31, 36, 37], and provided suggestions for concrete pedagogical interventions, such as integrating professional practices in classrooms, creating a work-related environment, and providing professional socialization opportunities and engineering experiences. In addition, organizational learning studies deriving from social identity theory have examined the role of the team in the formation of an engineering identity. Analysing research on social identity in organizations through a social psychology lens, Charness and Chen, in their systematic review [42], suggest that teambuilding tasks and team context enhance a sense of group identity, effecting a social identity through a sense of shared purposes. Research taking a sociocultural approach also suggests that teamwork plays an influential role in supporting engineering identity development [31], in particular for under-represented social groups such as female students [15]. While a wide range of educational activities has been reported to have a positive effect on engineering identity development, further research is called for to examine the impact of structured activities in diverse sociocultural contexts [24, 41].

2.3 Sources for Engineering Identity Development in PBL

Several researchers have explored ways in which students' engineering identity develops in the PBL context [2, 15, 43]. In PBL, the experience of working as real engineers in PBL programmes could narrow the gap between universities and industry by helping students better to prepare for their professional career [15]. Compared with non-PBL students, engineering students with PBL experiences have shown significant improvements in performance and professional competence and better prepared themselves for engineering jobs [2]. Tan et al. [43] pointed out that PBL experience could enhance students' professional self-efficacy by providing them with opportunities to approach real-world problems, act in a professional way, and conduct collaborative learning. However, apart from the aspect of professional self-efficacy, the authors also mentioned that the influence of PBL on other components of engineering identity remains inconclusive because the effectiveness of PBL at a single course level is limited. Further exploration is needed to understand how systematic PBL implementation contributes to students' engineering identity development.

Taking its conceptual foundation from the subject-centred sociocultural approach to identity development [5], this study understands engineering identity by embracing the underlying individual psychological and cognitive characteristics and the indispensable role of social context. This standpoint allows us to address the above-mentioned need for further research into the sources of engineering identity development in diverse contexts. Therefore, the study focuses on exploring students' experiences, subjectivity, sense of belonging, agentic choices and actions, and engagement in practices of "doing" engineering and "becoming" an engineer [35]. In particular, we examine how individual students make sense of their experiences using internal and external sources, and their perspectives on the importance of those sources for achieving an engineering identity in a PBL context.

For a structured understanding of engineering identity development, our review of the existing literature incorporated sources reported by engineering educational studies in two domains, namely internal sources and external sources, shown in Table 1. These two domains are interrelated and influence one another, indicating that personal values offer support as sources for individual

Table 1. Sources for engineering identity development based on the literature review

Domains of sources	Themes among sources for engineering identity development from the literature
Internal sources	**Interest** • Interest in STEM knowledge (Godwin et al., 2013, 2016; Patrick et al., 2018; Prybutok et al., 2016) • Interest in engineering topics (Jones et al., 2010; Pierrakos et al., 2016) • Interest in solving problems (Anderson et al., 2010) • Interest in design and innovation (Fleming et al., 2013) **Intentions** • Get an engineering degree (Cass et al., 2018; Fleming et al., 2013; Meyers et al., 2012) • Make efforts towards expected learning outcomes (Cass et al., 2018; Godwin and Kirn, 2020; Lent and Hackett 1994) • Expected career development (Cass et al., 2018) **Competence beliefs** • Understand the competences needed by engineers (Fleming et al., 2013; Knight et al., 2013) • Feel confident in mastering engineering knowledge and skills (Dehing et al., 2013; Godwin, 2016) • Feel prepared for professional practice and engineering tasks (Dehing et al., 2013; Fleming et al., 2013; Godwin, 2016; Pierrakos et al., 2016) **Self-recognition** • See oneself as becoming an engineer (Carlone and Johnson, 2007; Godwin et al., 2013; Prybutok et al., 2016) • Feel included in the engineering community (Stevens et al., 2015; Tonso, 2015) • Understand expectations of engineering behaviours/performance (Dehing et al., 2013; Fleming et al., 2013)
External (relational and contextual) sources	**Professional training from the curriculum** • Chance to learn theoretical knowledge and technical skills (Chemers et al., 2011; Hatmaker, 2013) • Chance to apply theoretical knowledge in practice (Pierrakos et al., 2016) • Chance to solve complex problems (Du, 2006; Hatmaker, 2013) • Chance for self-directed learning and decision-making (Du et al., 2020; Meyers et al., 2012) • Take responsibility for the consequences of actions (Meyers et al., 2012) • Development of coping strategies for different situations (Curşeu and Pluut, 2013; Eliot and Turns, 2011) **Team environment** • Construct the meaning of experience together (Knight et al., 2013; Tonso, 2015) • Share knowledge and values (Knight et al., 2013; Meyers et al., 2012) • Peer support for developing professional competencies (Tonso, 2006, 2015) • Have an emotional atmosphere for feeling professional (Anderson et al., 2010; Fleming et al., 2013; Tonso, 2006, 2015) • Communicate using technical terminology (Meyers et al., 2012) • Experience group diversity (Eliot and Turns, 2011; Tonso, 2006) • Develop trust and friendship (Fleming et al., 2013; Knight et al., 2013) **Professional socialization through interactions in the professional community** • Develop membership of an engineering group (Knight et al., 2013) • Explore how engineers work (Chemers et al., 2011; Eliot and Turns, 2011) • Find a role model (Capobianco et al., 2012) • Gain internship and job positions (Eliot and Turns, 2011; Hatmaker, 2013) **Recognition from others** • Be recognized as future engineers by other people (peers, teachers, parents, professional engineers, etc.) (Dehing et al., 2013; Godwin et al., 2016; Patrick et al., 2018)

choices and actions to construct their professional socialization experience, which are always related to others and to context [44]. On the other hand, individuals' experiences and sense-making are objective in relation to how they interpret their relations to others and the community, and how the context provides opportunities for the support of engineering identity development. The lack of such sources, meanwhile, can constrain the development of an engineering identity.

2.3.1 Domain 1. Internal Sources

In engineering education, students' internal sources of engineering identity can be derived from their interests, intentions, competences, beliefs, self-recognition, and other intrinsic motivations to explore engineering topics and stay in the engineering field [10, 45]. In the early stages of students' study process, interest plays a key role in engineering identity formation, which means students are willing to enrol in engineering majors and have the curiosity to explore engineering problems [10]. For students with an interest in engineering, engineering topics are intriguing, and their desire to explore can motivate them to learn related knowledge and skills and perform well in engineering [33, 46].

With more experience in engineering practices and a better understanding of an engineer's work, in addition to an interest in engineering, students can also develop a greater intention to persist in their study and more specific aspirations in relation to future engineering careers (desire to solve problems, design and create new things, etc.) [47, 48].

Along with students' intrinsic motivations, self-efficacy is another vital component of identity. Self-efficacy describes the belief in and judgement of one's own competence to execute actions and task-specific behaviours [38]. In particular, competence beliefs about engineering performance, referring to "subject-related and broader than task-specific behaviors" [39, p. 5], reflect a student's preparation for engineering practice, their capability in terms of understanding engineering content, and their ability to conduct engineering tasks [10, 49, 50]. Engineering efficacy describes how students perceive their ability to achieve learning objectives, develop characteristics as engineers, and prepare to take on the responsibilities of engineering practices [26, 27]. In addition to professional knowledge and technical skills, students' belief in their abilities with respect to professional skills like teamwork, communication, and leadership are also important for their engineering identity, since engineers need to work together on projects [26].

Students' self-recognition is also an indispensable source for their engineering identity development. Self-recognition means seeing oneself as being on the way to becoming an engineer [7, 50]. Through positive self-recognition, students can understand the rules of engineering behaviours and perform in a professional way, which contributes to their feeling of being included in an engineering community [26, 49, 51].

2.3.2 Domain 2. External Sources

In order to capture PBL as a learning environment, we reviewed external sources reported in prior engineering identity studies as references. The external domain is concerned with how curricula and institutional policies support students' professional practice and identity development [44], including the access and support provided by the environment which enable students to participate in professional socialization activities to develop their engineering identity.

This domain breaks down into four key areas. Firstly, it includes sources from learning activities in universities, where students learn theoretical knowledge and technical skills, apply knowledge in practice. and learn coping strategies for a range of professional situations [52–54]. Particular learning contexts, such as PBL, with the guidance of specific learning objectives, provide students with opportunities to conduct self-directed learning, work in diverse teams, and solve complex real-life problems [15, 54].

Secondly, interaction with peers is also a type of relational source for engineering identity development in the external domain. Interaction with peers includes students' group collaborations, co-construction of knowledge and meaning from their experience, sharing of discourse and values, and development of interpersonal relationships with each other [26, 31]. These processes provide an emotional atmosphere which encourages feeling professional, especially when students communicate using technical terminology [3, 26, 27]. In particular, teamwork, regarded as being central to engineering work, involves aspects of problem-solving, communication, self-directed learning, and personal contribution, thereby providing a significant environment for engineering identity production [3, 55].

Thirdly, interaction with members of the engineering community, such as engineering faculty, clients, and professional engineers in the private sector, is an important source for students' engineering identity development. Interaction with faculty includes supervision processes and in-class and non-classroom interactions, all of which have been reported to have positive effects on setting students' career goals and role models [26]. Satisfaction with supervision can also influence a student's persistence in engineering and professional identity formation [56]. Interaction with stakeholders in the industry, as an important component of the professional socialization process, creates opportunities for work-related experiences, such as internships, competition events, voluntary activities, and project work [4, 54]. These work-related experiences expose students to real engineering environments and enhance their community involvement, helping students gain a clearer idea of the nature of engineering work, find role models, and identify career goals [4, 52].

Last but not least, recognition from others, or how students are viewed and treated as engineers by others [39], is an important external source. How students perceive other people's comments and views can influence how they see themselves, affecting the formation of their engineering identity [39, 49]. Recognition is not only important for a student's choice of engineering major in the early stages of their study, but also affects the later stages of their engineering study's experience and outcomes [12]. In particular, in a team setting, students have more opportunities to communicate with and receive comments from peers, supervisors, and even companies. In the process, students transfer those messages into their beliefs as to their role as future engineers [15, 43]. Students who fail to gain recognition of their capabilities from peers and faculty in teamwork and other engineering practices find it difficult to gain a sense of belonging and develop membership of engineering communities. Regardless of the level of their engineering knowledge, skills, and competences, students who receive less recognition from others have a higher tendency to leave the engineering field [43]. Thus, recognition by others is an indispensable source of students' self-identity as future engineers, especially during teamwork processes.

Table 2. Sample questions of the interview protocol

Domains	Sample questions
Internal sources	**Interest** • Are you interested in engineering? Please elaborate more on your interest. • What makes engineering interesting for you? **Intentions** • What drove you to choose engineering study? **Competence beliefs** • In your opinion, what skills or knowledge are important for engineers? How do you assess yourself in these aspects? **Self-recognition** • How do you understand the work of engineers? • Do you see yourself as a future engineer? Why?
External sources	**Professional training from the curriculum** • In your current study, what influences/enhances your motivation to learn engineering? • What kind of projects would make you feel more like an engineer? **Team environment** • In what way does teamwork contribute to/constrain your learning? • Based on those teamwork experiences, what factors do you think could influence your choice of future jobs? **Professional socialization through interactions in the professional community** • Did you have the chance to work with industry/companies on this project? If so, how do you think these interactions with companies influenced you? **Recognition from others** • How do you think you are seen as an engineering student by others – peers, family, supervisors, etc.? • How do others' comments affect your self-identification?

In sum, this study underlines the interplay between individual subjective actions in the development of identity and interactions with the sociocultural context, highlighting the intertwining of individual professional identity and practices with individual choices about action and engagement [44]. Based on the above review of the sources of engineering identity development reported in prior research, this study aims to explore how individual students perceive their access to sources for constructing their engineering identity in a PBL context in which teamwork is formally structured, and how they take action to utilize these sources to form professional engineering identities. In particular, the study is guided by the following research question:

What sources are considered important by students for the development of their engineering identity in a PBL context?

3. Methodology

3.1 Research Design and Research Context

A qualitative method was utilized in this study. Individual semi-structured interviews were conducted to explore how students perceived their internal and external sources of engineering identity development in a PBL context. This method enabled us to hear the stories and voices of individuals and investigate their common experiences [57]. We applied a model with internal and external sources developed from the literature review on engineering identity research. Based on the proposed model and PBL context, an interview protocol was designed, tested, and revised for three rounds through pilot interviews and group discussion with two experienced experts in PBL research and qualitative methods. Examples of the questions used are shown in Table 2. Emerging questions and follow-up questions were also asked in the interview to let students tell their own stories, enabling researchers to remain open-minded and obtain information on the participants' individual experiences in their particular contexts [58].

The study took place in the context of a leading engineering institution in Denmark. This institution has adopted a systematic PBL curriculum design as a core value across the entire university over the past four decades in order to train engineering talents with strong employability and transferable skills. Professional learning activities are designed following PBL principles, which include problem identification and analysis, teamwork and project organization, interdisciplinarity, and student-centred and self-directed learning [59]. In this PBL model, students are required to gain 30 European Credit Transfer System (ECTS) credits every semester, comprising 15 ECTS for projects and 15 ECTS credits for courses. The courses are designed to equip students with the professional knowledge and skills needed to finish the projects. Students have the chance to identify the direction/core problems of their project, experience interdisciplinary teamwork, solve real-life problems, and work with real clients or engineering companies. In PBL, students meet with each other every workday and have regular meetings with their supervisors; thus, students become the centre of learning and construct their own knowledge together, lecturers and supervisors playing supporting roles to facilitate the students' project work [60]. To assess students' learning outcomes, individual oral examinations, project reports, group presentations and peer assessment are used in this PBL model.

3.2 Research Participants and Data Collection

With the aim of recruiting engineering students with rich PBL experiences, we began our data gathering process by sending interview invitations (via email) to four PBL programmes within the university. In each programme, students from different engineering subjects formed small groups (three to six students) to carry out interdisciplinary projects. The study was limited to students in their third or fourth year of studying engineering, since senior students were reported as having higher levels of engineering identity because of their greater work-related and PBL experience in working as real engineers [15]. Following these invitations, 16 engineering students participated in the individual interviews, representing a range of programmes including energy engineering, civil engineering, computer engineering, biotechnology, and robotics (see Table 3 for a full list of participants and their programmes of study). For the sake of privacy protection, pseudonyms are used for all interviewees.

The data were collected in semi-structured, individual interviews, and every interview lasted 30–45 minutes. All interviews were conducted at the end of semesters, which enabled students to review the whole PBL process. Sixteen participants were invited to share their understanding of engineering work, review their project and teamwork processes, and reflect on how those experiences contributed to and/or constrained their engineering identity development and their future career plans.

3.3 Data Analysis

In the data analysis process, all of the interviews conducted in this study were transcribed and reviewed twice, accumulating 112 pages of transcripts. The thematic analysis method was used for the data analysis, which enabled us to gather and extract students' descriptions of sources for engineering identity development in a PBL environment as codes from the interview transcript [62]. Based on the two previously established domains, the initial codebook was first built upon the analysis of five information-rich transcripts and was revised through three rounds of open coding, which constituted a relatively stable frame for coding [61]. In the first round, according to the theoretical model, five themes were identified in the domain of internal sources, including interest, intention, competence beliefs, self-recognition, and self-reflection. Four themes were identified in the domain of external sources, including the curriculum, teamwork, interaction in the engineering community, and recognition from others. These themes were examined for conceptual overlap, after which the theme of "self-reflection" was deleted and the themes of "sources from curriculum" and "interaction in the engineering community" combined into one theme of "sources from PBL environment." The latter change was made because in systematic PBL programmes, learning activities for engineering practice and involvement in the engineering community comprise an important component of the curriculum, making the two concepts difficult to separate.

Table 3. Basic information on the participants

Name	**Country of origin**	**Gender**	**Year of engineering study**	**Subjects**	*Group size*
Daisy	Croatia	Female	3	Energy engineering	4
Emma	Bangladesh	Female	4	Biotechnology	6
Gary	France	Male	4	Robotics	6
George	China	Male	4	Civil engineering	3
Ivy	Denmark	Female	3	Energy engineering	4
Jack	Denmark	Male	3	Computer engineering	4
Joe	Nepal	Male	3	Automotive engineering	4
Mark	Denmark	Male	4	Energy engineering	3
Martin	Denmark	Male	3	Energy engineering	4
Michael	Pakistan	Male	3	Civil engineering	5
Morten	Denmark	Male	4	Civil engineering	4
Nathan	Denmark	Male	4	Energy engineering	6
Neil	Iran	Male	3	Computer engineering	4
Oliver	India	Male	4	Combustion engineering	3
Rachel	Hungary	Female	3	Energy engineering	4
Steven	Denmark	Male	4	Light design	3

After the first round of coding, all subthemes were revised for two rounds to check if they appropriately described the meaning of the text segments, as well as to reduce overlap further and collapse those subthemes into themes. At the end of this process, four themes remained in the individual domain (interest, intention, competence-belief, self-recognition), while in the domain of external sources, we arrived at a final set of three themes: the PBL environment, the teamwork environment, and recognition from others. A revised codebook based on these themes was used to analyse the remaining transcripts. All codes were then reviewed, revised, and categorized as subthemes of the themes in each domain. Based on the content of the interviews, both sources and constraints for engineering identity development described by the students were coded and reported in this study.

In qualitative research, researchers are regarded as "the primary instrument for data collection and data analysis" and are required to be "responsive and adaptive" [63, p. 5]. In this study, researchers with prior PBL experience and basic pedagogical knowledge were involved in daily journaling and self-monitoring during the data collection and analysis, so they were aware of any potential bias and influences from prior experiences [57]. In addition to individual reflections on possible bias, collaborative correctives were also involved to enhance the validity of the data analysis. During the coding process, research group discussions with two experienced experts in engineering education and PBL research were conducted frequently as auditing procedures. Codes were modified and refined through these auditing processes. In addition, a graduate student in higher education who has rich qualitative research experience was invited to serve as an external coder to code one part of the transcripts and discuss this with the lead coder over two rounds. The inter-rater reliability (IRR) for every theme were found to be between 82 per cent and 88 per cent in the second round of coding.

4. Findings

In this section, we illustrate which sources were important for students to develop engineering identity in a PBL context. Theory-driven themes (from the literature) and bottom-up subthemes (from the data) are reported in both the internal sources and external sources domains.

4.1 Internal Sources

We define internal sources for engineering identity development as those which are related to students' self-reported intrinsic motivations and beliefs about becoming engineers via the PBL experience. Four themes were established in this domain: interest, intention, competence beliefs, and self-recognition. Various bottom-up subthemes were identified from the data under each of these themes, including "develop interest in interdisciplinary projects" (interest), "gain work-related experience" (intention), "connect engineering with humanity and society" (competence beliefs), "know more about oneself" (self-recognition) and so on. Detailed information on the themes and subthemes from the qualitative analyses can be found in Table 4.

4.1.1 Interest

Within the theme of interest, 14 students mentioned the importance of interests in maths, physics, science, and engineering for choosing engineering study; three of these students had a family background in engineering. In addition to initial interest in STEM fields, PBL was pointed out by participants as an effective way to help them identify their specific interests or career directions to become engineers. Eleven students reported that they had identified their interest in specific engineering topics through project processes, as reported by Gary:

> "In this semester, we worked on an artificial intelligence project, which I think is really interesting and it was completely different from the previous projects. To me, that's pretty exciting, and I'd like to work more on this topic."

More than half the students mentioned their interest in solving problems and applying theories in practice. For those students, rising to challenges was an enjoyable process. For example, in Martin's case, problem-solving through teamwork was an enjoyable way to figure out how to put his own understanding into practice. In PBL, students were able to directly experience the link between their efforts and changes in the real world, giving them a sense of agency and enhancing their interest in engineering.

> "PBL makes engineering more interesting for me. With the group work and working on a project, what we need to think about is the question of how technical skills should be applied in the real world. It's very interesting, and it gives you a feeling that what you do is important."

Six students reported that their choice to study engineering was due to their interest in creating new things because, in their view, innovation is a significant component of engineers' work. Four students developed an interest in academic research through joining supervisors' engineering research projects, and one of them planned to apply for a PhD in a related area. Based on these data, the inductive subtheme "new interest in interdisciplinary projects" was identified. Through PBL, the

Table 4. Themes and subthemes in the domain of internal sources

Theme	Subtheme
Interest	Have an interest in STEM fields Develop interest in solving problems Enjoy being challenged* Identify interest in specific engineering topics* Have an interest in applying theories in practice* Have an interest in creating new things Develop interest in engineering academic research* Develop interest in interdisciplinary projects*
Intention	Promote changes in one's hometown* Gain work-related experience* Get an engineering degree
Competence beliefs	Develop project management skills Develop communication skills Develop teamwork skills Gain technical skills and knowledge Have confidence in one's performance in current study Ability to connect engineering with humanity and society* Develop leadership Ability to do interdisciplinary projects* Solve real-life problems Learn from failure and mistakes* Link theories with practice* Believe in one's ability to do well in engineering practice
Self-recognition	Believe oneself to be on the right path to becoming an engineer Feel included in the engineering community Know more about oneself* Understand requirements of engineering work Feel uncertainty about being an engineer in the future*

*Bottom-up subthemes were denoted with *; the others were established in the model based on the literature review. Shading in the table signifies constraints for engineering identity development.*

participants realized the importance of interdisciplinary abilities for engineers. As Steven said:

> "I'm trying to put perceptions of music and light together in my [lighting design] project. It's so interesting, and that transdisciplinary work is very powerful for creating new things. It makes me realize I'm able to do more than one kind of work. I'm also in other fields."

In Steven's case, his project involved music computing and lighting design, requiring him to learn and utilize knowledge of both music and lighting design. Through this project, he realized the power of interdisciplinarity for innovation as well as his potential to work across subjects, and he developed an interest in those interdisciplinary projects.

4.1.2 Intention

Students frequently spoke in interviews of their intention to become engineers. Bottom-up subthemes discovered from the qualitative data included "promote changes in one's hometown" and "gain work-related experience," which were mentioned with high frequency. In contrast, the theory-driven subtheme "get an engineering degree" was only mentioned by two students. This was because for most participants, as candidate engineers, gaining an engineering degree was the most basic requirement of their long-term intention to become an engineer. For example, in George's case, he chose the subject because of the intention to transfer the advanced technology that he learned in a developed country to his home country:

> "In my home country, we're weak in core technology research in the field of petroleum and gas. So, my ambition is to gain related knowledge here and contribute my efforts to promote development in my home country after graduation. That's why I have chosen this subject and direction."

Several other international students mentioned that they had deliberately applied to engineering programmes which implemented PBL in order to gain more work-related experience to be better prepared for future engineering work. As Daisy put it:

> "PBL is the reason I came here. It is really something else, the problem-based learning, because you actually deal with tangible projects, and you actually see what components you need to think about in real life. That is what engineers actually do. I think that's great practice for future work in a company."

As shown in Daisy's comment, from her perspective, engineering work is conducting projects, and PBL can provide a similar environment. Thus, she applied for the current engineering programme with a PBL curriculum in order to gain more work-related experience.

4.1.3 Competence Beliefs

As part of the process of professional socialization at the university, it is important to enable students to review their learning outcomes and develop competence beliefs, which could become significant internal sources for their professional identity development. Within this theme, students expressed their perspectives on the necessary skills for engineers and self-assessed their levels of those engineering skills in a PBL context. Frequently discussed topics included learning outcomes, such as the improvement of project management skills (mentioned by 14 students), communication skills (14 students), teamwork skills (12 students), technical skills and knowledge (12 students), and problem-solving skills (8 students). Half the students explained that they had learned how to apply theories in practice and connect engineering with other subjects, such as the humanities and social sciences, through PBL. Nine students reported an improvement in their leadership skills, as mentioned by Gary:

> "I try to stay aware of what everyone is actually doing and whether it is contributing to the end goal, because I think, as engineers, especially our most motivated students, we sometimes really get caught up in details because we want to get it perfect. . . So, I have this overview of everything and it's my duty to encourage every teammate to work actively and move towards our goals."

As the team leader, he always had an overview of everyone's work, monitored the direction of their project's progress, and inspired teammates to use their initiative to realize the team's goals.

Subthemes related to students' self-efficacy were also reported. Eleven students expressed confidence in their performance as students, and seven showed belief in their ability to do well in future engineering practice.

> "PBL brings us new technology, new theory, and new ideas. We are not surface learning; we go in very deep. Because I've had that experience, I'm confident that I can do well in all tasks. I believe that after my training, I'll feel like I'm ready for work."

Emma pointed out that, in PBL, she can conduct deep learning and gain cutting-edge technology and skills, which enhances her confidence in accomplishing engineering tasks and feeling prepared for future jobs.

Eight students mentioned that they grew unafraid of failure and learned from mistakes through PBL experiences because they believe that experiencing and learning from mistakes is an unavoidable process for engineers to be able to solve new problems. From their perspectives, failure can help them to develop different solutions and identify appropriate ways to solve problems.

4.1.4 Self-Recognition

In general, the subthemes identified under "self-recognition" align with those expected in the proposed framework based on the literature review. In this theme, 13 students reported their belief that they were on track toward engineering careers; 13 felt included in the engineering community in teamwork and PBL processes; 12 felt that PBL enhanced their awareness of their own strengths and areas in which they needed to improve; and seven reported the development of their understanding of the requirements of professional behaviours. Neil indicated that solving problems in a group gave him a sense of achievement. In encountering new issues, he began to know how to deal with new problems in professional ways, which made him feel like an engineer:

> "That is really important and helpful, because for the first time in my life, I'm really working closely with a small group of people, which resembles my future work, working in a company. We started from zero and we're working a project that none of us had really encountered before, so we need to learn a lot and to apply the knowledge that we don't even have yet. I think that helps with my ability to confront new problems, just like engineers do."

However, constraints on students' engineering identity development also emerged from the data. Three students still felt uncertain about becoming engineers in the future; these individuals are highlighted with light grey shading in Table 3. The feeling of uncertainty persists in engineering fields due to limited experience in engineering work and uncertain industry trends.

> "Actually, now that I know more about this topic, I feel uncertain of my career direction. The project I'm working on now – how to extend the service life of the combustion engine – does not attract much attention in my home country. If I go back home, it might be hard to find a related job as an engineer, unless I choose to stay in Denmark."

In this response, Oliver, an international student, explained that due to the limited work positions in his home country in his specific field, he felt uncertain about his future career and believed he would not be able to persist in the current field if he went back home.

4.2 External Sources

External sources of students' engineering identity development include opportunities and support provided by the environment to participate in professional socialization activities, including contextual sources (opportunities from the environ-

Table 5. Themes and subthemes in the domain of external sources

Theme	Subtheme
PBL environment	Have work-related experience in PBL* Have the chance to improve engineering competences Explore how engineers work Have the chance to conduct self-directed learning Have more interactions with supervisors* Change ways of expression for different audiences* Have the chance to work with companies* Have opportunities for internship Take active responsibility Find role models Learn to listen and understand clients' demands* Lack feedback and instructions in PBL* Unable to adapt to interdisciplinary learning* Experience tough negotiation between stakeholders* Unable to adapt to self-directed learning* Have no chance with a company* Meet difficulties in dealing with criticism* Have limited freedom to choose project directions*
Teamwork environment	Experience group diversity Share the same goals* Have peer support for better learning Share knowledge and values Learn to look at things from others' perspectives* Construct the meaning of experience together Enjoy a good teamwork culture* Have an emotional atmosphere for feeling professional Develop trust and friendship Experience conflict or disagreement among team members* Experience ineffective communication* Prefer jobs with less teamwork*
Recognitions from others	Get recognition from faculty as good engineering students Get recognition from peers as smart students Get recognition from the industry as future engineers Get recognition from parents

*Bottom-up subthemes were denoted with *, while the others were established in the model based on the literature review. Shading in the table signifies constraints or challenges for engineering identity development.*

ment) and relational sources (interactions with stakeholders in professional communities). Unlike the proposed source model developed from the literature, in this domain, we merged two themes: "professional training from the curriculum" and "interactions in professional community." This is because, in a PBL context, students are required to experience professional practice by solving real-life problems and thus have more opportunities to interact with other members in engineering communities than in a traditional learning context. Therefore, in this study, curriculum and professional interactions are closely linked through the PBL environment, and we used the theme "sources from PBL environment" to cover both.

Through thematic analysis, three themes of external sources for engineering identity development were coded: sources from the PBL environment, sources from the teamwork environment, and recognition from others. However, constraints for engineering identity development from the environment were also reported by students, such as "transferring from traditional learning to self-directed learning," "conflict in project teams," "dealing with free riders in teams," "ineffective communication", "limited freedom", and "limited chance to work with company/industry". Those challenges and constraints have the potential to influence students' learning experiences and learning outcomes in PBL, and even have a negative influence on the development of their engineering identity. Subthemes of difficulties and constraints are highlighted with light grey shading in Table 5.

4.2.1 PBL Environment

Past studies have identified PBL as an effective way to help engineering students develop a professional identity by simulating the environment in which engineers work and exposing students to real-life problems [2, 15]. In this study, among the 16 participants, 14 students considered PBL an important contextual source of work-related experience, which made them more prepared for future engineering jobs. Thirteen mentioned the opportunities offered by the PBL environment to develop engineering competences, especially practical skills, critical thinking, interdisciplinary skills and so on. As Joe said:

> "PBL helps me prepare for work and everything. It not only improves my professional skills, but also broadens my horizons in engineering, because before I was

only engaged in theoretical learning, and I only saw one solution. But now when I'm engaged in practice, I can see many solutions, considering all aspects of cost, effectiveness, efficiency, or if it is an eco-friendly product."

In a PBL context, students emphasized the importance of having opportunities to communicate and interact with supervisors, facilitators, engineers, and other members of the engineering community. High levels of involvement in professional communities enabled them to explore how engineers work (as described by 12 students), collaborate with companies or industry (seven students), and gain opportunities for internships (five students). Ten students reported that working with a variety of stakeholders gave them the chance to learn different ways of communicating with audiences from diverse backgrounds. Moreover, exposure to engineering communities gave students the chance to find role models, which could inspire their passion for engineering and motivate them to become the engineer they want to be [26]. For example, in this study, Daisy mentioned that she considered her supervisor, who was an outstanding female engineer with rich knowledge and diverse experience, an inspiring role model.

"Our supervisor (an engineer from a company), she's actually a role model for me. She finished mechanical [engineering], electrical engineering, and law school. So, she has great interdisciplinary skills and knows a lot of different things. I would like to move in that direction, just like her."

However, according to students' interviews, lacking following sources could become constraints for their engineering identity development, including "lack feedback and instructions," "have no chance with a company" and "have limited freedom to choose project directions." One student also reported that he encountered difficulties in dealing with criticism, which negatively influenced his confidence in his professional abilities. One of the main challenges is the lack of feedback and instructions, especially for those students who had no PBL experience and in the situation of Covid quarantine, as reported by Emma. The Covid quarantine influenced the communication between Emma and her supervisor, resulting in a lack of instructions on her project. Moreover, as a student who needs to transfer from traditional learning to self-directed learning, she pointed out that the current formative assessment methods do not provide enough feedback on her performance during the project processes, and she preferred more daily quizzes and exams to help her identify her weak areas of knowledge.

"I meet difficulties transferring from learning through lectures to PBL. Sometimes I have no direction and I do not know what to do. Since the university has been in lockdown, we haven't seen my supervisor for a long time. . . Actually, I like daily quizzes and exams in the middle of the semester. They give you a score, and then you know your weaknesses. But in PBL, they would not grade your performance in each process, but only have an oral presentation at the end, which makes me have no idea of how I did in project processes. You need to be responsible for yourself during the processes, otherwise you will fail to pass the final presentation."

Another challenge is that students "experience tough negotiation between stakeholders," which was mentioned by two participants. Those who had opportunities to work with companies faced gaps between companies' and clients' demands and their team goals. One student even changed the topic of their project due to the mismatch between their expectations and the company's requirements. Sometimes, students received contradictory comments from their supervisors and engineers in companies, because the former had more of an academic perspective on new engineering subjects, while engineers who had been working for companies for decades might have a more traditional engineering paradigm. While PBL brought the chance to work for real clients, it also created challenges of effective communication with clients, who might have a range of professional backgrounds and hold different perspectives on engineering.

Mark: "Sometimes it doesn't work as well as we expected. We need to spend a lot of time explaining our thoughts, and feedback from supervisors, companies, and clients might be totally different. It's hard to keep a balance between many stakeholders and satisfy everyone. We must learn to negotiate and compromise . . . I guess engineers might face the same issues, so it's good to have this experience."

George: "The biggest challenge is communication with companies, because we have different perspectives. We focus on the academic level, but we cannot get full access to all the data we need from the company. We have to negotiate, compromise, and explain a lot of things, which costs us much effort and time. . . I have to say engineering work not only needs technology, but also requires high interpersonal skills."

According to Mark and George, their team devoted a lot of their time to explaining their opinions and designs to their clients because they had different standpoints. Another student mentioned that their client always insisted on his opinions, so they had to compromise and fulfil the client's expectations, even though they had proposed an easier and cheaper solution. Working with a company, students had to negotiate with different stakeholders, learn to compromise, and began to realize the difficulties of engineering work. On the other hand, this subtheme also offered an opportunity for students' engineering identity development, since students could learn to look at things from technical perspectives and have a complex understanding of engineering work.

4.2.2 Teamwork Environment

The subtheme relating to the teamwork environment reported by the most students is the "chance to experience group diversity." With different teams to work in, students realized that it was important for engineers to be able to work with different people with different ways of doing things, because they might not always have the freedom to choose work partners in their careers. As reported by Joe, working on projects in different groups every semester helped engineering students develop awareness, confidence, and skills to deal with issues in complex, real-work situations.

> "From what I've seen and heard, engineers always work in groups of people. I think whenever you're in a big company, you don't always get to pick who you want to be in a group with. Being able to work with people who you're happy with is good. But being able to work with people that you dislike is also important. We have experienced a lot and I have the confidence to deal with different situations in future work."

Teamwork also provided students with opportunities to identify shared goals (mentioned by ten students), have peer support to improve their learning (nine students), and share knowledge and values (eight students). Learning is not a lonely process for students and engineers. In PBL, students had opportunities to conduct self-directed learning, explore knowledge, and construct the meaning of their experience together, thereby potentially enhancing their ownership of knowledge. Several students reported that they had enjoyed the peer support that came with working in a team, and the fact that PBL created an emotional atmosphere for students to feel professional by working as engineers on real-world problems and using professional terms. When encountering issues, students also mentioned that they could get more insights or different angles on a problem from team members and learn to look at things from others' perspectives, as explained by Daisy:

> "I think we all really learn from each other. You learn from others' experience, past knowledge, skills, and perspectives, which makes you go further than when you learn alone. . . I guess it's same for engineers. Teamwork is the key."

However, the qualitative data also revealed external constraints. Six students reported they experienced conflicts and disagreement with team members on project direction, usage of materials, possible ways of solving problems, and individual performance in the teamwork process. Those students who acted in different ways, including overachievers, might face the peer pressure of being average to maintain an equal social identity and team membership [64]. Moreover, a few students reported ineffective communication, which they felt might influence their choice of future job type. Two students said that they would prefer their future job to involve less teamwork because they found individual work more effective and flexible.

> "It's interesting to try it [teamwork]. I'm happy I can try and learn how to work in a team. But the thing is, I still like working alone. I know it's not good, but it's true. . . I'm not good at teamwork, and I don't really like to speak in front of people. . . Sometimes our discussion is not very productive. . . I will consider more theoretical jobs or working in a lab, but with less teamwork."

Here, Rachel indicates that although this teamwork experience was a meaningful experience for her, she does not think of herself as being good at teamwork. She intends to pursue an independent job focusing on theoretical work and feels that she will improve her future productivity by seeking out jobs with less teamwork. In the interview, Rachel also mentioned that she was considering switching to physics, which involved more theoretical work. Even though Rachel had not decided whether to stay in engineering, lack of self-confidence and skills in teamwork might be a constraint for her engineering identity development.

4.2.3 Recognition From Others

In this theme, we found that recognition from peers, engineering faculty, parents, and engineers from industry or companies is a positive external source which can help students develop membership of engineering communities and enhance their engineering identity, in line with the findings from the literature. Through interaction with team members and supervisors on their projects, students were able to get feedback and be recognized by the people around them for their intelligence and engineering skills, which inspired their confidence to become engineers and encouraged them to engage more actively in teamwork processes. Students who had the chance to work with real engineers in companies or industry became more familiar with engineers' ways of thinking and working. Positive comments from professionals in these contexts could help them to develop their identity as future engineers, better prepare them for engineering jobs, or even offer the chance to enter the profession.

> "The company owners gave us very positive feedback – not just for me, they complimented the whole group, saying things such as 'you all got the points and did well in the project.' Then I know I'm doing well, and

> that pushes me to move forward for more compliments . . . And after that project, I got a chance to intern with this construction company . . . I believe it's a good start for my career."

When asked how they thought they were seen as engineering students by others, Michael mentioned compliments from the company he worked with. He said those positive comments enhanced his confidence and motivated him to move forward to perform better. Because of his good performance, he got the chance of an internship with the company, and he believed it was a good start for his career as an engineer.

5. Discussion

Within a subject-centred sociocultural approach, professional identity is seen as self-developed based on the individual's values and interactions with the environment [5]. Following this perspective, in this study, we explored how individual students perceive the importance of, and their access to, internal and external sources from the PBL environment to construct their engineering identity. PBL, as a contextual learning method, was found to enable students to improve their engineering competences, find new interests, understand engineers' responsibilities, and develop an initial plan for career development through working on real-life problems and accumulating work-related experience.

Our findings of some sources from a PBL context for engineering identity development context were in consonance with literature on engineering students' identity construction in other types of learning environment [3, 25–27]. Specifically, in the domain of internal sources, the importance of having interests in the STEM field and creating new things, having competence beliefs in one's professional knowledge and skills, and self-recognition as engineers was emphasized by students. More than half of the participants reported feelings of being included in the engineering community and believed that they were on the right path to becoming engineers; these feelings represent an important internal source to inspire their persistence in the engineering field [3, 51]. For external sources, chances of internship, conducting teamwork, and communicating with people from diverse backgrounds were reported as important sources for students in the PBL environment, which is in line with prior studies [4, 54]. In addition, through working together to solve problems, students learned how engineers work and realized the importance of teamwork for engineers. They experienced constructing knowledge together, sharing goals and values, and supporting each other to solve problems in professional ways, which created an emotional atmosphere conducive to feeling professional and included in their teams [3]. Higher social engagement in the engineering community enabled students to find their role model [26], especially female engineering students. Prior studies have pointed out that more female engineers and females in the field of engineering education could be a positive influence on female engineering students and help them to persist in engineering fields [65]. By being involved in the engineering community, the students were able to gain recognition from peers, academic staff, and engineers, which helped them to build self-confidence and contributed to their engineering identity development [49, 51].

In addition, bottom-up sources were identified based on the empirical data of this study, especially related to the PBL environment. For example, in the domain of internal sources, by exploring solutions to complex real-life problems, students reported that they developed an interest in specific engineering topics and expressed their wish to work in those areas in the future. In particular, students' interest in interdisciplinary projects was identified as a bottom-up internal source of their engineering identity development, because they realized the need for engineers to have interdisciplinary abilities, which could bring more potential for innovation [66]. Another bottom-up source of becoming engineers was "enjoying being challenged." The students who mentioned this source had the desire to overcome expected and unexpected problems and challenges by themselves in PBL processes: by doing so, they gained a sense of achievement and improvement. Moreover, by being exposed to real-life problems, students can apply theoretical knowledge in practice, link engineering with humanity and society, and become more familiar with engineers' work, which could reduce the gap between university and industry and help students better to prepare for their professional careers [67]. In the domain of external sources, students mentioned that they had more opportunities in PBL to interact with and get involved in engineering communities, including companies, industry, and clients. To become qualified engineers, students emphasized the importance of having experience of real-world projects with real engineers and clients, such as PBL, where they learn to listen to and understand clients' demands, learn different ways of expression for diverse audiences, and are able to negotiate between different stakeholders.

Furthermore, the outcomes of this study highlight the interrelatedness and inseparability of factors within each domain and the ongoing interaction between internal and external sources, as illustrated in Fig. 1. On the one hand, internal sources are context-bound, and individuals' experiences and

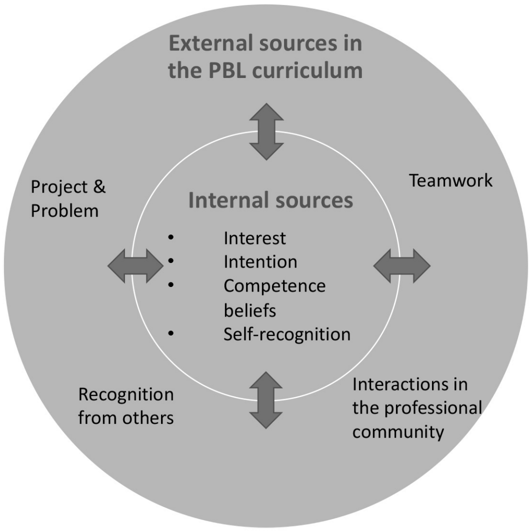

Fig. 1. The relationship between internal sources and external sources.

sense-making processes are always related to their interpretation of relations and opportunities offered by the learning context [44]. For instance, the development of students' competence beliefs in their professional knowledge and skills is an important learning outcome from professional socialization processes [70] such as PBL experiences. By working on real-life projects and being involved in engineering communities, students developed their understanding of how engineers work and realized the responsibilities of engineers. Their self-recognition as future engineers could be enhanced by receiving positive feedback and recognition from other members in engineering communities. On the other hand, internal sources could influence students' choice and utilization of external sources for engineering identity development, especially under the PBL curriculum in this study, because students are allowed to design their professional training pathways to become engineers. Specifically, while developing interests in specific engineering topics, such as artificial intelligence in Gary's example, students begin to consider what skills are required and what knowledge is needed to finish those projects, and they have the freedom to decide which lectures or workshops they should take under the university curriculum, which includes diverse professional and interdisciplinary learning sources in the fields of science, engineering, economics, social sciences, and humanities. Moreover, individuals' professional performance could bring additional external sources, as reported in Michael's case, where he got the opportunity for an internship in the company that he collaborated with for the projects. Thus, we recognize that internal sources are in interplay with external sources, both of which are integral for engineering identity development.

However, while the PBL environment brought sources to contribute to students' engineering identity development, constraints in engineering identity development were also reported by students. Transferring from a more traditional learning context and adapting to active learning methods challenged several participants and influenced their self-confidence, especially students who came from environments where teachers were the centre of learning and the authorities of knowledge [48, 68]. Several students also reported a feeling of self-doubt because of limited chance to work with companies, tough negotiation between stakeholders, and lack of feedback and instructions. For engineering educators, more attention should be devoted to designing effective learning activities in the professional socialization process and to constructing supportive learning environments in which students can access external sources to develop their engineering identity. To help students better adapt to the student-centred learning method in the PBL context, it is important for PBL newcomers to explore and to experience the teamwork and self-directed learning processes. Thus, we suggest that engineering educators set progressive learning objectives for students at different educational levels when designing a PBL course or curriculum. For a systematic PBL curriculum, the learning objectives for first-year students could focus on developing students' abilities to search for information, analyse the real-world context, and identify problems. The role of teachers at this stage should be that of instructors, who could guide students to learn professional approaches and tools to search and analyse information instead of telling them the answers directly [60]. Senior students are expected to achieve progressive learning goals such as hands-on skills, application abilities, interdisciplinary skills, negotiation skills, leadership and so on by finishing multiple tasks in a final product (a design, a model, or a device). In terms of PBL practices at the single course level, short-term pilot problems/projects could be set for students at the beginning of the courses which provide an opportunity for students to adapt to a new learning method and accumulate teamwork experience. Moreover, to enhance the effectiveness of sources from the teamwork and PBL environments, not only professional lectures but also teamwork and PBL training need to be provided for engineering students, such as scenario simulation of team conflict cases, discussion on possible solutions, tips for communication, and tools for time managements. In addition, engineering faculty need to be aware of developing students' engineering identity when facilitating students' project work, to take care of students' feeling of belonging, and to provide timely feedback to students, not only on their academic performance as students but also on the roles they take on as engineers. At the institutional level, universities need to provide students with more opportunities to be exposed to the engineering community and allow them to explore how to work in professional ways, including involving industry in joint projects in PBL, organizing student visits to a company/industry, and inviting engineers to join lectures, seminars and project evaluation [69].

This study has a few limitations. Firstly, we focused primarily on students in their third or fourth year of engineering study. Students at this stage have constructed and developed their engineering identity through previous learning experiences, and results might be significantly different for first-year students, for whom PBL can be a new learning experience. Secondly, this study mainly examined components of engineering identity from the students' perspectives, which may be different from the perspectives of engineering teachers and professional engineers. However, for professional identity, individual perceptions and attitudes are core and valid data, as they express students' feelings, values, and expectations of the future. Moreover, participants' belief in their competences for engineering work is an important source of engineering identity development, and self-assessments are widely used as an appropriate research method. Further study could include the perspectives of engineering teachers, professional engineers, and students from different academic levels as a longitudinal study in order to track students' engineering identity development through PBL and teamwork. Differences in students' identity development experiences and perspectives between genders and different engineering subjects also need more attention and further exploration.

6. Conclusion

This study provides an understanding of the internal and external sources in a PBL environment which are important for students' development of an engineering identity from the student perspectives. The findings contribute to the literature by proposing a model of sources of engineering identity development based on prior studies and by providing empirical evidence on available sources reported by students in a specific learning context, namely a PBL environment. Practical suggestions for multiple stakeholders in engineering communities are proposed in terms of optimizing the future design of PBL curricula and informing the incorporation of effective teaching and learning activities, thereby providing a supportive environment for students' engineering identity development.

References

1. D. Dannels, Learning to be professional: Technical classroom discourse, practice, and professional identity construction, *Journal of Business and Technical Communication*, **14**(1), pp. 5–37, 2000.
2. B. Johnson and R. Ulseth, *Development of Professional Competency through Professional Identity Formation in a PBL Curriculum*, 2016 Frontiers in Education Conference, Singapore, 2016.
3. K. L. Tonso, Engineering identity, in A. Johri and B. M. Olds (eds), *Cambridge Handbook of Engineering Education Research*, Cambridge University Press, Cambridge, pp. 267–283, 2015.
4. M. Eliot and J. Turns, Constructing professional portfolios: Sense-making and professional identity development for engineering undergraduates, *Journal of Engineering Education*, **100**(4), pp. 630–654, 2011.
5. A. Eteläpelto, K. Vähäsantanen, P. Hökkä and S. Paloniemi, What is agency? Conceptualizing professional agency at work, *Educational Research Review*, **10**(1), pp. 45–65, 2013.
6. G. A. Miller and L. W. Wager, Adult socialization, organizational structure, and role orientations, *Administrative Science Quarterly*, **16**(2), pp. 151–163, 1971.
7. H. B. Carlone and A. Johnson, Understanding the science experiences of successful women of colour: Science identity as an analytic lens, *Journal of Research in Science Teaching*, **44**(8), pp. 1187–1218, 2007.
8. K. Handley, A. Sturdy, R. Fincham and T. Clark, Within and beyond communities of practice: Making sense of learning through participation, identity and practice, *Journal of Management Studies*, **43**(3), pp. 641–653, 2006.
9. M. Capobianco, F. French and A. Diefes-Dux, Engineering identity development among pre-adolescent learners, *Journal of Engineering Education*, **101**(4), pp. 698–671, 2012.
10. A. Godwin, *The Development of a Measure of Engineering Identity*, 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana, 2016.
11. Z. Hazari, P. M. Sadler and G. Sonnert, The science identity of college students: Exploring the intersection of gender, race, and ethnicity, *Journal of College Science Teaching*, **42**(5), pp. 82–91, 2013.
12. A. D. Patrick, A. N. Prybutok and M. J. Borrego, Predicting persistence in engineering through an engineering identity scale, *International Journal of Engineering Education*, **34**(2a), pp. 351–363, 2018.
13. P. Hernandez-Martinez, "Lost in transition": Alienation and drop out during the transition to mathematically demanding subjects at university, *International Journal of Educational Research*, **79**(1), pp. 231–239, 2016.
14. S. Billett, Work, subjectivity and learning, in S. Billett, T. Fenwick, and M. Somerville (eds), *Work, Subjectivity and Learning: Understanding Learning through Working Life*, Springer, Dordrecht, pp. 1–20, 2006.
15. X. Y. Du, Gendered practices of constructing an engineering identity in a problem-based learning environment, *European Journal of Engineering Education*, **31**(1), pp. 35–42, 2006.

16. E. H. Erikson, *Identity: Youth and Crisis (No. 7)*, Norton & Company, New York, 1968.
17. J. P. Gee, Chapter 3: Identity as an analytic lens for research in education, *Review of Research in Education*, **25**(1), pp. 99–125, 2000.
18. J. Lave, and E. Wenger, *Situated Learning: Legitimate Peripheral Participation*, Cambridge University Press, Cambridge, 1991.
19. M. B. Brewer, and W. Gardner, Who is this "we"? Levels of collective identity and self-representations, *Journal of Personality and Social Psychology*, **71**(1), p. 83, 1996.
20. E. Wenger, *Communities of Practice: Learning, Meaning, and Identity*, Cambridge University Press, Cambridge, 1999.
21. H. Markus, and E. Wurf, The dynamic self-concept: A social psychological perspective, *Annual Review of Psychology*, **38**(1), pp. 299–337, 1987.
22. C. Ewan, Becoming a doctor, in K. Cox and C. Ewan (eds), *The Medical Teacher*, Churchill Livingstone, Edinburgh, Scotland, pp. 83–87, 1988.
23. J. Higgs, Physiotherapy, professionalism and self-directed learning, *Journal of the Singapore Physiotherapy Association*, **8**(14), pp. 8–11, 1993.
24. J. R. Morelock, A systematic literature review of engineering identity: Definitions, factors, and interventions affecting development, and means of measurement, *European Journal of Engineering Education*, **42**(6), pp. 1240–1262, 2017.
25. A. Godwin and A. Kirn, Identity-based motivation: Connections between first-year students' engineering role identities and future-time perspectives, *Journal of Engineering Education*, **109**(3), pp. 362–383, 2020.
26. L. N. Fleming, K. C. Smith, D. G. Williams and L. B. Bliss, *Engineering Identity of Black and Hispanic Undergraduates: The Impact of Minority Serving Institutions*, 2013 ASEE Annual Conference & Exposition, Atlanta, Georgia, 2013.
27. K. L. Meyers, M. W. Ohland, A. L. Pawley, S. E. Silliman and K. A. Smith, Factors relating to engineering identity, *Global Journal of Engineering Education*, **14**(1), pp. 119–131, 2012.
28. B. E. Ashforth, *Role Transitions in Organizational Life: An Identity-Based Perspective*, Lawrence Erlbaum Associates, Inc, New Jersey, 2001.
29. C. E. Foor, S. E. Walden and D. A. Trytten, "I wish that I belonged more in this whole engineering group": Achieving individual diversity, *Journal of Engineering Education*, **96**(2), pp. 103–115, 2007.
30. R. L. Kajfez and L. D. McNair, *Graduate Student Identity: A Balancing Act between Roles*, 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana, 2014.
31. D. Knight, J. F. Sullivan, D. A. Kotys-Schwartz, B. A. Myers, B. Louie, J. T. Luftig and J. M. Hornback, *The Impact of Inclusive Excellence Programs on the Development of Engineering Identity among First-Year Underrepresented Students*, 2013 ASEE Annual Conference & Exposition, Atlanta, Georgia, 2013.
32. S. Craps, M. Pinxten, H. Knipprath and G. Langie, Exploring professional roles for early career engineers: A systematic literature review, *European Journal of Engineering Education*, pp. 1–21, 2020.
33. A. Godwin and G. Potvin, Pushing and pulling Sara: A case study of the contrasting influences of high school and university experiences on engineering agency, identity, and participation, *Journal of Research in Science Teaching*, **54**(4), pp. 439–462, 2017.
34. D. A. Trytten, A. Wong Lowe and S. E. Walden, "Asians are good at math. What an awful stereotype" – The model minority stereotype's impact on Asian American engineering students, *Journal of Engineering Education*, **101**(3), pp. 439–468, 2012.
35. A. Patrick, and M. Borrego, *A Review of the Literature Relevant to Engineering Identity*, 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana, 2016.
36. K. Keltikangas and M. Martinsuo, Professional socialization of electrical engineers in university education, *European Journal of Engineering Education*, **34**(1), pp. 87–95, 2009.
37. F. Trede, R. Macklin and D. Bridges, Professional identity development: A review of the higher education literature, *Studies in Higher Education*, **37**(3), pp. 365–384, 2012.
38. R. W. Lent and G. Hackett, Sociocognitive mechanisms of personal agency in career development: Pantheoretical prospects, in M. L. Savikas and R. W. Lent (eds), *Convergence in Career Development Theories: Implications for Science and Practice*, pp. 77–101, Consulting Psychologists Press, Sunnyvale, 1994.
39. A. Godwin, G. Potvin, Z. Hazari and R. Lock, Identity, critical agency, and engineering: An affective model for predicting engineering as a career choice, *Journal of Engineering Education*, **105**(2), pp. 312–340, 2016.
40. M. Borrego, A. Patrick, L. Martins and M. Kendall, *A New Scale for Measuring Engineering Identity in Undergraduates*, 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah, 2018.
41. S. L. Rodriguez, C. Lu and M. Bartlett, Engineering identity development: A review of the higher education literature, *International Journal of Education in Mathematics, Science and Technology*, **6**(3), pp. 254–265, 2018.
42. G. Charness and Y. Chen, Social identity, group behavior, and teams, *Annual Review of Economics*, **12**(1), pp. 691–713, 2020.
43. C. P. Tan, H. T. Van der Molen and H. G. Schmidt, To what extent does problem-based learning contribute to students' professional identity development? *Teaching and Teacher Education*, **54**, pp. 54–64, 2016.
44. P. Jääskelä, A. M. Poikkeus, K. Vasalampi, U. M. Valleala and H. Rasku-Puttonen, Assessing agency of university students: Validation of the AUS Scale, *Studies in Higher Education*, **42**(11), pp. 2061–2079, 2017.
45. B. D. Jones, M. C. Paretti, S. F. Hein and T. W. Knott, An analysis of motivation constructs with first-year engineering students: Relationships among expectancies, values, achievement, and career plans, *Journal of Engineering Education*, **99**(4), pp. 319–336, 2010.
46. O. Pierrakos, N. A. Curtis and R. D. Anderson, *How Salient is the Identity of Engineering Students? On the Use of the Engineering Student Identity Survey*, 2016 IEEE Frontiers in Education Conference, Singapore, 2016.
47. C. Cass, A. Kirn, M. A. Tsugawa, H. Perkins, J. N. Chestnut, D. E. Briggs and B. Miller, *Board #18: Improving Performance and Retention of Engineering Graduate Students through Motivation and Identity Formation*, 2017 ASEE Annual Conference & Exposition, Columbus, Ohio, 2017.
48. X. Du, K. K. Naji, S. Sabah and U. Ebead, Engineering students' conceptions of collaboration, group-based strategy use, and perceptions of assessment in PBL: A case study in Qatar, *The International Journal of Engineering Education*, **36**(1), pp. 296–308, 2020.
49. F. Dehing, W. Jochems and L. Baartman, Development of an engineering identity in the engineering curriculum in Dutch higher education: An exploratory study from the teaching staff perspective, *European Journal of Engineering Education*, **38**(1), pp. 1–10, 2013.

50. A. Prybutok, A. Patrick, M. Borrego, C. C. Seepersad and M. Kirisits, *Cross-Sectional Survey Study of Undergraduate Engineering Identity*, 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana, 2016.
51. R. Stevens, A. Johri and K. O'Connor, Professional engineering work, in A. Johri and B. M. Olds (eds), *Cambridge Handbook of Engineering Education Research*, Cambridge University Press, Cambridge, pp. 267–283, 2015.
52. M. M. Chemers, E. L. Zurbriggen, M. Syed, B. K. Goza and S. Bearman, The role of efficacy and identity in science career commitment among underrepresented minority students, *Journal of Social Issues*, **67**(3), pp. 469–491, 2011.
53. P. L. Curşeu and H. Pluut, Student groups as learning entities: The effect of group diversity and teamwork quality on groups' cognitive complexity, *Studies in Higher Education*, **38**(1), pp. 87–103, 2013.
54. D. M. Hatmaker, Engineering identity: Gender and professional identity negotiation among women engineers, *Gender, Work & Organization*, **20**(4), pp. 382–396, 2013.
55. K. J. B. Anderson, S. S. Courter, T. McGlamery, T. M. Nathans-Kelly and C. G. Nicometo, Understanding engineering work and identity: A cross-case analysis of engineers within six firms, *Engineering Studies*, **2**(3), pp. 153–174, 2010.
56. A. Barbarà-i-Molinero, R. Cascón-Pereira and A. Beatriz Hernández-Lara, Professional identity development in higher education: Influencing factors, *International Journal of Educational Management*, **32**(2), pp. 189–203, 2017.
57. J. W. Creswell, *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research*, Prentice Hall, Upper Saddle River, New Jersey, 2002.
58. S. Kvale and S. Brinkmann, *Interviews: Learning the Craft of Qualitative Research Interviewing*, SAGE Press, Thousand Oaks, California, 2009.
59. A. Kolmos and E. de Graaff, Problem-based and project-based learning in engineering education, in A. Johri and B. M. Olds (eds). *Cambridge Handbook of Engineering Education Research*, Cambridge University Press, Cambridge, pp. 141–161, 2015.
60. A. Guerra and A. Kolmos, Comparing problem-based learning models: suggestions for their implementation, in *Proceedings of PBL Across the Disciplines: Research into Best Practice*, 3rd International Research Symposium on PBL, pp. 3–14, 2011.
61. K. M. MacQueen, E. McLellan, K. Kay and B. Milstein, Codebook development for team-based qualitative analysis, *Cam Journal*, **10**(2), pp. 31–36, 1998.
62. G. Terry, N. Hayfield, V. Clarke and V. Braun, Thematic analysis, *The SAGE Handbook of Qualitative Research in Psychology*, **2**, pp. 17–37, 2017.
63. S. B. Merriam, *Qualitative Research and Case Study Applications in Education. Revised and Expanded from "Case Study Research in Education"*, Jossey-Bass Publishers, San Francisco, California, 1998.
64. R. McQuade, E. Ventura-Medina, S. Wiggins and T. Anderson, Examining self-managed problem-based learning interactions in engineering education, *European Journal of Engineering Education*, **45**(2), pp. 232–248, 2020.
65. C. N. Sinkele and D. M. Mupinga, The effectiveness of engineering workshops in attracting females into engineering fields: A review of the literature, *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, **84**(1), pp. 37–42, 2011.
66. B. Vogel-Heuser, M. Böhm, F. Brodeck and U. Lindemann, Interdisciplinary engineering of cyber-physical production systems: Highlighting the benefits of a combined interdisciplinary modelling approach on the basis of an industrial case, *Design Science*, **6**(5), pp. 1–36, 2020.
67. L. Carder, P. Willingham and D. Bibb, Case-based, problem-based learning: Information literacy for the real world, *Research Strategies*, **18**(3), pp. 181–190, 2001.
68. G. Lutsenko, Case study of a problem-based learning course of project management for senior engineering students, *European Journal of Engineering Education*, **43**(6), pp. 895–910, 2018.
69. K. Roach, E. Tilley and J. Mitchell, How authentic does authentic learning have to be? *Higher Education Pedagogies*, **3**(1), pp. 495–509, 2018.
70. J. C. Weidman, D. J. Twale and E. L. Stein, Socialization of graduate and professional students in higher education: A perilous Passage? *ASHE-ERIC Higher Education Report*, **28**, Jossey-Bass, San Francisco, California, 2001.

Juebei Chen is a PhD student at the UNESCO Centre for Problem-Based Learning in Engineering Science and Sustainability (UCPBL Centre), Aalborg University, Denmark. She obtained a master's degree in higher education from Shanghai Jiao Tong University, China. Her current interests focus on students' learning experience and learning outcomes in the PBL context, PBL training for engineering staff, and gender issues in engineering education.

Xiangyun Du is a Professor at the College of Education, Qatar University, and an adjunct professor at Aalborg University's UNESCO Centre for Problem-Based Learning in Engineering Science and Sustainability, Denmark. She has over 160 publications on pedagogical development, particularly problem-based and project-based learning (PBL) methods in fields ranging from engineering, medicine and health to foreign languages and teacher education in diverse social, cultural and educational contexts. Dr Du has also done research on gender and intercultural teaching and learning issues surrounding learning and PBL. She has also engaged with educational institutions in over 20 countries in substantial work on pedagogy and curriculum development.

Anette Kolmos is Professor in Engineering Education and PBL; Director for the UNESCO Category 2 Centre: Aalborg Centre for Problem-Based Learning in Engineering Science and Sustainability; and Chair-holder for UNESCO in Problem-Based Learning in Engineering Education, Aalborg University, Denmark. She has been Guest Professor at KTH Royal Institute of Technology, Associate Editor for the European Journal of Engineering Education, Associated Editor of *Journal of Engineering Education* (ASEE) and President of the European Society for Engineering Education. She was awarded the IFEES Global Award for Excellence in Engineering Education in 2013. Over the last 20 years, Professor Kolmos has researched the development and evaluation of project-based and problem-based curricula, changes from traditional to project-organized and problem-based curricula, the development of transferable skills in PBL and project work, and methods for staff development.