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BY
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CV

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ENGLISH SUMMARY

Engineering identity refers to an awareness of the skills required for an engineer, a sense of belonging among the engineering community, and self-identification as future engineers (Capobianco et al., 2012; Knight et al., 2013; Meyers et al., 2012). Due to its predictive power in terms of students' persistence in engineering and their readiness for practical engineering work, engineering identity as a research focus has been gaining more attention in recent years. Previous studies have shown that students' engineering identity development relates to their individual values and their engagement in the engineering community during the professional socialization process. Notably, the impact of professional training provided by universities in promoting engineering identity is under discussion, which reveals a gap between academic attainments in educational settings and work requirements in real-world engineering projects. As a result, graduates tend to find it challenging to transfer their role from a student to an engineer.

Within this context, PBL (problem- and project-based learning) has been recognized as an effective way to bridge the gap; it can enable students to have a deeper understanding of the standards of the engineering profession, expose students to genuine engineering problems, and allow them to accumulate some work-related experience – all of which will contribute to their future engineering career. Although PBL is assumed to be an effective approach to cultivating engineering talents, it remains unclear how PBL works on students' engineering identity development. Therefore, to gain further insights into the development of engineering identity across learning environments, this study is intended to elucidate the influence of the elements in a systemic PBL context on students' feelings about becoming engineers.

The research question refers to ways in which students' engineering identities could be developed in a PBL environment. Methodologically, this study builds on exploratory mixed methods, which consist of a systematic review, qualitative interviews, and a quantitative survey, to synthesize the current knowledge about the implementation of PBL, identify relevant elements from the PBL context, and examine the impact of these elements on students' engineering identity development. This doctoral research is composed of three articles published in international journals.

Paper I presents a systematic review of diverse implementations of PBL and the challenges reported by practitioners and students. Four levels of implementation have been identified: course level, cross-course level, curriculum level, and project level. Challenges faced by students in PBL contexts include a low level of self-efficacy, as well as a lack of teamwork skills, project management skills, and work-related engineering practice. These challenges could affect the effectiveness of PBL as an

approach to professional socialization and thereby influence students' persistence in the field of engineering.

Paper II adopts a qualitative interview method and explores how students perceive the importance of the elements of a systemic PBL environment for their engineering identity development. Based upon a literature review on engineering identity, a conceptual model with two domains of internal sources and external sources for engineering identity development is proposed. Internal sources, such as students' interest in specific engineering topics and self-confidence in their professional competences, and external sources, such as chances to solve real-world problems and collaborate with a company, are found to be beneficial for students' engineering identity development. The results also highlight the continuing interaction between internal and external sources, indicating that internal sources could support students' individual choices of professional socialization experience, while external sources from the learning environment also play a role.

Based on diverse elements identified in the qualitative study, Paper III identified what elements of the PBL environment are considered by students to be contributing to their engineering identity development by designing and validating a survey. The results reveal that students' engineering identity development is positively influenced by their interest in innovative work, self-efficacy in overcoming learning difficulties, the opportunities to approach real-life problems, and peer collaboration. A lack of sources, such as a lack of role models and limited opportunities to work with a company, was reported as a potential constraint for students' engineering identity development.

In summary, this Ph.D. thesis enriches the theoretical understanding of professional identity and discusses the interplay between sources from the PBL environment and students' engineering identity development. By exposing students to a simulated engineering working environment where they could address real-life problems or projects in groups, PBL could enhance students' interest in engineering, self-efficacy in professional competence, and engagement in the engineering communities. Based on the identified sources and constraints, practical suggestions are proposed for practitioners to optimize current PBL design at both single course level and curriculum level. This study recommends that more attention be paid to students' long-term development of engineering identity, which can benefit from diverse learning contexts and various PBL implementations.

DANSK RESUME

Ingeniøridentitet refererer til en bevidsthed om de nødvendige færdigheder for en ingeniør, en følelse af at høre til blandt ingeniørsamfundet og selvidentifikation som fremtidige ingeniører. På grund af dens forudsigelige kraft af studerendes vedholdenhed i ingeniørarbejde og deres parathed til praktisk ingeniørarbejde, har ingeniøridentitet som forskningsfokus fået mere opmærksomhed i de senere år. Tidligere undersøgelser har vist, at studerendes ingeniøridentitetsudvikling relaterer sig til deres individuelle værdier og deres engagement i ingeniørsamfundet under den professionelle socialiseringsproces. Navnlig er virkningen af professionel uddannelse leveret af universiteter til at fremme ingeniøridentitet under diskussion, hvilket afslører en kløft mellem akademiske præstationer i uddannelsesmiljøer og arbejdskrav i ingeniørprojekter i den virkelige verden. Som et resultat har færdiguddannede en tendens til at finde det udfordrende at overføre deres rolle som studerende til en ingeniør.

Inden for denne sammenhæng er PBL (Problem- og Project-based Learning) blevet anerkendt som en effektiv måde at bygge bro over kløften; det kan gøre det muligt for studerende at få en dybere forståelse af ingeniørfaget ved at give dem mulighed for at akkumulere arbejdsrelateret erfaring, hvilket kan bidrage til deres fremtidige karriere. Selvom PBL antages at være en effektiv tilgang til at udvikle ingeniørkompetencer, er det stadig uklart, hvordan PBL har indflydelse på studerendes identitetsudvikling. For at få yderligere indsigt i udviklingen af ingeniøridentitet, vil denne undersøgelse identificere faktorer der har betydning for studerendes oplevelse.

Forskningsspørgsmålet er, på hvilke måder studerendes ingeniøridentiteter kan udvikles i et PBL-miljø. Metodisk bygger denne undersøgelse på eksplorative mixed methods, som består af et systematisk review, kvalitative interviews og en kvantitativ undersøgelse. Denne phd afhandling er sammensat af tre artikler publiceret i internationale tidsskrifter.

Artikel I præsenterer et systematisk review af forskning om implementering af PBL og de udfordringer der er rapporteret af undervisere og studerende. Der er identificeret fire niveauer for implementering: kursusniveau, på tværs af kurser, uddannelses- og projektniveau. Udfordringer, som studerende står over for i PBL-sammenhænge omfatter et lavt niveau af effektivitet, mangel på samarbejdskompetencer, projektledelse og forståelse af arbejdsrelateret ingeniørpraksis. Disse udfordringer kan påvirke effektiviteten af PBL som en tilgang til professionel socialisering og derved påvirke de studerendes vedholdenhed inden for ingeniørområdet.

Artikel II anvender en kvalitativ interviewmetode og undersøger, hvordan de studerende identificer faktorer i et systemisk PBL-miljø for deres ingeniørmæssige identitetsudvikling. Baseret på en litteraturgennemgang om ingeniøridentitet udvikles en konceptuel model med to domæner af interne kilder og eksterne kilder til ingeniøridentitetsudvikling. Interne kilder, såsom studerendes interesse for specifikke ingeniøremner og deres selvtillid til deres ingeniørkompetencer; og eksterne kilder, såsom muligheder for at arbejde med virkelige problemer og at samarbejde med en virksomhed, findes gavnligt for de studerendes udvikling af ingeniøridentitet. Resultaterne viser også den fortsatte interaktion mellem interne og eksterne kilder, hvilket indikerer at organisering af læringsmiljø er vigtigt.

Baseret på forskellige faktorer identificeret i den kvalitative undersøgelse, identificerede artikel III hvilke elementer i PBL-miljøet, der af studerende anses for vigtigst. Baseret på review og kvalitative interviews i artikel 2, udvikles der et spørgeskema. Resultaterne herfra viser, at studerendes ingeniøridentitetsudvikling er positivt påvirket af deres interesse for innovativt arbejde, selveffektivitet til at overvinde læringsvanskeligheder, mulighederne for at nærme sig virkelige problemer og peer-samarbejde. Mangel på rollemodeller og begrænsede muligheder for at arbejde med en virksomhed blev rapporteret som potentielle begrænsninger for studerendes ingeniøridentitetsudvikling.

Afslutningsvis beriger denne ph.d.-afhandling den fagcentrerede sociokulturelle teori om identitetsudvikling og diskuterer samspillet mellem kilder fra PBL-miljøet og studerendes ingeniørmæssige identitetsudvikling. Ved at udsætte eleverne for et simuleret ingeniørarbejdsmiljø, hvor de kunne tage fat på virkelige problemer eller projekter i grupper, kunne PBL øge elevernes interesse for ingeniørarbejde, selveffektivitet i faglig kompetence og engagement i ingeniørsamfundene. Baseret på de identificerede kilder og begrænsninger, foreslås praktiske forslag til praktikere for at optimere det nuværende PBL-design på både enkeltkursusniveau og uddannelsesniveau. Det anbefaler, at der lægges mere vægt på studerendes langsigtede udvikling af ingeniøridentitet, som kan drage fordel af forskellige læringskontekster og forskellige PBL-implementeringer.

LIST OF ARTICLES

The thesis is based on three articles:

[1] Chen, J., Kolmos, A., & Du, X. (2021). Forms of implementation and challenges of PBL in engineering education: A review of literature. *European Journal of Engineering Education*, *46*(1), 90–115.

[2] Chen, J., Du, X., & Kolmos, A. (2022). Students' views on sources of engineering identity development in a collaborative PBL environment. *International Journal of Engineering Education*, *38*(2), 525–542.

[3] Chen, J., Ahmed, M. H. Du, X., & Kolmos, A. (2022). Exploring students' perception of influence of PBL elements on the development of engineering identity. *IEEE Transactions on Education* (in review).

Other related publications:

[1] Chen, J., Kolmos, A., Guerra, A., & Zhou, C. (2019). Aalborg UNESCO Certificate: Staff development and challenges in PBL training programme. *Journal of Engineering Education Transformations*, *33*(1), 1–8.

[2] Zhu, J., Chen, J., McNeill, N., Zheng, T., Liu, Q., Chen, B., & Cai, J. (2019). Mapping engineering students' learning outcomes from international experiences: Designing an instrument to measure attainment of knowledge, skills, and attitudes. *IEEE Transactions on Education*, *62*(2), 108–118.

[3] Chen, J., Kolmos, A., & Du, X. (2020). The role of teamwork on students' engineering professional identity development in the AAU PBL Model: From the perspectives of international engineering students. *Paper presented at the 8th International Research Symposium on PBL* (pp. 405–413). Aalborg Universitetsforlag.

[4] Chen, J., Kolmos, A., & Du, X. (2020). An exploration of students' engineering identity development in a PBL team setting. *Paper presented at the 2020 ASEE Virtual Annual Conference Content Access*.

[5] Guerra, A., Chen, J., Winther, M., & Kolmos, A. (2020). *Educate for the Future: PBL, Sustainability and Digitalisation 2021*. Aalborg Universitetsforlag.

[6] Chen, J., Kolmos, A., Guerra, A., & Zhou, C. (2021). Academic staff's motivation, outcomes, and challenges in a pedagogical training programme of PBL. *International Journal of Engineering Education*, *37*(4), 900–914.

[7] Guerra, A., Chen, J., Winther, M., Kolmos, A., & Nielsen, S. R. (2021). *Educate for the Future: PBL, Sustainability and Digitalisation 2021*. Aalborg Universitetsforlag.

[8] Chen, J., Zhu, J., & Zheng, T. (2022). From initiators to free-riders: Exploring the spectrum of female engineering students' functional roles in project-based learning using phenomenography. *International Journal of Engineering Education* (accepted).

[9] Chen, J., Kolmos, A., & Clausen, N. R. (2022). Gender differences in engineering students' understanding of professional competences and career development in the transition from education to work. *International Journal of Technology and Design Education* (accepted).

PREFACE

This thesis is submitted to the Technical Faculty of IT and Design at Aalborg University in partial fulfillment of the requirements for the degree of PhD at Aalborg University. The thesis contains two sections: a summary of this study and a collection of three articles. The first section introduces the research background, a review of current related literature, an overview of the research design, a summary of main findings, and contributions from the three separate articles. The second section consists of three articles, which have been published in or submitted to engineering education journals.

The PhD program was commenced in September 2018 and finished in May 2022 in the Aalborg Centre for PBL in Engineering Science and Sustainability under the auspices of UNESCO, Institute for Advanced Study in PBL, Aalborg University. The fantastic period as a PhD student becomes my precious memory and inspires my passion for educational research. There are many people to whom I would like to express gratitude for their generous help in my PhD life.

First of all, I would like to thank my wonderful supervisors, Anette Kolmos and Xiangyun Du for their ongoing support throughout my PhD study. Anette always trusts me, encourages me to explore my interests and passions, and takes care of me both in research and in life. Xiangyun is always energetic, elegant, and intelligent. She gives endless patience and priceless guidance to me throughout the research process. Both of them are my academic role models, and I always admire their idealistic thinking and insightful view. With their ongoing help and support, I have more courage to explore new areas and face different challenges in my life.

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Last but not least, I would like to give thanks to my parents and my boyfriend, who continually stand behind my back, give trust and love to me, and accompany me through all ups and downs in life.

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CHAPTER 1. INTRODUCTION

1.1. RESEARCH BACKGROUND

Global advances in engineering bring the increasing demand for engineering talents with comprehensive knowledge, skills, and abilities, including problem-solving skills, lifelong learning, entrepreneurship, leadership, communication skills, and teamwork skills (UNESCO, 2017). Accordingly, one of the significant objectives of engineering education is to educate engineering graduates who are highly qualified and career ready by promoting a curriculum design with aligned learning activities. In this context, engineering identity is getting more attention in higher engineering education (Morelock, 2017; Tonso, 2015) because it indicates students' insistence on engineering fields and preparedness for practical engineering work (Dannels, 2000; Johnson & Ulseth, 2016). Engineering identity, or a student's professional identity as an engineer, can be understood as an awareness of the qualities needed to be an engineer, a sense of belonging to engineering, and self-identification as future engineers (Capobianco et al., 2012; Chen et al., 2020; Dehing et al., 2013; Knight et al., 2013; Meyers et al., 2012). Engineering identity is a self-developed concept involving subjectivity of individual values, but it is also the result of the formation of an engineering community (Patrick et al., 2018). Engineering identity involves a dynamic development process of internal and external sources. It could be developed through interactions with members in the engineering communities and engagement in engineering practice (Eliot & Turns, 2011; Wenger, 1999). It also influences students' choice of professional socialization experience simultaneously (Godwin et al., 2016).

To understand various aspects of engineering identity, existing scholarship has adopted diverse theoretical perspectives to conceptualize its definitions and components (Carlone & Johnson, 2007) and design tools for measuring engineering identity (Capobianco et al., 2012; Godwin, 2016). Several researchers explored impact factors promoting students' engineering identity development, especially the influence of various professional training in universities, which is an indispensable component of professional socialization processes (Hernandez-Martinez, 2016). Prior to university, due to limited exposure to engineering practice, students' interest in STEM (Science, Technology, Engineering, and Mathematics) disciplines became the primary intrinsic motivation for students' choice of studying engineering (Godwin et al., 2016). When entering a university, students' engineering identity development path could differ between individuals since learning activities, institutional environments, and sociocultural contexts in which students are situated, have diverse functions in engineering identity development (Morelock, 2017; Tonso, 2015). For example, formal engineering education experiences, such as lectures and laboratory work, could enhance students' sense of becoming engineers by acquiring foundational science theory, engineering knowledge, and technical skills (Lappenbusch & Turns, 2007). Internships enable students to participate in a real engineering work environment and communicate with practical engineers, providing opportunities for them to find role models and experiment with a new understanding of engineering roles and identity (Capobianco et al., 2012; Crede et al., 2010; Dehing et al., 2013). Collaborative learning contributes to engineering identity development by providing opportunities for students to construct the meaning of knowledge together, share the same goals and values, and develop membership in their groups (Capobianco et al., 2012; Hazari et al., 2013). Thus, for further insight into the functions of diverse learning activities in engineering identity development in various learning environments, there is a need to investigate how individual students make sense of their learning experiences for engineering identity development under a variety of specific training and curriculum design.

In this context, efforts have been made by higher engineering education institutions to develop innovative learning approaches and improve learning and teaching, thereby better preparing students for a future engineering career. However, existing literature also points out the gap between education and work, where graduates face the challenge of transferring their role from students to practical engineers (Mourshed et al., 2013; Spinks et al., 2006). With this challenge, it has been pointed out that PBL (problem- and project-based learning) can bridge the gap by providing students with a simulating engineering work environment to learn about solving problems (Kolmos et al., 2021). A learning environment, considered as an indispensable component for professional socialization, could provide powerful support for students' professional identity development, and PBL fulfills the characteristics of a supportive environment to develop students' engineering identity (Du, 2006). In PBL, students are exposed to real-world and open-ended problems, and they could share values, co-construct their understanding of engineering contents, and work collaboratively as professional engineers (Chen et al., 2020). These experiences in PBL environments not only bring students the foundational knowledge and technical skills, but also provide them the chance to acquire a membership in an engineering group as well as the sense of becoming engineers, thereby improving their engineering identity construction and development (Chen et al., 2020; Du, 2006; Johnson & Ulseth, 2016).

However, although the positive influence of PBL on students' learning experience and learning outcomes has been reported, it is still unclear how PBL, especially a systemic PBL curriculum, could contribute to students' sense of becoming engineers and how engineering students perceive the importance of, their access to, and influences of elements in PBL to develop their engineering identity. Since there are different ways to practice PBL and understand its effectiveness, a comprehensive understanding of the diversity of PBL implementation is needed to explore what practices and characteristics of PBL may contribute to engineering students' professional identity development.

In addition, a limited number of analytical tools for examining impact factors on students' professional identity construction have been designed and tested in a systemic PBL environment, because, based on a literature review, most tools for measuring engineering identity and its impact factors were developed from traditional learning contexts (lectures, lab work, in-class group discussion, etc.) and focused on individual learning processes rather than a collaborative learning perspective (Chen et al., 2020; Morelock, 2017). Thus, to get further insights into professional identity development in various learning contexts, assuming PBL to be a supportive learning environment for producing career-ready engineers, more attention needs to be given to exploring the influence of specific elements in PBL on students' engineering identity development and to developing and validating relevant analytical tools.

1.2. AIMS AND RESEARCH QUESTIONS

This thesis aims to explore the ways in which students' engineering identities could be developed in a PBL environment. To do so, an overview of various PBL implementations could be helpful for identifying elements in PBL contexts contributing to students' engineering identity development. Thus, the purposes of this dissertation are threefold: to recognize diverse PBL implementations and their characteristics in engineering education; to identify important elements/sources for engineering identity development in PBL, and to analyze the influence of various elements/sources from a PBL environment on students' engineering identity development (Figure 1-1). The following research questions are posed:

1) What characterizes PBL practices in engineering education, and what challenges are addressed in current PBL implementation? (Paper I)

2) What sources are considered important by students for the development of their engineering identity in a PBL learning environment? (Paper II)

3) What elements of the PBL environment do students consider contribute to their engineering identity development? (Paper III)

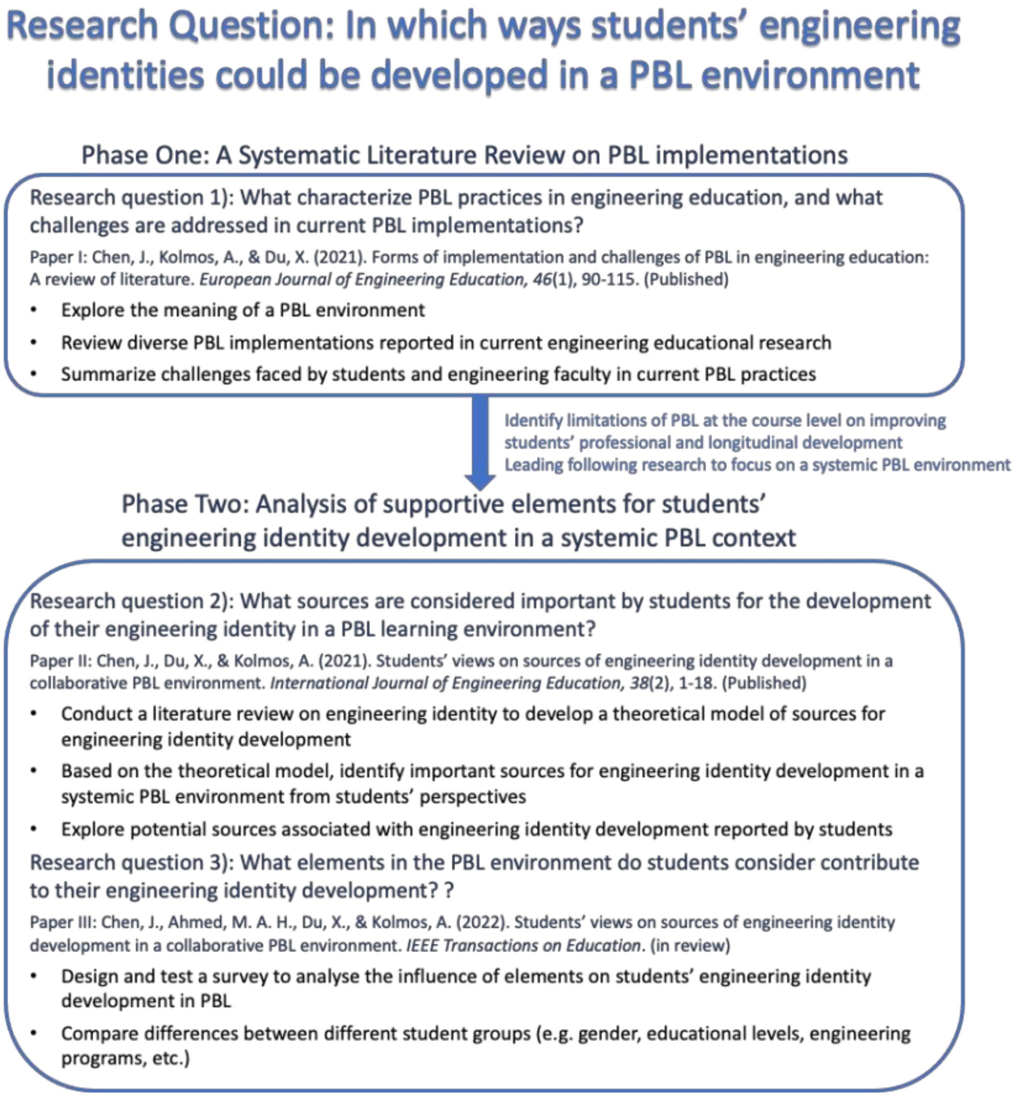

Figure 1-1 An overview of this study

The contribution of Paper I is to provide an overview of how PBL has been implemented in higher engineering education. This paper emphasizes the variation of PBL implementation, which means that PBL is not one type of learning approach but includes diverse implementations applied at different levels in the curriculum. Moreover, challenges faced by individuals in different PBL practices are summarized in Paper I. In particular, prior studies pointed out that PBL at the course level makes only a limited contribution to students' professional identity and longitudinal development (Arman, 2018), and it is unclear how students' engineering identity could be developed in PBL at the curriculum level (Du et al., 2019). The results highlight the importance of more empirical studies to investigate the efficiency of PBL at diverse levels in educating qualified and career-ready engineers, and attract our attention to the systemic PBL context.

Paper II contributes by enriching engineering identity development theories from a subject-centered sociocultural perspective and expanding understanding of engineering identity development in a variety of learning contexts. Theoretically, this study emphasizes the interplay between individual personalities and the indispensable function of the learning environment, which enables researchers to address the research gap mentioned above. A theoretical model of internal and external sources is proposed based on existing literature and empirical evidence on students' perspectives of available sources influencing their engineering identity development in a specific learning environment, namely a systemic PBL curriculum.

Paper III develops the contribution of a validated analytical tool for assessing impact factors on engineering identity development in PBL programs that might be used in other PBL designs. Thirty elements in the survey and their specific influence have been reported. Although this survey is developed in a systemic PBL environment, we believe that it has the potential to be generalized into similar learning environments with elements of problem solving and collaborative learning, which is also a future research direction for researchers in this study.

The results of this study show the variety of PBL implementations and reflect how engineering students perceive the importance of, their access to, and influences of elements from a systemic PBL environment to develop their understanding of engineering work and engineering identity. Suggestions for future PBL practice are proposed, and we call for more research attention to be given to students' longitudinal development of engineering identity in diverse learning contexts, including various PBL implementations.

1.3. OUTLINE OF THE THESIS

Chapter 1 introduces the research background, research aims, and research questions of this thesis. This introductory section points out the importance of exploring students' engineering identity development in the PBL environment.

Chapter 2 presents a historical overview of the PBL methods, including PBL concepts, history, principles, categories, and implementation. This chapter also reviews the concepts of identity and professional identity from diverse perspectives, paying particular attention to engineering identity, measurement tools, and related impact factors. Here, the research gap regarding how students could develop their engineering identity in a systemic PBL environment is highlighted.

Chapter 3 describes this research methodology, adopting an exploratory mixed method. This section illustrates the research context, the overall research design, and connections between the three included papers. Data collection, analysis processes, and validity and reliability are presented separately in the qualitative and quantitative studies.

Chapter 4 presents the main findings and contributions from the three separate papers. Firstly, Paper I presents the current PBL implementation based on a systematic literature review. Secondly, Paper II illustrates students' perceptions of important internal and external sources for engineering identity development in PBL, using a qualitative interview method. Thirdly, using a quantitative method, Paper III explores diverse elements of the PBL environment seen by students as contributing to their engineering identity development through designing and validating a survey that illustrates the interrelationship between sources from the PBL environment and engineering identity development.

Chapter 5 concludes by discussing the findings in relation to the theoretical model of sources for engineering identity development. Suggestions for future PBL design, PBL implementation, and research directions are proposed in this chapter.

CHAPTER 2. LITERATURE REVIEW

2.1. PBL IN ENGINEERING

2.1.1. CONCEPTUALIZING PBL

Problem-based learning originated from the reform universities founded during the 1960s and 1970s and aimed to train graduates with cutting-edge knowledge and practical skills for the labor market (Kolmos & de Graaff, 2015). Different definitions and principles of this new learning approach were developed and applied by these reform universities. The learning principles of the problem-based learning method were first adopted by the medical school of McMaster University (Spaulding, 1969). Aimed at training general medical practitioners, PBL has been defined as a student-centered learning approach, in which students conduct self-directed learning in small groups (Barrows, 1996). At the same time, teachers play the roles of facilitators and supervisors (Barrows, 1996). In contrast to traditional lecture teaching, the roles of facilitators and supervisors are to guide students toward solving problems on their own instead of providing the answers directly (Barrows, 2002). PBL enables students to apply knowledge in practice by solving patients' problems, in which process the relevance of the material studied is guaranteed, and students' learning experience becomes more lively and more practical (Barrows & Tamblyn, 1980).

At the same time, problem-oriented and project-based learning were also introduced to Danish reform universities. While the Danish approach shares similar principles with problem-based learning, it also emphasizes the problem orientation, as all projects begin by identifying problems. During the project processes, students are expected to work in teams, conduct self-directed and exemplary learning, figure out real-world problems, and have opportunities to join interdisciplinary projects (Du et al., 2009; Kolmos & de Graaff, 2015). Kolmos and de Graaff (2015) describe the progression of problem-oriented and project-based learning, in which process these approaches developed, merged, and occurred in blended forms, and therefore were defined as sets of learning principles for the acronym "PBL." Since PBL proved its effectiveness in improving the teaching and learning quality at these reform universities, more and more institutions and disciplines have adopted these learning approaches at the course and curriculum levels (Gijbels et al., 2005; Kolmos & de Graaff, 2015).

In engineering education, engineering talents are expected to have professional knowledge, practical skills, and complex competences through professional training, including communication skills, problem-solving skills, leadership, and so on (UNESCO, 2017). With these demands, PBL has been widely implemented for decades at different educational levels among various engineering education institutions since it provides students with the opportunity to solve real-world and ill-structured problems (Jonassen et al., 2006). The diversity of PBL implementation leads to a continuous debate on the PBL concept, especially in distinguishing between project-based and problem-based learning. Several researchers have pointed out the differences between problem-based learning and project-based learning. Prince and Felder (2006) pointed out that problem-based learning focuses on the process of identifying problems while project-based learning emphasizes the problem-solving process and the creation of a product – a design, a model, or a device. However, several other researchers have different interpretations. De Graaff (1995) characterizes the differences and similarities between problem-based and project-based learning in five dimensions: input, situation, qualification of teachers, orientation, and output (Kolmos & de Graaff, 2015). Both problem-based learning and project-based learning begin with problems and focus on students' self-directed learning. However, while problem-based learning could be applied in a teacher-directed classroom, the situation of project-based learning is usually a simulated workplace, where teachers could also be involved in the learning processes as a source of professional knowledge (Kolmos & de Graaff, 2015). Since in project-based learning, students are expected to construct a product by solving problems, which requires a higher level of students' professional abilities, PBL is often utilized at the end of study programs (Kolmos & de Graaff, 2015; Savin-Baden, 2014). However, with the increasing practice of PBL methods, for many engineering educators, PBL is regarded as a coalition involving both elements of problem orientation and project-organized learning (Kolmos et al., 2004; Wilkerson & Gijselaers, 1996). Especially in international literature, PBL could mean both problem-based learning and project-based learning (Kolmos & Fink, 2004; Savin-Baden, 2014).

For further understanding of PBL, researchers have conducted reviews on the definitions of PBL, the history of PBL, the theoretical foundation of PBL, and diverse PBL designs (Dochy et al., 2003; Thomas, 1997). Savin-Baden (2014, p. 202-203) proposed nine types of PBL constellations, namely: 1) "Problem-based learning for knowledge management"; 2) "Problem-based learning through activity"; 3)"Project-led problem-based learning"; 4) "Problem-based learning for practical capabilities"; 5) "Problem-based learning for design-based learning"; 6) "Problem-based learning for critical understanding"; 7) "Problem-based learning for multimodal reasoning"; 8) "Collaborative distributed problem-based learning"; and 9) "Problem-based learning for transformation and social." The division of PBL constellations was based on the type of problems, learning objectives, level of interaction, and assessment method (Savin-Baden, 2014, p. 202-203). For example, the basic level of PBL – constellation one focuses on the understanding of knowledge; thus, summative assessments such as exams and tests are often utilized in this constellation. Constellations with higher interaction levels place weight on learning in and with uncertainty and complexity, in order to develop students' critical thinking (constellation seven), teamwork skills (constellation eight), and interrogation of diverse knowledge (constellation nine).

Consequently, in these constellations, formative assessment approaches such as self-analysis and peer review are adopted to assess students' learning outcomes.

Although the strategies of PBL implementation vary from the program to single-course level, from problem-orientated to project-orientated, the fundamental learning principles have been identified (Edström & Kolmos, 2014; Kolmos et al., 2009):

1) Cognitive learning: Problem orientation is the central principle in this dimension, serving as the starting point as well as the basis for learning, no matter whether the types of problems are ill-structured or well defined. To inspire students' learning motivation, problems are set in a specific context, identified by students based on their experience and interests. Then students become the center of learning to analyze problems and find possible solutions. In this dimension, problem orientation emphasizes the formulation of a question instead of finding an answer. Moreover, this dimension also contains project orientation, which is developed based on problem orientation. When doing projects, students would be faced with multiple tasks of analyzing and solving complex problems.

2) Contents: This dimension includes links between theory and practice, interdisciplinary learning, and exemplary practice. In PBL, problems mostly come from the real world. To solve those problems, students need to use theories to analyze the problems and apply their professional knowledge in practice. In this dimension, interdisciplinary learning has been identified as a necessary component for formulating and solving real-world problems since it enables students to consider the problems from various perspectives of different subjects. Meanwhile, the exemplary practice has also been emphasized in this dimension, meaning that students could develop their understanding of the selected problems in complex situations and transfer what they have learned into similar contexts or fields.

3) Collaborative learning: Teamwork and self-directed learning are highlighted as central principles in this dimension. PBL includes the social approach where learning occurs via communication, interaction, and negotiation. Thus, students do not learn alone in PBL, but work in teams to reach a shared goal. During the teamwork process, students can identify the learning goals and problems together, construct the meaning of their experience, share knowledge and values, and organize the teamwork, which enables students to become the center of learning and to develop a collective ownership of learning in teams.

These three broad PBL principles cover both problem-based learning and project-based learning. The variation of PBL lies in practice, and it is important to emphasize the fundamental learning principles behind the diverse practices. For PBL implementation, no matter what educational level the PBL design is, the three learning principles need to be considered and reflected in practice.

In this study, PBL is conceptualized as a student-centered learning approach, in which students form teams and work on real-life problems while teachers become the instructors, supervisors, or facilitators (Edström & Kolmos, 2014; Kolmos et al., 2009). This definition includes both project-based and problem-based learning practices, ranging from the single-course to the curriculum level, and from one discipline to multiple disciplines. And no matter in what types of PBL practice, the same fundamental principle is that students, as the center of learning, have the ownership of their learning processes (Edström & Kolmos, 2014). We acknowledge that PBL has diverse definitions depending on different research, and we choose this wording because of the principles of the AAU PBL model.

2.1.2. IMPLEMENTATION OF PBL

With the guidance of the learning principles of PBL, studies on PBL implementation have boomed in recent decades, including PBL design among engineering educational institutions (Johnson & Ulseth, 2016; Kolmos & Fink, 2004; Perrenet et al., 2000), students' learning outcomes in PBL (Beddoes et al., 2010; Thomas, 1997), the effectiveness of PBL (Dochy et al., 2003), and practice of pedagogical PBL training for academic faculty (Chen et al., 2021). Many researchers have reported their PBL practices at the course level, the curriculum level, and the cross-institution level.

Taking an overview of current PBL implementation, the course level PBL has been reported with the highest frequency because a single course could provide a more controlled environment for changing and practicing new learning methods (Dochy et al., 2003). PBL practices at the course level range from solving a single problem in a short period (such as one week) or learning cases in one month to conducting a project in one semester, in which processes the problems could be well defined or illustrated, proposed by a teacher or by students themselves (Ahern, 2010; Chaparro-Peláez et al., 2013; Gratchev & Jeng, 2018; Hugo et al., 2012; McCrum, 2017). It was pointed out that compared with traditional lectures, adding PBL methods into courses effectively fosters students' motivation and engagement in learning professional knowledge, improving hands-on skills, and solving complex problems (Bani-Hani et al., 2018; Beddoes et al., 2010; Gijbels et al., 2005). However, applying PBL in a single course also brought new challenges, such as a lack of support from the university level, heavy workloads for both students and teachers, and a lack of repercussions throughout the curriculum (Arman, 2018; Chan, 2016; Du et al., 2019; Hassan et al., 2015).

In comparison, PBL implementation at the curriculum level could overcome these challenges since it focuses on students' sustainable and comprehensive development, and universities could provide pedagogical training and support for both teachers and students (Ahern, 2010; Lehmann et al., 2008). At this level, PBL, regarded as an institutional-level learning strategy, is utilized in all study programs (Dahms et al., 2017; Guerra, 2017) or is applied as a part of the curriculum (1–3 years) (Hosseinzadeh & Hesamzadeh, 2012; Perrenet et al., 2000; Simcock et al., 2007). Several universities have reported their PBL practice at the curriculum level, including Aalborg University, University College Dublin, Universidad Europea de Madrid, and Clemson University. Diverse problems and projects are designed for students at different educational levels, based on the progressive learning objectives in the curriculum design (Kolmos et al., 2021). For instance, in accordance with Bloom's Taxonomy of learning objectives, students could begin their learning with understanding knowledge, identifying problems, and learning engineering tools, and then, with more PBL experience, students could have the opportunity to collaborate with companies or industry on real-life projects (Zhou, 2012), which could develop their teamwork skills, negotiation skills, project management skills, and leadership, etc. (Du, 2006; Yadav et al., 2011). Of course, it does not mean there is a proper progression in the learning of PBL competences, since in many cases, students are the ones who decide what project they prefer to join in, what course they choose to take to support the project, and what PBL competences they intend to improve (Kolmos, 2017; Johnson & Ulseth, 2016).

Several researchers have reported their PBL implementation at the cross-institutional level (Du et al., 2013; Ota & Punyabukkana, 2016; Simcock et al., 2007). This type of PBL practice involves collaboration between universities from one or more countries, and the projects or programs could take from one semester to one academic year. Compared with other levels, PBL at the cross-institution level not only provides a simulated environment for students to work as professional engineers, but also enables students to experience cultural diversity and develop their international horizons, which is important for global engineering talents (Du et al., 2013).

While a growing number of engineering programs have adopted PBL methods at diverse levels, many meta-analysis studies have reviewed different project-based or problem-based learning cases (Dochy et al., 2003; Gijbels et al., 2005; Reis et al., 2017). Nevertheless, in recent years, few literature reviews explored diverse levels of PBL practices and challenges faced by students, academic faculty, and universities regarding PBL practice. With blooming research on various PBL designs in recent 20 years, an updated systematic literature review is needed to summarize the current PBL practice, learning principles of PBL, and challenges for PBL implementation (Chen et al., 2021).

For this study, in order to explore how PBL supports students' engineering identity development, we need to understand PBL as a concept itself firstly. Thus, in Phase one, this study presents a systematic literature review on PBL research, aimed to answer the first research question (Paper I): What characterizes PBL practices in engineering education, and what challenges are addressed in current PBL implementation?

2.2. ENGINEERING IDENTITY

2.2.1. CONCEPTUALIZING IDENTITY

The notion of identity has been conceptualized in various theoretical approaches, including developmental psychology, social psychology, and sociocultural perspectives. From a psychological perspective, the key elements of selfhood, including self-concept, self-efficacy, and motivational beliefs, are critical to identity formation. Scholars taking this approach consider identity to be primarily an internal developmental process that is impacted by social circumstances with the participation of, and in connection to, others (Erikson, 1968).

From a social psychology perspective, which highlights the collective nature of human identity, the term "group identity" is used to explain the phenomenon of people developing a sense of identity from the group they belong to, along lines such as ethnicity or gender (Tajfel et al., 1979). In their proposal of social identity theory, Tajfel et al. (1979, p. 33) suggest that

> “Social identity is a person’s sense of self, derived from perceived membership in social groups.”

Three major components within social identity provide the psychological basis for such belongingness: 1) categorization, which is the process of labeling by putting people into categories; 2) identification, which refers to how we associate ourselves with certain groups according to our self-image; and 3) comparisons, which refers to how we compare the groups to which we have a sense of belonging with other groups. Social categorization has been described as a relational, flexible, and interactive component of self-categorization (Turner & Reynolds, 2011). Social identity and group membership affect individual behavior according to the norms of the environment; therefore, relevant knowledge may enhance one’s ability to use one’s sense of identity as a positive force (Charness & Chen, 2020).

Gee (2000) defines identity as seeing oneself as “a certain kind of person" (p. 99), and suggests that individuals accept, adjust to, and negotiate multiple dimensions of their identity. Gee identifies four interconnected aspects of identity, namely: 1) the nature identity, which is shaped by uncontrollable forces such as ethnicity and gender; 2) the institutional identity, which is formed by one’s institutional and professional positions; 3) the discourse identity, which highlights how individuals are recognized by others; and 4) the affinity identity of group membership, emerging through participation in shared practices.

In contrast to psychological approaches, sociocultural views of identity place greater emphasis on emergent interaction between individuals and their social settings. Individuals’ identity formation process is considered to include more agentic actions and choices by individuals rather than their being merely passive recipients of expected outcomes and the reproduction of established practices (Holland et al., 1998). This approach underscores the "becoming" and "belonging" (instead of "being") aspects of identity formation and the mutual shaping of individuals and their environments.

While the psychological approach to understanding identity has been criticized for giving insufficient attention to relationships and the environment, the sociocultural approach has been criticized for its lack of focus on the personal subject (Billett, 2006). Consequently, a subject-centered sociocultural approach has been proposed (Eteläpelto et al., 2013), arguing for the inseparability of contextual factors and personal values in the process of identity development. The function of the environment could support or constrain an individual's identity construction and development. In line with this view, this study conceptualizes identity as not only individuals' accounts of their social psychology and cognization, but also their interaction with social factors. Instead of merely focusing on the constitution of identity, this perspective also examines how individuals achieve identity, particularly in a professional setting, through the interaction of individual values and sources/constraints from the sociocultural environment (Eteläpelto et al., 2013). Based on this perspective, identity development is agentic and dynamic, influenced by and influencing the socio-cultural and institutional context in which it is situated (Billett, 2006). In addition, with this theoretical starting point, we can link the analysis of identity development to the discussion of learning, seeing identity as being situated in a larger historical, social, and cultural setting and within circumstances undergoing changes (Lave & Wenger, 1991; Vygotsky, 1978). According to Vygotsky's (1978) sociocultural theory, individuals are agentic with wills and the power to control their own behaviors. Learning is a process that creates change in identity through participation and through the shift from peripheral to full participation (Wenger, 1999). In this change process, individuals may have a purposeful influence on their environments through interactions with peers, teams, instructors, and communities (Billett, 2006; Vygotsky, 1978). The identity negotiation integrated with the learning process is a dynamic process in which agency is manifested, and which exhibits continuity with past experiences and involves the current practice and the future plan via expected objectives (Billett, 2006).

2.2.2. CONCEPTUALIZING ENGINEERING IDENTITY

As an important component of identity, professional identity has increasingly received research attention. It has been defined as follows:

> Professional identity is the self-image that permits feelings of personal adequacy and satisfaction in the performance of the expected role. (Ewan, 1988, p. 85)

Professional identity could be constructed through the dynamic process of professional socialization. It could help individual development by

> "Developing individuals' attitudes, beliefs, and standards that support the practitioner role and identify themselves as members of the profession (Higgs, 1993, p. 10)."

When it comes to the field of engineering education, students' professional identity as engineers, or their "engineering identity" (Morelock, 2017, p. 1241), not only includes an understanding of their professional responsibilities and abilities, but also involves the processes in which they identify and prepare themselves to become engineers in practice (Dannels, 2000; Godwin, 2016).

To conceptualize engineering identity, diverse theoretical frameworks have been taken as guidance. Key concepts associated with the scholarship of engineering identity include role identity, professional roles, and professional identity (which is often referred to as "engineering identity"). From the psychology and social cognition perspectives, scholars have examined how engineering identity negotiating involves students' interests and motivation (Godwin, 2016; Godwin & Kirn, 2020), their efficacy in engineering academic studies (Fleming et al., 2013), and their developmental stages (Meyers et al., 2012). Especially, the notion of role identity was proposed:

> Role identity is a role-based persona complete with goals, values, beliefs, norms, interaction styles, and time horizons. (Ashforth, 2001, p. 51)

Role identity has been employed as the conceptual base for several studies on engineering identity, highlighting how individuals navigate particular roles through fulfilling socially defined positions, conforming to established norms, and engaging in negotiation between multiple identities (Foor et al., 2007; Godwin & Kirn, 2020; Kajfez & McNair, 2014).

From the perspective of the socialization theories, engineering identity has been regarded as "a feeling of fitting with the engineering group" (Knight et al., 2013, p. 7), which is a learning outcome of students' integration into the engineering communities and participation in professional socialization activities (Bragg, 1976; Hernandez-Martinez, 2016). Through professional socialization, students could acquire fundamental knowledge, professional skills, and acceptable behavior for the roles of engineers (Bragg, 1976; Miller & Wager, 1971). It is a continuous process in which students are able to identify professional roles based on the interpretations of their positions in the engineering communities and the expectations from the environment (Craps et al., 2020).

Similarly, in sociocultural theories, engineering identity is constructed and developed through negotiation between individual values and social expectations of the specific professional roles, which means engineering identity development is not only an outcome of professional socialization but also a sociocultural production process including the interaction of individual autonomy and social agency (Eliot & Turns, 2011; Tonso, 2015). Considering the identity as a nexus of multiple members, students' various backgrounds, including gender, ethnicity, prior experiences, social capital, and so on, also influences their engineering identity negotiation experience (Trytten et al., 2012). In this study, following the sociocultural approach (Eteläpelto et al., 2013), engineering identity has been defined as an awareness of the required skills for an engineer, a sense of belonging among the engineering community, and self-identification as future engineers (Capobianco et al., 2012; Knight et al., 2013; Meyers et al., 2012). And engineering identity development has been regarded as a dynamic process in which the subjectivity of individual values (including motivation, interest, efficacy, self-beliefs, etc.) is incorporated with the socio-cultural sources (including interpersonal relations, environmental, institutional, and cultural aspects).

2.2.3. STUDIES OF ENGINEERING IDENTITY

With diverse definitions of the concepts of engineering identity, a large body of literature has explored in which way engineering identity could be measured. One widely adopted framework is Gee's (2000) academic identity framework with four dimensions: nature identity (developed from our nature), institution identity (developed from our positions authorized by institutions), discourse identity (developed from others' recognition), and affinity identity (developed from experiences shared with affinity groups). These interactional dimensions of identity construct one's whole identity in specific ways according to the context and situations. Applying Gee's (2000) academic identity framework in the field of engineering education, Capobianco et al. (2012) designed and tested an instrument with 20 items to explore engineering identity. Through factors analysis, their work reported two components of engineering identity, labeled as academic and engineering career. Moreover, in order to explore racial, ethnic, and gender identities in STEM fields, Carlone and Johnson (2007) proposed an optimized identity framework with the three dimensions of performance, recognition, and competence. Specifically, performance refers to students' social performances of related professional practices, such as their "ways of talking and using tools." In the dimension of recognition, how students recognized themselves and how others (e.g., peers, teachers, and parents) recognized them as good engineering students were measured. The third dimension, competence, means students' knowledge and understanding of professional content. Exemplifying Carlone and Johnson's model, Hazari et al. (2013) added a new dimension, interest, through a survey of science and engineering students. This dimension refers to students' interest in STEM content (Hazari et al., 2013).

Subsequently, based on previous work on engineering identity measurement (Hazari et al., 2013), Godwin and Kirn (2020) identified three dimensions of engineering identity by exploring engineering students' attitudes and beliefs in choosing to study engineering from the angle of a role identity theory. Godwin's (2016) model of engineering identity involved three dimensions – recognition, performance, and interest. Based on this model, an instrument with 11 items was also designed and developed (Godwin, 2016), including questions related to students' interest in STEM fields, self-confidence in terms of doing well in studying engineering, and recognition from parents, peers, and academic faculty.

While several previous studies have explored the measurement of engineering identity, mainly focusing on individual learning processes (Chen et al., 2020), other researchers emphasized the link between personal identity development and involvement in the engineering communities. Meyers et al. (2012) proposed and tested a scale to measure engineering identity, which not only included individual learning experience and engineering competence beliefs, but also highlighted the importance of students' collaboration with peers on engineering work. Experience of communicating with technical terminology, sharing goals and ideas, and leading a design team have been identified as necessary components for students to be considered as engineers (Meyers et al., 2012). Similar items of teamwork were also included in the Engineering Student Identity Survey conducted by Pierrakos et al. (2016). The level of cooperation with others in the engineering community has been pointed out as having a demonstrated effect on students' self-categorization as a valued member of a group, consequently influencing their choice to become engineers or not (Pierrakos et al., 2016). In addition, research guided by sociocultural theories also acknowledged students' evolvement in the engineering communities as a significant element of engineering identity. And related items were reported, such as interaction with industry or companies, gaining practical engineering experience during undergraduate study, establishing relationships with fellow engineers, and finding a role model in the industry or companies (Meyers et al., 2012, Pierrakos et al., 2016).

2.2.4. IMPACT FACTORS OF ENGINEERING IDENTITY DEVELOPMENT

With diverse understanding and measurement tools of engineering identity, a large body of literature has also identified impact factors of engineering identity development, including both sources and constraints.

In terms of factors and sources contributing to students' engineering identity development, both internal and external sources were reported by prior studies and summarized by Paper II, as shown in Table 2-1. This framework with two domains of sources was built upon the conceptual foundation of identity from a sociocultural approach, which emphasizes that the engineering identity development process embraces interactions between the individual cognitive characteristics and the social context. Specifically, internal sources refer to intrinsic motivations that drive engineering students to explore engineering topics, learn engineering content, and stay in engineering fields, such as interest, orientation, competence beliefs, self-recognition, and so on (Godwin, 2016; Jones et al., 2010). At the early stages of a student's studies, interest in STEM fields, especially in engineering content, had a significant function in students' evolvement of the engineering professional socialization process (Godwin, 2016; Patrick et al., 2018). For these students, exploring engineering topics was intriguing and could motivate them to choose engineering programs to learn professional knowledge and skills (Godwin & Potvin, 2017; Pierrakos et al., 2016). With higher exposure to engineering practice as well as the process of personal development and maturation, students' expected learning outcomes, intentions, career orientation, and life expectancy became the key intrinsic motivation influencing students' persistence in engineering fields (Barbarà-i-Molinero et al., 2017; Cass et al., 2017).

Students' competence beliefs were also regarded as internal sources for engineering identity development. Competence beliefs reflected a student's preparation for becoming a qualified engineer and self-confidence in his/her capabilities to do well in engineering work (Dehing et al., 2013; Godwin, 2016; Prybutok et al., 2016). Students' competence beliefs were not limited to engineering fields but also included their performance in science, math, and physics, since student performance in these subjects had a significant influence on their engineering identity development (Godwin et al., 2016; Patrick et al., 2018; Prybutok et al., 2016). Meanwhile, along with professional knowledge and skills, generic abilities, such as teamwork skills, project management skills, leadership, and so on, were also reported as indispensable components of engineering students' competence beliefs (Fleming et al., 2013; Meyers et al., 2012).

Another internal source for engineering identity development is self-recognition, meaning that students have the feeling of being included and melding themselves into being recognizable as engineers, which enables them to position themselves in engineering communities (Marra et al., 2014; Stevens et al., 2015; Tonso, 2015). With self-recognition as future engineers, students could learn and follow the rules of professional behaviors to fulfill socially defined positions of engineers (Fleming et al., 2013; Stevens et al., 2015).

In addition to internal sources, external sources have been recognized as another key aspect of engineering identity development, being concerned with how the learning environment provides opportunities for students to conduct engineering practice and get involved in professional socialization activities.

Specifically, external sources include four key aspects: professional training from the curriculum, interactions with peers (teamwork), interactions with members of the engineering community (engineers, companies, industry, etc.), and recognition from others. Firstly, based upon specific learning objectives, the professional curriculums were designed for students to provide opportunities to learn theoretical STEM knowledge, basic technical skills, and acceptable behavior for engineers (Chemers et al., 2011; Hatmaker, 2013). This could be the main approach to, and the beginning of, a student's professional socialization process.

Secondly, during the professional socialization process, students could have opportunities to interact with peers, including in-team collaboration, after-class communication, and other formal or informal interactions. These activities enabled students to identify learning goals together, co-construct knowledge and meaning of their experience, share goals and values, and learn from each other (Fleming et al., 2013; Knight et al., 2013). On the one hand, these learning processes permitted students to better understand their abilities and aspirations through matching book learning to real-life situations with peers, effectively affecting their engineering identity development (Pierrakos et al., 2016; Tonso, 2006). Meyers et al. (2012, p. 119) reported that "making competent design decisions," "working with others to share ideas," and "accepting responsibility in groups" were the necessary experiences contributing to students' engineering identity development. On the other hand, opportunities to use engineering terminology, grow together with peers, and move towards a specific engineering field could create an emotional atmosphere of feeling professional and becoming engineers (Fleming et al., 2013; Meyers et al., 2012). Several researchers, such as Pierrakos et al. (2016) and Tonso (2006), pointed out that teamwork allows students to build self-categorization and develop in-group membership, sequentially, supporting their engineering identity development and strengthening their persistence in engineering fields.

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 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)

Table 2-1. Sources for engineering identity development based on the literature review (Paper II, Chen et al., 2022)

Thirdly, interaction with academic staff and other stakeholders in engineering communities means a student's connections with instructors, lecturers, supervisors, engineers, employers, and other members of engineering communities. Guidance and facilitation from academic staff in the universities provided sources for students to identify their interests, set their career orientation, and find role models (Capobianco et al., 2012; Fleming et al., 2013). Interaction with other stakeholders in engineering communities, such as internships, competition events, volunteer activities, and participation in real-world projects, exposed students to a real-life engineering work context and promoted students' engineering identity development by improving their involvement in a professional community (Chemers et al., 2011; Eliot & Turns, 2011).

Through engaging in a professional curriculum and interacting with members in the engineering community, students might receive others' comments and recognition as engineering students or future engineers. How students perceive these comments could affect their self-cognition and self-belief in becoming engineers (Dehing et al., 2013; Godwin et al., 2016), which is the fourth key aspect of external sources. For students who failed to get positive feedback and recognition of their capabilities from other members in the engineering community, even though they had equipped themselves with engineering knowledge, skills, and abilities, it would be hard for them to develop a sense of belonging in an engineering group (Tonso, 2006).

While prior studies illustrated the constructive impact factors and sources for students' engineering identity development, detractive factors and constraints were also reported by researchers. As with constructive impact factors, the lack of sources, especially the external sources from the learning environment, was the biggest constraint (Morelock, 2017). Lacking professional training and engineering practical experience could decrease students' exposure to engineering, leading students to have fewer opportunities to develop their understanding of engineering work and negotiate engineering identity with other identity (Beam et al., 2009; Du, 2006). Based on a comparison study, Adams et al. (2006) also pointed out that students with more professional experience and higher engagement in professional socialization activities might develop higher levels of professional identity than students with fewer related experiences. It should be noted that, even though students were exposed to the engineering world, they might feel stressed from ineffective teamwork and interactions in the engineering communities, and face unsuccessful identity negotiation in universities or the workplace (Fleming et al., 2013; Morelock, 2017).

Other detractive factors and constraints were related to marginalization issues faced by minorities, especially women in engineering fields (Morelock, 2017). Although more and more attention has been given to increasing diversity, the engineering profession, including education and workplace, is still considered as a male-dominated field owing to the low representation of women (Morton et al., 2016). In terms of external constraints, some women engineering students experienced a "chilly climate" in their learning experience, including a lack of female supervisors and role models, potential gender bias, unequal growth opportunities, and other marginalization situations (Blosser, 2017; Godwin & Potvin, 2017; González-González et al., 2018). These constraints from the learning environment could become obstacles for women engineering students to develop a sense of belonging in engineering groups (Godwin & Potvin, 2017; Hatmaker, 2013). Moreover, researchers pointed out that the "chilly climate" also had a negative influence on internal sources for engineering identity, including higher pressure to pursue engineering, lower competence beliefs, fewer intrinsic motivations, and less self-recognition as future engineers (Baker et al., 2007; Direito et al., 2018; Godwin et al., 2016; Pierrakos et al., 2009).

2.2.5. ENGINEERING IDENTITY DEVELOPMENT IN PBL

While a large body of studies has illustrated the effect of learning activities and engineering-related experiences on students' engineering identity, future research is needed to explore the influence of structured learning design in various sociocultural contexts (Morelock, 2017). In this study, we focus on PBL, which has been adopted as the specific learning context to examine students' engineering identity development. This is because PBL provides a simulated environment for students to work together as real engineers, meeting those components of engineering identity development mentioned above. PBL, as a widely used active learning method to expose engineering students to work-related experiences and teamwork, was reported as a supportive learning environment for engineering identity development (Du, 2006; Johnson & Ulseth, 2016; Johnson et al., 2015; Tan et al., 2016). Students' PBL experience provided students with a high-level involvement in the engineering communities by working on real-life projects in engineering teams, which could fill the gap between university learning outcomes and employer demands (Du, 2006). Similarly, Tan et al. (2016) also emphasized that PBL experience, including teamworking, solving real-life problems, acting like real engineers, using professional terminology, and so on, contributed to the enhancement of students' competence beliefs as future engineers. Based on a comparison study between students from two universities – a community college (PBL) and a traditional university (non-PBL) in the U.S. – Johnson and Ulseth (2016) reported that students with PBL experience showed better professional performance, self-reported higher confidence in their engineering competences, and were better prepared for a future engineering career.

Despite those benefits of PBL for engineering students, research also showed that engineering students still faced difficulties and challenges when working as teams in a PBL context, which might weaken the effectiveness of PBL in their learning outcomes and identity development. One of the biggest challenges was that students needed to transform their traditional learning perspectives into a PBL environment, where they became the center of learning (Du, 2006). In this case, students might run into difficulties when identifying their roles in groups, finding core problems to solve, and constructing professional knowledge and skills. Zastavker et al. (2006) pointed out that engineering students, particularly female students, might experience anxiety, heavy workload, and even marginalization in teamwork processes. With these challenges, although PBL was identified as an effective pathway to improve students' engineering identity by limited studies under the related topics of PBL and engineering identity, the way in which teamwork enables the development of engineering identity in PBL is still unclear. Moreover, among limited studies on PBL and engineering identity, most PBL implementations were at the single-course level rather than in a systemic PBL curriculum, where PBL has been regarded as the core learning principle for the professional programs and has greater effectiveness on students' longitudinal development (Arman, 2018; Du et al., 2019). Research remains inconclusive regarding how a student's sense of professional belonging is developed in such a context (Du, 2006; Du et al., 2021; Morelock, 2017). Thus, concentrating on engineering identity development in a systemic PBL environment, this study attempted to answer the following questions:

1) What characterizes PBL practices in engineering education, and what challenges are addressed in current PBL implementation? (Paper I)

2) What sources are considered important by students for the development of their engineering identity in a PBL learning environment? (Paper II)

3) What elements of the PBL environment do students consider contribute to their engineering identity development? (Paper III)

CHAPTER 3. METHODOLOGY

3.1. CONTEXT OF THE EMPIRICAL STUDIES

This research took place in the context of a university in engineering education in Denmark, Aalborg University (AAU), which has adopted PBL as the core learning approach for the entire curriculum design since the 1970s, referred to as a systemic PBL context in this research. In a systemic PBL context, four constituting elements have been identified: “an inclusive mix of knowledge and problem modes”; “diverse problem types and project approaches”; “an interlinked curriculum with progressive learning objectives and learning outcomes”; and “the emphasis on PBL competence development,” including employability skills, organizational understanding, critical thinking, problem identification and analysis skills, and abilities to apply knowledge in different situations (Kolmos et al., 2021, p. 4).

For the AAU PBL model, the same fundamental learning philosophy and learning principles have been applied to various designs of professional learning programs, including problem solving, student-centered learning, self-directed learning, collaborative learning, new roles for teachers as facilitators, and interdisciplinary learning (Kolmos, 1996; Kolmos et al., 2021). In this PBL curriculum, every semester offers 30 ECTS (European Credit Transfer System) credits, comprising 15 ECTS credits for projects and 15 ECTS credits for courses. The model for every semester is shown in Figure 3-1. With projects in every semester, this PBL curriculum could create a progression in learning outcomes, including both professional knowledge and PBL competences. This is what frames a systemic PBL approach (Kolmos et al., 2021).

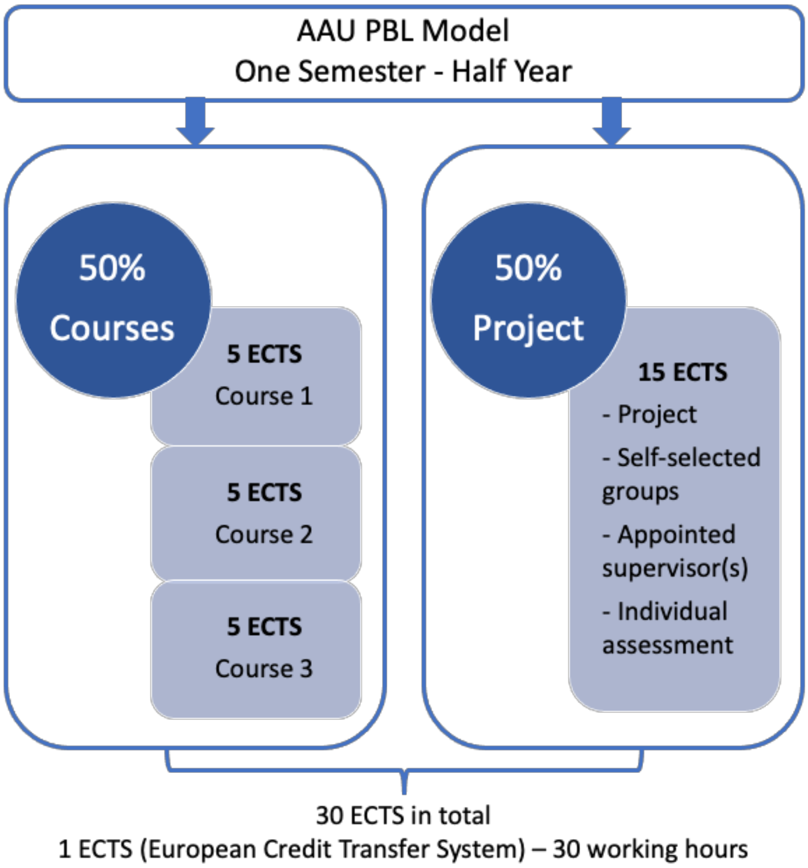

Figure 3-1 The AAU PBL model (adapted from Kolmos et al., 2013, p. 292)

In this section of the project, students have opportunities to identify the problems/themes of projects, conduct self-directed learning, work on interdisciplinary projects, experience collaborative learning, and cooperate with practical engineers and companies. Specific learning goals are set for students at different educational levels, which are categorized as knowledge, skills, and competences, based on the European qualification framework adopted by the Danish Agency for Science, Technology, and Innovation (Ministry of Higher Education and Science, 2013). In the AAU PBL model, students usually have a daily meeting with group members on workdays as well as a regular meeting with supervisors. The role of teachers has changed from lecturers and instructors to supervisors and facilitators, who provide guidance for students' projects and facilitate the teamwork process instead of giving the answers directly. To assess students' learning outcomes, diverse assessment methods are combined in this PBL model, including individual oral examination, group oral defense, project reports, and peer assessment.

The implementation of the AAU PBL model has received satisfying feedback from the industry and provided empirical evidence on the effectiveness of PBL for training qualified engineers with both professional and generic competences (Edström & Kolmos, 2014; Kolmos & Holgaard, 2010; Kolmos et al., 2021). Thus, this study selects the AAU PBL model as the context of this research to explore the interplay of diverse elements/sources for students' engineering identity development. Students from this systemic PBL context have experienced PBL several times, and their perspectives might provide us with a deeper understanding of what elements/sources contribute to their professional identity development.

3.2. RESEARCH DESIGN

The research questions and their purpose characterize the nature of the methodology of data collection and analysis, indicating the investigation methods under possible paradigms (Creswell, 2009). This research aims to explore how engineering students perceive the importance of their access to, and influences of, elements from the PBL environment to develop their understanding of engineering work and engineering identity. The research goal could be subdivided into three aspects: developing a comprehensive understanding of the PBL environment, identifying diverse sources that have the potential to improve engineering identity development in a PBL context, and exploring the influence of identified sources/elements on engineering identity development. For these purposes, this research seeks to comprehend and gather students' perspectives in a specific context named a "systemic PBL curriculum," and design an analytic tool to explore the influence of diverse elements in this context on students' engineering identity development. According to Creswell (2009), an exploratory sequential design, involving the procedure of collecting qualitative data and following up with a quantitative study, enables us to identify sources from the PBL context firstly, design and test an instrument accordingly, and subsequently further explore the influence of these sources on engineering identity development.

For Phase One of this study, a systemic literature review method is adopted to develop a comprehensive understanding of the characteristics of diverse PBL practices. The research question is:

1) What characterizes PBL practices in engineering education, and what challenges are addressed in current PBL implementation? (Paper I)

The systematic review outcomes support the need for an explorative study focusing on students' engineering identity development in a systemic PBL environment. In Phase two of this study, the research design adopts an exploratory mixed method due to the following research questions:

2) What sources are considered important by students for the development of their engineering identity in a PBL learning environment? (Paper II)

3) What elements in the PBL environment do students consider contribute to their engineering identity development? (Paper III)

Figure 3-2 illustrates an overview of the research design with an exploratory mixed method. Specifically, in the first phase, a literature review was conducted to develop a theoretical understanding of key concepts in this research, including a systematic literature review on PBL implementation and a review on the concepts of engineering identity as well as its development process. In order to answer the first research question, the literature review on PBL implementation reports current PBL practices at diverse levels, ranging from the course level to the curriculum level. This review of current PBL implementation highlights that PBL is not one type of learning approach but includes various types of practices that could be applied at different levels. In addition, similar and different challenges for applying effective PBL methods from the course level to the curriculum level were summarized, calling for further exploration of, and discussion on the functions of various PBL implementations in training qualified engineers. In particular, the literature review also identifies the challenges of students' longitudinal development in single-course-level PBL contexts (Arman, 2018). The functions of the course-level PBL practice in students' professional identity development are limited, and it is unclear in which way students could construct and develop their engineering identity through a curriculum-level PBL practice (Du et al., 2021). Thus, the results of the literature review on diverse PBL implementations lead our following research to focus on the PBL practice at the curriculum level – a systemic PBL environment.

In the second phase, firstly, a literature review on engineering identity was conducted to develop a comprehensive understanding of the concept of engineering identity and relevant analytical tools from the perspectives of different theories. Through the literature review, a theoretical model of sources for engineering identity development has been proposed. This model provides inspiration and guidance for further exploration of important sources from a specific PBL environment contributing to students' engineering identity development.

In the next step, to answer the second research question, a qualitative study was conducted to investigate students' perspectives of important sources in PBL contributing to their engineering identity development, which enabled researchers to listen to students' own learning stories and PBL experiences. Diverse sources in two domains – internal sources and external sources – were identified as contributing factors in developing students' sense of becoming engineers, informing the design of a relevant analytical tool in the following quantitative study by providing empirical evidence.

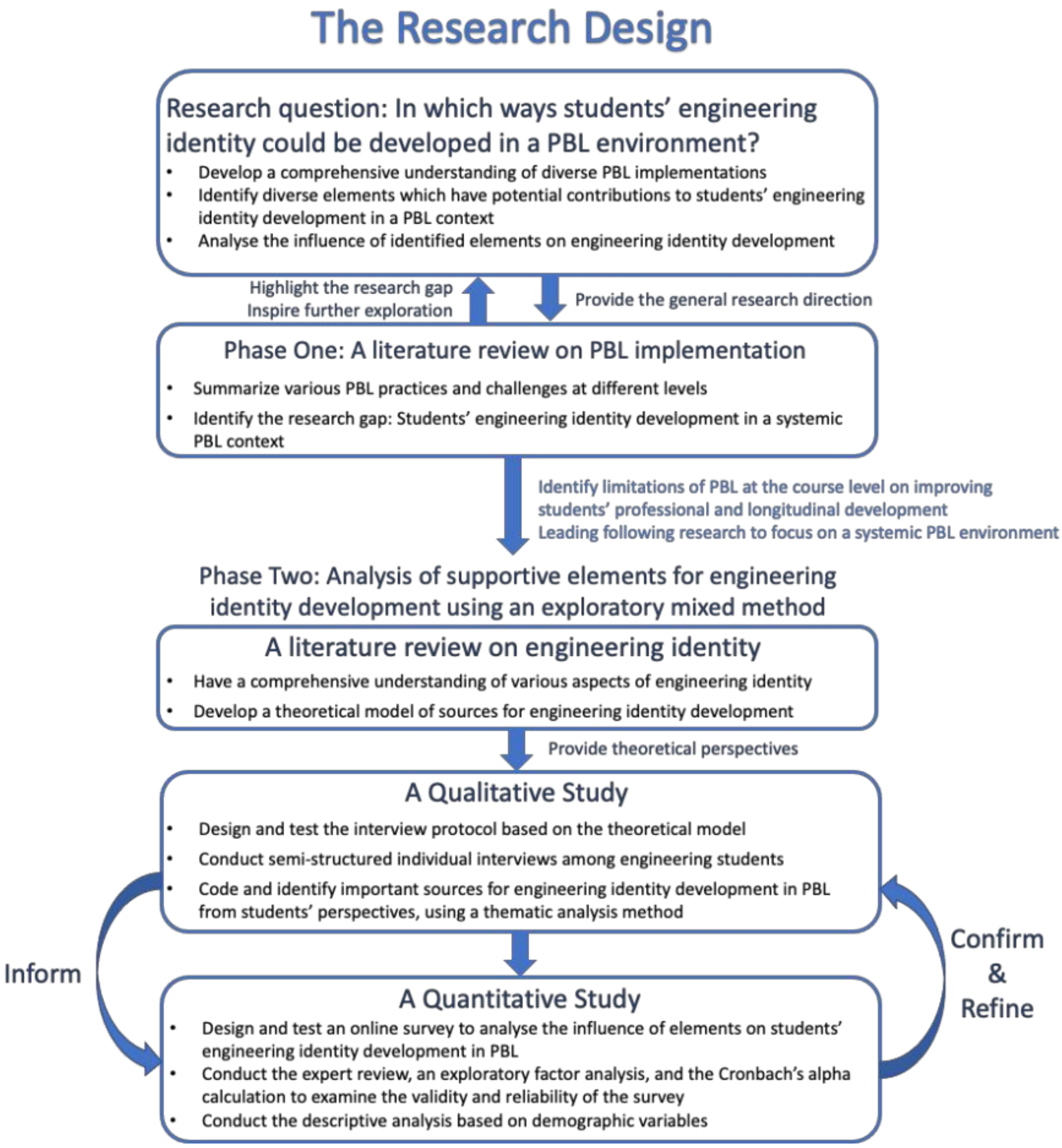

Figure 3-2 An overview of the research design

To answer the third research question, a quantitative method was used in this phase. A survey to explore the contributions of diverse elements to engineering identity development was designed and validated in a systemic PBL context. By collecting different demographic variables (e.g., gender, educational levels, and programs), differences between students' engineering identity and related impact factors are also discussed.

The qualitative and quantitative studies are complementary. Evidence from the literature review and findings in prior qualitative studies (Chen et al., 2020; Chen et al., 2022) became the basis for designing the survey. The model of sources for engineering identity development, including seven themes and 52 codes, provides inspiration for the content of items in the survey. The results from this quantitative study could refine and confirm the findings in our prior studies by validating the analytical tool and conducting the survey among a larger student group. For example, the quantitative data indicate that PBL could enhance students' interests in engineering content and interdisciplinary projects. Through collaboration with engineering companies, students could develop the feeling of inclusivity in an engineering community, understand how to perform in professional ways, and learn to take responsibility actively. These findings are in line with those in the qualitative study. In addition, data from these two studies also indicate the differences between individual experiences and common patterns among a student group. For instance, the experiences of negotiating between different stakeholders and finding a role model were identified as important sources for engineering identity development in the interviews, while the results of the quantitative study reflect that only a few students had similar experiences. Based on similar and different findings between the qualitative and quantitative studies, we could have a comprehensive understanding of the ways in which PBL could contribute to students' engineering identity development.

3.3. PAPER I – A SYSTEMATIC REVIEW IN PHASE 1

3.3.1. DATA COLLECTION

This systematic literature review on current PBL implementation and the challenges of practicing PBL followed Borrego et al.'s (2014) instruction on literature review in engineering education. Firstly, criteria were set for selecting and analyzing relevant articles (Chen et al., 2021), including:

1) Peer-reviewed empirical research written in English

2) Research conducted in PBL (problem-/project-based learning) environments

3) Research conducted in the context of higher engineering education

4) Research conducted in a real-life classroom or study programs rather than under controlled experiment situations

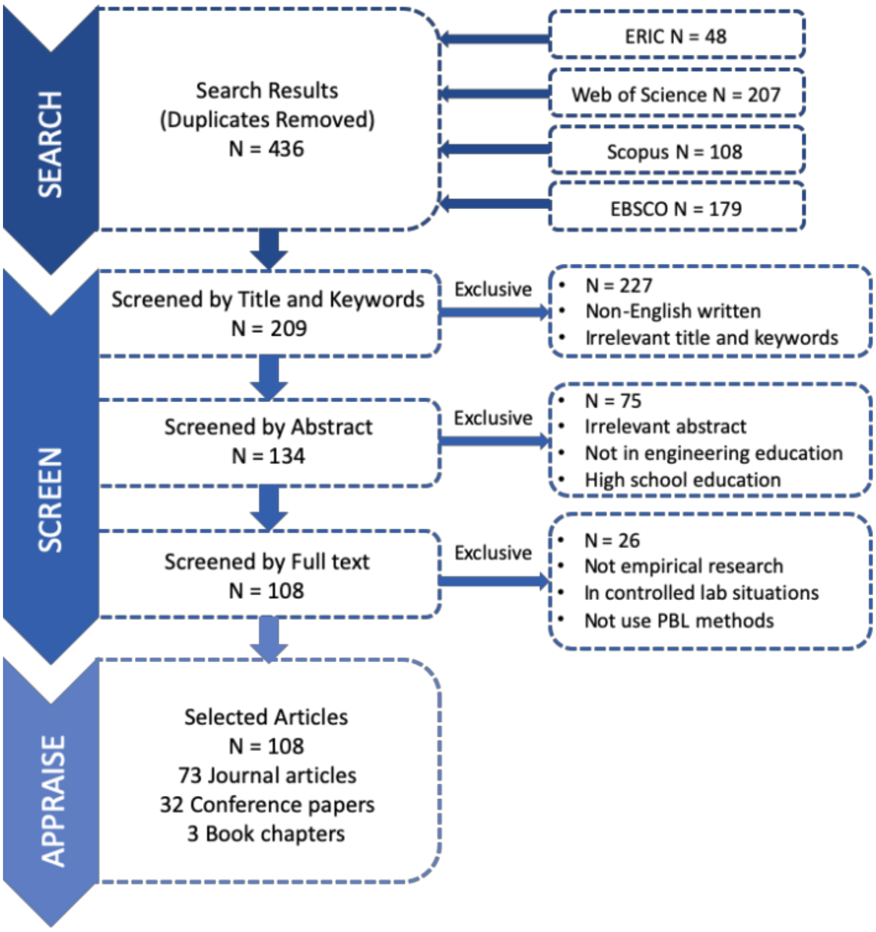

Figure 3-3 Data collecting process for the literature review (Chen et al., 2021)

A time frame from 2000 to 2019 was set for the inclusion process, aimed to have an updated overview of current PBL practices in engineering education. To illustrate the diversity of PBL implementations in different engineering educational institutions, four databases were selected for searching and selecting conference proceedings, journal articles, and book chapters, namely EBSCO, ERIC, Web of Science, and SCOPUS. A series of keywords and alternative words were combined and used for searching, such as "PBL (or problem-based, project-based, problem-oriented, etc.)," "engineering education (or manufacturing, etc.)," "implementation (or practice, etc.)," and "challenge (or difficulty, etc.)." The results of data collection are shown in Figure 3-3. After three rounds of the searching and selecting process, 108 articles were contained in this study, including 32 conference proceedings, 73 journal articles, and three book chapters. Details of demographic information on selected articles are shown in Paper I.

3.3.2. DATA ANALYSIS

With the aim of providing an overview of diverse PBL practices, we conducted the thematic analysis, and initial themes of characteristics of PBL implementation were set up to guide the coding process, such as learning objectives, types of problems/projects, team size, and assessment methods. With initial (first level) themes, the lead coder conducted open coding on ten randomly selected articles among all included papers to build a structured codebook (Creswell, 2009). In this process, Savin-Baden's (2014) theoretical framework of PBL classification was utilized as a guide to identify different categories of PBL implementations, which includes nine PBL constellations as mentioned in Section 2.1.1. in Chapter 2.

After three rounds of revision, the codebook was built and applied to all selected articles. With a developed codebook, information on PBL practice levels, PBL types, learning objectives, types of problems/projects, project duration, team size, evaluation methods, and challenges of PBL implementations reported in prior empirical research was coded in the data analysis process. Specifically, four levels of PBL implementation were acknowledged, including the course level, cross-course level, curriculum level, and project level (Chen et al., 2021). Under the initial code of challenges, subthemes were also identified through open coding, containing challenges for individuals, challenges for institutions, and challenges at the culture level.

3.3.3. VALIDITY

Multiple strategies were adopted to improve the validity of coding processes. Firstly, researchers in this study, especially the lead coder, read all the selected papers multiple times and practiced self-reflection throughout the data selection and analysis process. To minimize the researchers' bias, researcher triangulation was conducted, including two experts in PBL and one external researcher in engineering education. A regular group discussion on the inclusion of articles and data analysis was conducted with the two experts. To build a structured codebook, all codes and themes were named, revised, and refined for two rounds via review and discussion in the research group. Then, in the third round of code revision, an external researcher, who is experienced in engineering education research and qualitative methods but was not a co-author of this study, was introduced to the basic information of this study and invited to code eight selected papers independently, using the same built codebook. The eight papers were chosen randomly. Codes and themes were revised through discussion between the external researcher and the lead coder, resulting in a. acceptable agreement rate of over 88% in each category (Creswell, 2009).

3.4. PAPER II – A QUALITATIVE METHOD IN PHASE 2

3.4.1. DATA COLLECTION

With the guidance of a qualitative method, 16 semi-structured interviews were conducted to illustrate students' perceptions of the importance of sources from a systemic PBL environment to develop their engineering identity. The usage of the qualitative interview method enables researchers to hear students' own stories of their learning experiences in PBL programs (Creswell, 2009). Based on the theoretical model of sources for engineering identity development, an interview protocol was designed and revised for three rounds through five pilot interviews, researchers' reflections, and discussions within the research group. Questions for the interview protocol were proposed under two domains (internal sources and external sources) and four themes in each domain, namely interest, intention, competence belief, self-recognition, professional training from the curriculum, teamwork, engagement in a professional community, and recognition from others. For example, in terms of intention in the domain of internal sources, the question "What drove you to choose to study engineering?" was asked in the interview. To understand students' competence beliefs, the first question was: "In your opinion, what skills or knowledge are important for engineers?" The follow-up question for this topic reads: "How do you assess yourself in these aspects?" In the domain of external sources, in terms of professional training from the curriculum, students were asked: "In your current study, what influences/enhances your motivation in learning engineering?" And this was followed by another question: "What kind of projects would make you feel more like engineers?" We also interviewed students about their interactions with others in the engineering community, with a series of questions, such as "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?" All questions in the interview protocol are listed in Appendix A.

In order to recruit students with PBL experience, the method of purposeful sampling was utilized in this research. Interview invitation emails were sent to third- and fourth-year students from different engineering programs with a PBL curriculum at Aalborg University, including energy engineering, biotechnology, computer engineering, civil engineering, and so on. Within each program, students from one subject or multiple subjects formed student groups (with 3–6 students) to finish projects under one discipline or interdisciplinary projects. The reason for selecting junior and senior students is that those students were assumed with higher engineering identity and career plans than first-year students because of their richer PBL experience (Du, 2006). Basic information about the participants can be seen in Table 3-1, where pseudonyms are used to protect their privacy. Of the 16 participants, four students are female and 12 are male. Ten students are from Europe, five are from Asia, and one is from the Middle East. We acknowledge that in a Danish university, international students might have different learning experiences in PBL compared with Danish students, since Danish students could well have more prior PBL experience, while international students might face the challenges of cultural differences, language issues, a lack of PBL skills, and transference from teacher-centered to self-directed learning, especially for students without project and teamwork experience (Chen et al., 2020). These challenges might become barriers for some students to developing the feeling of inclusivity in engineering groups, but at the same time, through experiencing PBL, international students also realized the benefits of PBL in improving their practical skills and transferable competences (Chen et al., 2020). Involving international students could provide us with diverse perspectives of the influence of PBL on engineering identity development.

Table 3-1. Sources for engineering identity development based on the literature review

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

Qualitative data were collected through 16 semi-structured individual reviews, which lasted from 30 to 50 minutes. Every interview was conducted in the last month of the semester, in order to enable students to review the whole PBL process, reflect on their performance, and share their understanding of engineers' work.

3.4.2. DATA ANALYSIS

Sixteen audio-recorded interviews were transcribed and checked twice by the author. The transcriptions were reviewed repeatedly, allowing the lead coder to understand the contents of the transcripts initially. The theoretical model of sources for engineering identity development based on a literature review was utilized to guide the data analysis process before open-ended coding came in. Specifically, two domains and eight themes were defined as the a priori codes (Table 3-2). This model provides a comprehensive understanding of diverse sources based on the subjectivity of individual values and different learning experiences. The theme-related teamwork and project work include key elements of the PBL approach.

Table 3-2. Domains and themes from literature are predefined as the a priori codes

Domains (First-level codes)	**Themes (Second-level codes)**
Internal sources	- Interests - Intentions - Competence beliefs - Self-recognition
External sources	- Professional training from the curriculum - Team environment - Interactions in the professional community - Recognition from others

Qualitative scholarship has pointed out the importance of a structured coding process (Creswell, 2009; MacQueen et al., 1998; Miles & Huberman, 1994), in which a structured codebook is needed by researchers to have a relatively stable frame (MacQueen et al., 1998). Thus, to develop a structured codebook in line with the theoretical model, initial coding was conducted for five information-rich transcripts. The selection of the five transcripts was based upon our initial understanding of the conversation content in each transcript. Under the guidance of the source model, thematic analysis was conducted, and open coding was then used for each theme. Students' descriptions of internal and external sources to promote their sense of becoming engineers were extracted as third-level codes for the thematic content analysis, highlighting common patterns and determining new characteristics in the given PBL context (Krippendorff, 2018).

In the first round of the coding process on the five selected transcripts, five themes were identified in the domain of internal sources. In addition to the four prior second-level codes, the theme "self-reflection" emerged. In the domain of external sources, the initial four themes were identified. However, after discussing the definitions of these themes and examining their conceptual overlap by researchers in this study, the theme "self-reflection" was deleted, and two themes, "professional training from the curriculum" and "interactions in the professional community," were combined into one theme, "sources from the PBL environment." This is because in a systemic PBL context, to increase students' involvement in the engineering profession, learning activities designed for students to conduct engineering practice are indispensable components of the curriculum. "Professional training from the curriculum" and "interactions in the professional community" are hard to separate in this learning context. Then, all themes and subthemes were reviewed in two rounds to make sure they appropriately described the meaning of the text segments, and to further reduce overlaps. After the third round of coding, a codebook was built, as shown in Table 3-3. According to the content of the transcripts, both sources and constraints for students' engineering identity development were coded and reported in this study.

Table 3-3. The final codebook with domains, themes, and subthemes

Domains (First-level codes)	Themes (Second-level codes)	Subthemes (Third-level codes)
Internal sources	Interests	Have an interest in STEM fields Develop interest in solving problems Enjoy being challenged Identify interest in specific engineering topics Have an interest in putting theories into practice Have an interest in creating new things Develop interest in engineering academic research Develop interest in interdisciplinary projects
	Intentions	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 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 abilities 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
External sources	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 expressing oneself for different audiences Have the chance to work with companies Have opportunities for internship Take responsibility actively Find role models Learn to listen and understand clients' demands
	Team 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 conflicts or disagreement among team members
	Recognition 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

3.4.3. VALIDITY AND RELIABILITY

In qualitative research, researchers are regarded as the research tools:

> Qualitative researchers are the primary instrument for data collection and data analysis and are required to be responsive and adaptive. (Merriam, 1998, p. 5)

This role of researchers could benefit the objectives of understanding students' lived experiences and hearing their own learning stories in PBL. In this study, daily journaling and self-monitoring of coding processes were conducted by the lead coder and discussed within the research group, to avoid potential bias and influences from the researchers' own perspectives (Creswell, 2009). Further explanation of the researchers' reflection and position in this study is presented in Section 3.6.

In addition to researchers' self-reflection, inter-coder reliability was measured to assess the extent to which codes in transcripts assigned to the lead coder and the other coders are in agreement with the guidance of the same codebook (Miles & Huberman, 1994). A graduate student in engineering education who has rich qualitative research experience but is not a co-author of this study was introduced to the theoretical model and invited to be the external coder working on the five selected transcripts. After two rounds of coding and discussion on disagreement, the inter-rater reliability (IRR) was calculated at each level of codes, resulting in 96% in the internal domain and 92% in the external domain at the first level, 82% – 88% of each theme at the second level, and 74% at the third level.

3.5. PAPER III – A QUANTITATIVE METHOD IN PHASE 2

3.5.1. SURVEY DEVELOPMENT

Evolving from Godwin's (2016) framework of engineering identity, a theoretical model of elements for engineering identity development was proposed in the author's previous work (Chen et al., 2020; Chen et al., 2021; Chen et al., 2022), in which two domains of sources for engineering identity development – internal sources and external sources – were identified based on a literature review.

In the first step, an items pool with 63 items was proposed for the survey, based on a literature review and open-ended interviews in the prior studies. Specifically, 38 items in the domain of internal sources were designed, including the subthemes of competence and motivation. In the domain of external sources, 11 items under the subthemes of recognition and 14 items under the subthemes of professional engagement were included. Through two rounds of research group discussion, 17 items were deleted because of overlap or irrelevant content. External experts in PBL and engineering identity were invited to review the survey and items. Based on the research group discussion and external expert review, the initial two domains were divided further into three dimensions – internal motivations, competence beliefs, and external support. This was because for several items, they could be individuals' intrinsic values as well as learning outcomes in the PBL environment, such as items related to students' competence beliefs.

Dimension	Definition	Sample Elements
Internal Motivation	Students' interest, intentions, desire, and other intrinsic motivations to develop an engineering career	- Gain interest in design and innovation - Make efforts towards expected learning outcomes - Promote changes of the society -
Competence Beliefs	Students' beliefs in their abilities to conduct engineering work	- Understand the competences needed by engineers - Feel confident in mastering engineering knowledge and skills
External Support	Opportunities from the environment to support students' learning and professional practice	- Experience group diversity - Find a role model - Collaborate with engineers from companies

Table 3-4. Definitions of dimensions and sample elements (Paper III)

Thus, the theoretical model with three dimensions is used as guidance for this study. The definitions and sample elements of three dimensions are shown in Table 3-4. Then, in the pilot phase, five engineering students were invited to answer the initial survey and comment on all items and the whole survey, items with unclear meaning for students were revised, and repeated information was deleted. Eventually, with guidance from the theoretical model, 30 items were designed in English and put into the survey. The survey question posed to participants was "Based on your personal experience within a PBL environment, to what extent have the following aspects supported you in developing a sense of becoming an engineer?" Students were required to rate from 1 to 5 showing the extent from no support to strong support.

3.5.2. SAMPLING

A survey of elements contributing to students' engineering identity development in a systemic PBL environment was conducted online via SurveyXACT as a tool for sending questionnaires. Appendix B shows the content of the survey. The survey was distributed to 1,014 engineering students at Aalborg University in the academic years 2021/2022, including both undergraduate students and graduate students. The subjects of participants included energy, biotechnology, architectural engineering, and software engineering. In total, 391 students completed the questionnaire and gave their consent, representing a rate of participation of 39%, i.e., 371 effective responses. Participants' demographic information is presented in Paper III.

3.5.3. DATA ANALYSIS

Quantitative data were analyzed through SPSS statistical software. To ensure the validity of this survey, exploratory factor analysis was conducted to explore which dimension the items were loaded on, which provides support in showing a clear structure of this instrument. To examine the reliability of the survey, the internal consistency analysis was conducted through calculating Cronbach's alpha. In addition, descriptive statistics were calculated to show the influence of diverse elements in PBL on students' sense of becoming engineers, including means, standard deviations of factors, a paired samples t-test, and survey results of every item. Comparisons between demographic factors (gender, educational level, and subjects) were also conducted by calculating the independent sample t-test and one-way ANOVA. The results of the qualitative study are presented in Paper III.

3.5.4. VALIDITY AND RELIABILITY

In terms of the validity of this survey, content validity and construct validity were examined in this study. Firstly, content validity reflects if the statements in the survey are understandable to readers (DeVellis & Thorpe, 2021). Three engineering students and six experts who have rich experience in engineering education and identity research were invited to review all items and the survey structure. After two rounds of the review process, two items were removed because of repeated information or irrelevant content.

Secondly, construct validity was examined through exploratory factor analysis on 371 cases, with an acceptable Kaiser-Meyer-Olkin (KMO) value (0.941) and a significant level of Bartlett's test of sphericity ($p < 0.001$). Using the principal components' extraction and varimax rotation method, this study identifies three factors, separately named "internal motivations," "competence beliefs," and "external support." Three items were removed because of the low factor loadings of 0.4 on every dimension. Ten items were loaded on factor one, representing the dimension of internal motivation. Eleven items were loaded on factor two, named "competence beliefs." Six items were loaded on factor three, meaning "external support."

Thirdly, to examine the reliability of this survey, we conducted the internal consistency analysis through calculating the Cronbach's alpha of each factor as well as the whole survey. The Cronbach's alpha value higher than 0.7 could be considered acceptable (DeVellis & Thorpe, 2021). The results of each factor and the survey were all above 0.8, at 0.943 (competence beliefs), 0.858 (internal motivation), 0.808 (external support), and 0.963 (in total), providing evidence of a good reliability of this developed survey.

CHAPTER 4. FINDINGS

4.1. PAPER I

This paper, entitled "*Forms of implementation and challenges of PBL in engineering education: A review of literature*," was submitted to the *European Journal of Engineering Education* on 24 October 2019 and accepted for publication on 15 January 2020. The Editor-in-Chief of the *European Journal of Engineering Education*, Professor Kristina Edström, kindly gave permission for it to be used in this thesis.

The article is available online at: https://doi.org/10.1080/03043797.2020.1718615

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This study aims to overview diverse PBL implementations and challenges reported in prior PBL studies. Using a systematic literature review method, this study explores two research questions: 1) At what levels is the currently reported PBL practice being implemented in engineering education? 2) What kinds of challenges in PBL practices faced by both students and teachers are addressed in current studies in the field of engineering education? For a structured understanding of the types of reported PBL implementation, this study refers to Savin-Baden's (2014, p. 197) conceptual framework of "constellations of PBL implementation," which categorizes PBL practices into nine types based on learning objectives, problem types, levels of interactions, forms of facilitation, and focus of assessment.

To answer the first research question, this paper identifies four PBL practice levels by reviewing 108 articles about problem-based learning or project-based learning in engineering education from 2000 to 2019 in four databases (EBSCO, ERIC, Web of Science, and SCOPUS). The four levels are: course level (73 articles), cross-course level (6 articles), curriculum level (23 articles), and project level (6 articles). Specifically, PBL at the course level refers to a course design with PBL methods to help students acquire targeted professional knowledge and skills. At this level, in several cases, PBL units are combined with other learning methods, such as following lectures and lab work, to promote students' understanding and usage of knowledge (Williams & Ringbauer, 2014). In other cases, PBL, serving as the core learning method, requires students to conduct teamwork to solve one or more ill-structured or well-structured problems in one semester (Garcia-Robles et al., 2009; Hassan et al., 2015).

Compared with the course-level PBL, PBL practices at the cross-course level enable students to have more opportunities to work on interdisciplinary and complex problems, since those practices usually involve multidisciplinary courses (Calvo et al., 2017). In several cases of PBL at the cross-course level, external partners, such as engineering companies, are invited to collaborate with student teams, exposing students to a real-world engineering work environment and training their generic skills (Chen & Teng, 2011).

The third level is PBL at the curriculum level, where PBL methods are used as the core learning method for the curriculum design of undergraduate or graduate programs. Several universities state that they adopt the curriculum-level PBL methods, including Aalborg University (Balve et al., 2017; Guerra, 2017), University College Dublin (Ahern, 2010), the Universidad Europea de Madrid (Terrón-López et al., 2017), and Clemson University (Qattawi et al., 2014). At this level, based on a combination of PBL practice types, the curriculums with progressive learning objectives in every academic year are designed to promote students' longitudinal development.

PBL practice at the project level refers to PBL projects outside the curriculum system in one university, meaning that students could decide by themselves whether to participate or not. Ranging from short-term (less than one month) to long-term (several months to one year) projects, PBL at this level usually involves collaboration between diverse universities from one or more countries, providing more chances for students to conduct international collaborations, work on global problems, and experience the culture variety (Du et al., 2013; Ota & Punyabukkana, 2016).

To answer the second research question, with a basic understanding of current PBL implementation, this study also presents individual, institutional, and cultural challenges of PBL practices at the four levels. Firstly, for individuals, both students and teachers, report the challenges of lacking PBL training. In PBL, teachers need to transfer their roles from lecturers and instructors to supervisors and facilitators. Without pedagogical knowledge, engineering faculty might meet the difficulties in facilitating students' teamwork, designing effective PBL practice, and keeping the balance between helping with and influencing students' work, coping with students' individual differences, and designing effective assessment methods (Bani-Hani et al., 2018; Chan, 2016; Hugo et al., 2012). For students, a lack of teamwork skills, self-directed learning skills, and project management skills could affect the effectiveness of PBL as an approach for professional socialization, consequently influencing students' persistence in engineering fields.

At the institutional level, a lack of support from universities is the main challenge, including few communications to change PBL practical experience between faculties, limited resources from universities to promote educational changes, and a lack of supportive and incentive policies from universities (Arman, 2018; Clyne & Billiar, 2016). In particular, PBL at the single-course level lacks repercussions in the curriculum to improve students' longitudinal development. The functions of PBL in students' engineering identity development could be limited in the context of PBL at the course level (Du et al., 2021). Thus, this paper also calls for more empirical studies to explore the efficiency of PBL at diverse levels in educating qualified and career-ready engineers. The results of the review work also inspire our attention to exploring students' engineering identity development in the systemic PBL context.

At the cultural level, challenges related to cultural differences are reported, mainly in PBL practices involving international projects. With diverse world views and cultural backgrounds, students have different teamwork habits and paradigms of working, resulting in gaps in understanding others' perspectives (Bani-Hani et al., 2018; Ota & Punyabukkana, 2016). For students who are not native speakers of English, language barriers also become a difficulty for effective communication and teamwork. All these challenges at the cultural level require more effort from participants and more guidance from facilitators in the team-building process.

In general, this paper provides a basic understanding of current PBL implementation as well as a summary of challenges faced by students, teachers, and universities. The findings in this study call for further exploration of, and discussion on, functions of various PBL implementations in training qualified engineers. Challenges in terms of lacking resources for applying effective PBL methods inspire our interest in investigating the influence of elements from the PBL environment on training career-ready engineering talents.

4.2. PAPER II

This paper, entitled "*Students' views on sources of engineering identity development in a collaborative PBL environment*," was submitted to the *International Journal of Engineering Education* on 14 September 2020 and accepted for publication on 24 November 2021. The Editor-in-Chief of the *International Journal of Engineering Education*, Professor Ahmad Ibrahim, kindly gave permission for it to be used in this thesis.

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Inspired by the findings presented in Paper I, specifically the challenges faced by students in the PBL context, this paper focuses on the functions of PBL in developing students to become future engineers. Specifically, this paper aims to explore how engineering students perceive the elements in a systemic PBL context regarding their importance, accessibility, and effects in developing their engineering identity. The research question for this study is: What sources are considered important by students for the development of their engineering identity in a PBL context?

For further insight into elements associated with engineering identity development in diverse learning contexts, a literature review is conducted to provide a theoretical understanding of diverse elements contributing to students' engineering identity development. A theoretical model with two domains – internal sources and external sources – for engineering identity development is proposed. Internal sources refer to students' interests, intentions, self-efficacy, self-recognition, and other intrinsic motivations that inspire their desire to explore engineering topics and find engineering-related jobs (Godwin, 2016; Jones et al., 2010). External sources are concerned with how elements from the learning environment support students' engineering practice and professional identity development (Jääskelä et al., 2017). In the external domain, both relational and contextual sources are included, and four themes are identified: professional training from the curriculum, teamwork, interactions in the professional community, and recognition from others. Through reviewing the internal and external sources for engineering identity development, this study also underlines the interplay between personal values and interactions with the learning environment, highlighting the link between individual engineering identity and practices with personal decisions on action and engagement (Jääskelä et al., 2017).

Using a qualitative method, this study provides empirical evidence on important elements for students to develop an engineering identity in a systemic PBL environment. Based on the proposed theoretical model of internal and external sources for engineering identity development, both theory-driven themes (from the literature) and bottom-up subthemes (from the data) are reported. In the domain of internal sources, students' interest in STEM fields, intention to get engineering degrees, competence beliefs in professional knowledge and technical skills, and feeling of being included in the engineering community contribute to students' engineering identity development, which aligns with prior studies (Godwin & Kirn, 2020; Meyers et al., 2012; Tonso, 2015). In the domain of external sources, having opportunities to conduct self-directed learning, exploring how engineers work, sharing knowledge and values with peers, and getting recognition from members in the engineering community are reported to enhance students' feelings about becoming engineers.

In addition to these theory-driven themes (from the literature), bottom-up sources were identified, especially associated with the PBL context. For the internal domain, by being exposed to real-life problems in PBL, participants could develop an interest in interdisciplinary projects, enjoy being challenged on engineering problems, and improve their abilities to apply theoretical knowledge in practice and link engineering with social science. These internal sources are highlighted by participants as enriching their understanding of engineers' work and helping them feel prepared for their professional careers. In the domain of external sources, PBL provides participants with more opportunities to engage in engineering practices, such as working with engineering companies, communicating with clients, and negotiating with different stakeholders in projects, which are important professional socialization experiences for students in developing their engineering identity.

The findings in this paper highlight the inseparability of elements within each domain and the ongoing interaction between internal and external sources from the PBL context. Internal sources, including individuals' beliefs, values, subjective actions, and sense-making processes, are context-bound, and associated with relational and contextual sources (Tonso, 2015). Meanwhile, internal sources also influence students' utilization of external sources in the learning environment and their choice of what professional socialization process they prefer to experience. Thus, this paper emphasizes that both internal sources and external sources are integral for engineering identity development, calling for more effort in exploring the influence of these identified sources on engineering identity development, the interplay between diverse sources, and differences in students' identity development experiences between genders, subjects, and educational levels.

4.3. PAPER III

This paper, entitled "*Exploring students' perception of influence of PBL elements on the development of engineering identity*," was submitted to *IEEE Transactions on Education* on 04 March 2022.

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Based on diverse important elements reported by students in developing their engineering identity, this study focuses on further exploring the influence of these elements from a PBL environment on students' engineering identity development. The research question for this study is: What elements of the PBL environment are considered by students to contribute to their engineering identity development?

Aiming to identify supportive elements for engineering identity development in PBL, this study uses a quantitative method and conducts an online survey. The survey is designed based on our prior qualitative studies and tested in the context of Aalborg

University. Content validity, construct validity, and reliability of the survey are examined through conducting an expert review, exploratory factor analysis, and calculating Cronbach's alpha. Based on the statistical results, three dimensions supporting students' engineering identity development are confirmed, namely internal motivation, competence beliefs, and external support.

Specifically, in the dimension of internal motivation, the most contributive element is "PBL suits my personal learning preferences." In line with findings in our qualitative studies, intentions to promote the change of society and improve people's quality of life also play a key role for students in choosing an engineering career. Meanwhile, interests in engineering content and interdisciplinary projects are also pointed out as supportive elements (Godwin et al., 2016; Knight et al., 2013). In the dimension of competence beliefs, the highest-ranked element is learning to take responsibilities actively during teamwork and project processes. Moreover, PBL improved students' confidence in their ability to work in teams, carry out interdisciplinary projects, solve problems, solve conflicts, and apply theory to practice, which helps students better prepare for future engineering practical work. In the dimension of external support, opportunities to conduct innovative work and collaborate with companies and industry are identified as supportive elements for students' engineering identity development. These experiences enable students to work as professional engineers and feel included in the engineering community (Marra et al., 2014). However, the results show that the function of role models, such as supervisors and mentors from companies, is limited because most participants did not have experience in finding a role model from engineering professions, especially for first-year students.

Among the three dimensions, internal motivation was reported as the most supportive aspect for students' engineering identity development, while the contribution of external support was the lowest. Nonetheless, external support is reported with higher contributions for students who are still considering whether to choose an engineering career or not. These students rely more on the external environment to develop their engineering identity. Thus, to increase their engagement in the engineering community, more opportunities to expose students to practical engineering work such as developing joint industry projects, organizing company visit tours, and inviting engineers to project expos need to be added to the curriculum design.

CHAPTER 5. DISCUSSION

5.1. ANSWERS TO THE RESEARCH QUESTIONS

Starting with a literature review on the overall practices of PBL, this study aims to understand PBL as a concept itself firstly. The results of the literature review indicate the research gap regarding the ways in which students' engineering identities could be developed through PBL, and support the choice of a systemic PBL environment. The specific research questions for this study are as follows:

1) What characterizes PBL practices in engineering education, and what challenges are addressed in current PBL implementation? (Paper I)

2) What sources are considered important by students for the development of their engineering identity in a PBL learning environment? (Paper II)

3) What elements in the PBL environment do students consider contribute to their engineering identity development? (Paper III)

To answer the first research question, Paper I (Chen et al., 2021) scrutinizes empirical evidence on current PBL implementations and challenges faced by students and engineering educators. Through reviewing these PBL practices, this paper emphasizes the diversity of PBL methods, including different learning objectives, problem types, and assessment methods (Chen et al., 2021). While PBL implementation varies from the course level and the cross-course level to the curriculum level and the project level, similar challenges were identified from both individual and systemic perspectives. For individuals, including engineering students and academic faculty, have faced challenges of heavy workloads, limited resources, a lack of PBL skills, and their adaptability to PBL approaches (Chan, 2016; Du et al., 2019; Hassan et al., 2015). For engineering educational institutions, a lack of financial support and resources to practice PBL, infrastructure and learning equipment, and motivational policy for teachers have been pointed out as the main challenges that need to be solved (Clyne & Billiar, 2016; Du et al., 2019).

Moreover, we also identified particular challenges for the single-course level PBL practice, in which the PBL methods have been used with the highest frequency. Specifically, PBL at the single-course level lacks repercussions in the curriculum design, limiting the functions of PBL in students' longitudinal and professional development (Du et al., 2021). These results highlight the importance of more empirical studies on further exploring the functions of PBL at different levels in educating qualified and career-ready engineers, especially at the curriculum level.

For the second research question, Paper II explores how individual students perceive the importance of, and their access to, diverse sources from the PBL environment to construct their engineering identity. In consonance with literature on engineering students' identity construction in other types of learning contexts, many sources important for engineering identity development are also identified by students from PBL programs, including interests in the STEM fields, interests in creating new things, competence beliefs in professional competences, teamwork experience, chances of internship, and so on. Meanwhile, bottom-up sources also emerged from the empirical data, especially sources in regard to the PBL environment. In terms of internal sources, through working on real-world problems in PBL, students could develop new interests in specific engineering topics and interdisciplinary projects, and they realize the need for engineers to have comprehensive competences, such as interdisciplinary skills, communication and negotiation skills, and a global horizon, to create more potential for innovation. Another important aspect of PBL as a supportive environment for students to develop engineering identity is that PBL provides opportunities for students to apply theoretical knowledge in practice, link engineering with humanity and society, and become more familiar with engineers' work. In addition, based on real-life problems and projects, students have more opportunities to interact with professional engineers from companies and industries, and get involved in engineering communities. These experiences could reduce the gap between university and industry and help students better prepare for their professional careers.

In terms of the third research question, Paper III illustrates the influence of diverse elements from a PBL context on students' engineering identity development. Based on various sources identified by qualitative data in prior studies, a theoretical model of supportive elements is proposed, including the three dimensions of internal motivation, competence beliefs, and external support. Under the guidance of the theoretical model, a survey was conducted among students from five engineering programs at Aalborg University in the academic year of 2021–2022. In the dimension of internal motivation, the quantitative data indicate that the most supportive element is that PBL suits students' personal learning preferences. Their intention to improve people's quality of life and their interest in engineering content also have important contributions for students to develop engineering identity and choose an engineering career. In the dimension of competence beliefs, the element that contributes most is related to taking active responsibilities during teamwork and project processes. By experiencing PBL, students could gain a deeper understanding of themselves and their abilities, and develop self-confidence in their problem-solving skills, teamwork skills, communication skills, interdisciplinary skills, and practical skills, which is in line with prior studies (Beddoes et al., 2010; Kolmos et al., 2021). In the dimension of external support, opportunities for innovative work and collaborations with companies were noted by students as significant elements contributing to the development of their engineering identity.

However, the influence of academic staff and professional engineers as role models is limited and differs from individual to individual. In the qualitative study, a participant expressed the significant encouragement and inspiration of her supervisor as a role model of an outstanding female engineer on her decision to become an engineer. Nonetheless, in the quantitative study, more than 40% of participants reported that PBL supervisors offered no support or low support for their decision to become engineers, and only 26% of students gave a positive response. One possible reason is that many students did not have the chance to find a visible role model from the engineering faculty or companies because of limited exposure to engineering communities, especially for students in the early years of study. Meanwhile, other challenges in PBL, such as individuals' adaptability to PBL, the experience of inefficient teamwork, conflicts between group members, a lack of supervision and feedback, a lack of communication with professional engineers, and tough negotiations between stakeholders, led to some students' feeling of self-doubt, which might become a constraint for their engineering identity development.

On the basis of these findings, it is concluded that PBL is a supportive environment for engineering students to develop an engineering identity and be better prepared for future professional work, while challenges for students' engineering identity development in a PBL environment are also identified. Thus, in the following sections, the implications of the findings in this research are discussed and presented. Suggestions for students, academic faculties, and educational institutions are proposed to overcome these reported challenges and optimize future PBL design at different levels.

5.2. CONTRIBUTIONS AND IMPLICATIONS FOR PRACTICE

5.2.1. CONTRIBUTIONS TO ENGINEERING EDUCATIONAL RESEARCH

With the call for exploring students' engineering identity development in diverse learning environments, this study provides an understanding of elements contributing to engineering identity development in a specific learning context, namely a PBL environment.

The first theoretical perspective of this study aims to explore what characterizes PBL practices in engineering education. The PBL literature review presented in Paper I gives an overview of diverse PBL practices from 2000-2019, illustrating that PBL is a complex concept containing diverse methods of implementation rather than one type of learning approach. Based on the literature review, four practice levels of current PBL implementation are identified, namely course level, cross-course level, curriculum level, and project level. At every level, characteristics of PBL practices are presented, containing learning objectives, problem types, project duration, size of student groups, and assessment methods. Across these four levels, similar challenges of PBL practice are described in detail, while the limitations of students' longitudinal and professional development in PBL at the single-course level are also identified. These findings highlight the importance of a structured PBL curriculum design and inspire the further exploration of students' professional identity development in a systemic PBL environment, such as the AAU PBL model.

This study also contributes to the engineering educational research by proposing a theoretical model of various elements contributing to students' engineering identity development. Inspired by Godwin's (2016) framework of engineering identity, the theoretical model has been proposed based on the literature review on engineering identity and revised through qualitative and quantitative studies. The final version of this model contains three dimensions, namely internal motivation, competence beliefs, and external support. Within every dimension, diverse elements from the PBL environment are identified, highlighting the complexity of supportive sources and diverse pathways in developing engineering identity. With guidance from this model, an analytical tool for assessing the influence of elements in PBL programs on engineering identity development is designed and validated in the context of Aalborg University. While the analytical tool is developed in a systemic PBL environment, it might be generalized to similar learning environments involving problem-solving and collaborative learning methods.

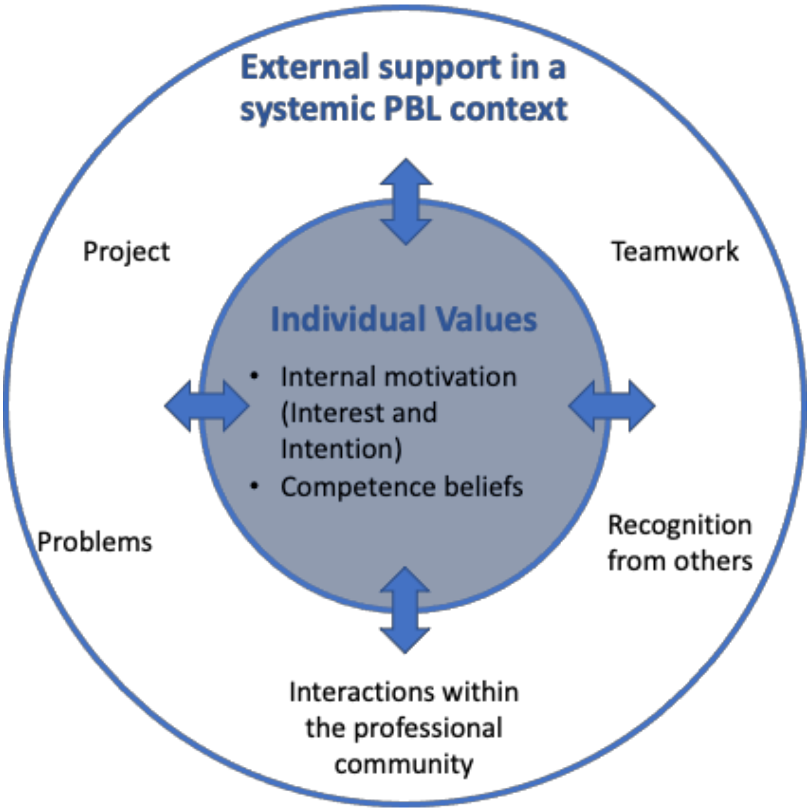

Figure 5-1 The interaction between individual values and external support

While diverse elements/sources for engineering identity development in PBL are identified, findings of this study also highlight the interrelatedness and inseparability of elements in every dimension and the ongoing interaction between students' individual values and external support from the PBL environment (Figure 5-1). Individual values, including internal motivation and competence beliefs, are context-bound. Students' learning experience and sense-making processes are always related to the interpretation of relations and opportunities offered by the learning context (Jääskelä et al., 2017). For example, when students' competence belief is discussed as an important source for professional identity development, it is also a learning outcome of professional socialization processes (Weidman et al., 2001). In a PBL context, by being exposed to real-world problems and projects, students could experience how professional engineers work and develop their understanding of the role of engineers. When engaging in an engineering community, recognition from peers, supervisors, professional engineers, or other members in this community could contribute to students' sense of becoming engineers. Meanwhile, students' individual values also influence their choice of what activities for professional socialization to engage in. Especially in a systemic PBL environment, students could identify their interests and project topics and choose their ways to solve problems. Their utilization of external sources and support leads to their individual professional training pathways to become engineers. In addition, individuals' professional performance could bring additional external support from the environment. One case from this study is that a student got an internship opportunity in a leading company because of his excellent performance in the company's joint project. Based on these findings, we emphasize the ongoing interaction between individual values and external support, both of which are indispensable aspects of engineering identity development.

Although both individual values and external support from the PBL context are found to have a significant influence on students' engineering identity development, their contributions are different. Based on the statistical results, students' internal motivation is reported as the most important aspect of engineering students' choice to become engineers, while the influence of external support is the lowest among the three dimensions. This finding supports the notion that engineering identity is a self-developed concept. External sources (relational and contextual elements) could have an effect on engineering identity development, but the core construction process depends on the subjectivity of individual values (motivation, interest, efficacy, self-belief, etc.) (Eteläpelto et al., 2013).

5.2.2. IMPLICATIONS FOR PRACTICE

This study is conducted in a systemic PBL context, which is called the "AAU PBL model." The PBL curriculum organization is explained in detail in Section 3.1. The findings of this study, presented in three papers, show that the AAU PBL model contributes to the development of engineering identity as it promotes:

1) Students' interest in STEM contents, specific engineering topics, and/or interdisciplinary work by engaging in engineering or interdisciplinary projects and applying theoretical knowledge to practice.

2) Students' intentions to contribute to changes in the society by working on real-life problems or global issues.

3) Students' self-beliefs in their professional and transferable competences by experiencing complex and multi-contextual problem scenarios, diverse project themes, and teamwork across different disciplines.

4) Students' understanding of engineering work and professional behaviors by interacting and communicating with members of the engineering communities (e.g., professional engineers, companies, industry, and clients).

5) Students' feeling of inclusiveness in an engineering group by involving themselves in work-related engineering practices and getting support/recognition from engineering companies.

However, although PBL is reported as an effective learning approach in supporting students' engineering identity development, limitations and challenges are also identified. As mentioned above, some students faced difficulties in transferring from traditional learning methods to self-directed learning and interdisciplinary work, especially students without prior PBL experience. Several students experienced ineffective teamwork, conflicts among team members, or tough negotiations between stakeholders, leading to their self-doubt and preference for jobs with less teamwork. Even though in a systemic PBL context, the university has provided students with more resources and freedom to conduct self-directed learning, a lack of sources is still a challenge faced by students, such as a lack of training to improve PBL skills, a lack of feedback and instructions on projects, limited freedom to choose project directions, few opportunities to collaborate with companies, and so on.

Thus, based on the empirical evidence, suggestions are proposed to improve students' experience of professional socialization in PBL and to optimize future PBL design at different levels.

Firstly, for engineering students, it is important to develop the awareness that both successful and unsuccessful PBL experiences could contribute to their growth. Students are encouraged to go through diverse problem scenarios and different approaches to teamwork, share their PBL experience with peers, and review their learning processes through self-reflection, which could benefit their interpersonal and professional competence development (Long et al., 2017).

Secondly, engineering educators need to develop the awareness that they are not only responsible for facilitating students' professional learning, but they also have an influence on students' engineering identity development. Thus, engineering educators need to act as visible role models for students by showing them how to perform in a professional way (Felstead, 2013).

Thirdly, for engineering educational institutions, to improve students' learning experience and learning outcomes through PBL experience, it is necessary to provide PBL pedagogical training for students. At the course level of PBL practice, short-term pedagogical training on PBL skills could be arranged at the beginning of the courses, such as pilot projects, lectures on tips and tools for teamwork and project management, and workshops given by senior students to share PBL experience, etc. At the curriculum level of PBL practice, systemic and progressive learning objectives need to be set for students in different semesters. For example, for first-year students, identifying problems to solve and experiencing self-directed learning could be the main learning tasks, focusing on developing students' abilities to absorb and share information, analyze the real-world context, and address issues and problems. For senior students, the learning objectives could focus on improving their practical skills, interdisciplinary skills, leadership, and critical thinking. Based on these progressive learning goals, students need to figure out complex problems, work on multiple tasks, and produce final products (e.g., a design, a model, or a device). During these learning processes, the roles of engineering educators are those of supervisors and facilitators. The roles of supervisors and facilitators could give students suggestions on professional ways to solve problems, and they construct the meaning of experience together with students, rather than telling students the answers directly as the authority of knowledge (Kolmos et al., 2008).

Last but not least, we call for engineering educational institutions to create a supportive learning environment that focuses on the diversity of individual students. Based on the quantitative data, the influence of external support from the PBL environment is different among students with different engineering identity levels. Compared with students who have clearly confirmed their intention to become engineers in the future, students still considering their career direction are found to rely more on a supportive learning environment to develop their engineering identity. Thus, engineering educational institutions need to provide more opportunities for students to experience various aspects of different problem scenarios, projects within and across disciplines, and teamwork with different people with diverse backgrounds. More practical engineering activities and external support to enable students to interact with members of the engineering communities are needed, such as university-industry projects, company visits, cross-institution collaboration, and communication with practical engineers through workshops, seminars, lectures, and project expos. Moreover, for a systemic PBL curriculum design, students could benefit from more freedom to choose the direction of their projects, types of problems, and collaboration with different companies. By experiencing diversity and engaging in different activities of professional socialization, students are able to design their professional training pathways to become engineers, which also indicates the interaction between individual values and external support for students' engineering identity development.

5.3. LIMITATIONS AND FUTURE RESEARCH

While this study provides insights into supportive elements from a systemic PBL environment for students' engineering identity development, the limitations of this study are also identified. Firstly, in terms of the review of current PBL implementation, one limitation is that this study only includes peer-reviewed journal articles, conference papers, and book chapters from four databases. Many other materials from reports and books, which are not included in this review work, could also present different PBL implementations. Based on the review of current PBL implementations, we emphasized the diversity of PBL methods in engineering education. However, this study only focuses on a systemic PBL environment. Our theoretical model and the analytical tool are developed based on this PBL environment, which might limit the use of our survey and generalization of results in diverse learning environments.

Secondly, this study only explores students' values and perceptions, which are often regarded as subjective data. For professional identity, individual perceptions and attitudes are valid data because they express their values as a core component of students' anticipation of the future as well as their feeling of preparedness. These subjective perceptions and individual values could affect their career choices. In addition, individual beliefs in their competences for engineering work are important aspects of engineering identity, in which self-assessments are widely used as an appropriate research method. Thus, self-reported data are indispensable for understanding students' engineering identity development.

Thirdly, this study has not fully explored the differences between genders and students from different educational levels, subjects, and countries. With the comparison between different student groups, further exploration could focus on potential reasons for these differences. For example, students from higher educational levels and with rich PBL experience might have different opinions on engineering identity and related impact factors, compared with first-year students, for whom PBL can be a new learning experience.

Thus, in relation to the findings identified, it would be interesting to expand this study to diverse engineering student groups and different PBL environments. A future research direction could focus on differences between different student groups (e.g., genders, educational levels, subjects, and cultures) and further explore the reasons underlying these differences. A longitudinal study could be conducted to track the stories of participants' engineering identity development through PBL and teamwork. Diverse perspectives of engineering teachers and professional engineers could be included to provide a comprehensive understanding of engineering identity.

Moreover, a need exists for further implementation of our analytical tools in diverse PBL environments. The survey of this study is based on a systemic PBL context, where PBL has been adapted as the core learning approach for the whole curriculum.

We believe it also has potential for application in similar learning environments, where teamwork skills and problem-solving skills are important learning objectives for students. The generalization process requires further validation processes and diverse data sources, e.g., applying the survey to different engineering programs and different educational institutions.

REFERENCES

Adams, K., Hean, S., Sturgis, P., & Clark, J. M. (2006). Investigating the factors influencing professional identity of first-year health and social care students. *Learning in Health and Social Care, 5*(2), 55–68.

Ahern, A. A. (2010). A case study: Problem-based learning for civil engineering students in transportation courses. *European Journal of Engineering Education, 35*(1), 109–116.

Arman, A. (2018). Students' attitudes toward Problem-based Learning–Analog electronic course in the electrical engineering programs in PPU case study. *Journal of E-Learning and Higher Education, 3*(14), 1–9.

Ashforth, B. E. (2001). *Role transitions in organizational life: An identity-based perspective*. Lawrence Erlbaum Associates, Inc.

Baker, D., Krause, S., Yaşar, S., Roberts, C., & Robinson-Kurpius, S. (2007). An intervention to address gender issues in a course on design, engineering, and technology for science educators. *Journal of Engineering Education, 96*(3), 213–226.

Balve, P., Krüger, V., & Tolstrup Sørensen, L. (2017). Applying the Kanban method in problem-based project work: A case study in a manufacturing engineering bachelor’s programme at Aalborg University Copenhagen. *European Journal of Engineering Education, 42*(6), 1512–1530.

Bani-Hani, E. H., Sedaghat, A., AL-Shemmary, M., Hussain, A., Alshaieb, A., & Kakoli, H. (2018). Feasibility of highway energy harvesting using a vertical axis wind turbine. *Energy Engineering, 115*(2), 61–74.

Barbarà-i-Molinero, A., Cascón-Pereira, R., & Beatriz Hernández-Lara, A. (2017). Professional identity development in higher education: Influencing factors. *International Journal of Educational Management, 32*(2), 189–203.

Barrows, H. (2002). Is it truly possible to have such a thing as PBL? *Distance Education, 23*(1), 119–122.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning, 1996*(68), 3–12.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education (Vol. 1).* U.S.: Springer Publishing Company.

Beam, T. K., Pierrakos, O., Constantz, J., Johri, A., and Anderson, R. (2009, June). Preliminary findings on freshmen engineering students’ professional identity: Implications for recruitment and retention. *Paper presented at the 2009 ASEE Annual Conference and Exposition, Austin*, TX, USA, 14–17.

Beddoes, K. D., Jesiek, B. K., & Borrego, M. (2010). Identifying opportunities for collaborations in international engineering education research on problem- and project-based learning. *Interdisciplinary Journal of Problem-based Learning, 4*(2), 7–34.

Billett, S. (2006). Work, subjectivity and learning. In Billett, S., Fenwick, T., & Somerville, M. (Eds.), *Work, subjectivity and learning: Understanding learning through working Life* (pp.1–20). Springer.

Blosser, E. (2017). Gender segregation across engineering majors: How engineering professors understand women's underrepresentation in undergraduate engineering. *Engineering Studies, 9*(1), 24–44.

Borrego, M., Foster, M. J., & Froyd, J. E. (2014). Systematic literature reviews in engineering education and other developing interdisciplinary fields. *Journal of Engineering Education, 103*(1), 45–76.

Bragg. A. K. (1976). *The socialization process in higher education.* The American Association of Higher Education.

Calvo, I., Cabanes, I., Quesada, J., & Barambones, O. (2017). A multidisciplinary PBL approach for teaching industrial informatics and robotics in engineering. *IEEE Transactions on Education, 61*(1), 21–28.

Capobianco, M., French, F., & Diefes-Dux, A. (2012). Engineering identity development among pre-adolescent learners. *Journal of Engineering Education*, *101*(4), 698–716.

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of colour: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187–1218.

Cass, C., Kirn, A., Tsugawa, M. A., Perkins, H., Chestnut, J. N., Briggs, D. E., & Miller, B. (2017). Improving performance and retention of engineering graduate students through motivation and identity formation. *Paper presented at 2017 ASEE Annual Conference & Exposition*, Columbus, Ohio, USA.

Chan, C. K. (2016). Facilitators' perspectives of the factors that affect the effectiveness of problem-based learning process. *Innovations in Education and Teaching International, 53*(1), 25–34.

Chaparro-Peláez, J., Iglesias-Pradas, S., Pascual-Miguel, F. J., & Hernández-García, Á. (2013). Factors affecting perceived learning of engineering students in problem-based learning supported by business simulation. *Interactive Learning Environments, 21*(3), 244–262.

Charness, G. & Chen, Y. (2020). Social identity, group behavior, and teams. *Annual Review of Economics, 12*(1), 691–713.

Chemers, M. M., Zurbriggen, E. L., Syed, M., Goza, B. K., & Bearman, S. (2011). The role of efficacy and identity in science career commitment among underrepresented minority students. *Journal of Social Issues*, *67*(3), 469–491.

Chen, C. Y., & Teng, K. C. (2011). The design and development of a computerized tool support for conducting senior projects in software engineering education. *Computers & Education, 56*(3), 802–817.

Chen, J., Kolmos, A., & Du, X. (2020, June). An exploration of students' engineering identity development in a PBL team setting. *Paper presented at the 2020 ASEE Virtual Annual Conference Content Access*.

Chen, J., Kolmos, A., & Du, X. (2020). The role of teamwork on students' engineering professional identity development in the AAU PBL Model: From the perspectives of international engineering students. *Paper presented at the 8th International Research Symposium on PBL* (pp. 405–413). Aalborg Universitetsforlag.

Chen, J., Kolmos, A., Guerra, A., & Zhou, C. (2021). Academic staff's motivation, outcomes and challenges in a pedagogical training programme of PBL. *International Journal of Engineering Education, 37*(4), 900–914.

Chen, J., Kolmos, A., & Du, X. (2021). Forms of implementation and challenges of PBL in engineering education: A review of literature. *European Journal of Engineering Education, 46*(1), 90–115.

Chen, J., Du, X., & Kolmos, A. (2022). Students' views on sources of engineering identity development in a collaborative PBL environment. *International Journal of Engineering Education, 38*(2), 525–542.

Clyne, A. M., & Billiar, K. L. (2016). Problem-based learning in biomechanics: Advantages, challenges, and implementation strategies. *Journal of Biomechanical Engineering, 138*(7), 070804.1-9. doi:10.1115/1.4033671.

Craps, S., Pinxten, M., Knipprath, H., & Langie, G. (2020). Exploring professional roles for early career engineers: A systematic literature review. *European Journal of Engineering Education, 46*(2), 266-286.

Crede, E. D., Borrego, M., & McNair, L. D. (2010). Application of community of practice theory to the preparation of engineering graduate students for faculty careers. *Advances in Engineering Education, 2*(2), 2.

Creswell, J. (2009). *Research design: Qualitative, quantitative, and mixed methods approac*h. Sage Publications.

Dahms, M. L., Spliid, C. M., & Nielsen, J. F. D. (2017). Teacher in a problem-based learning environment: Jack of all trades?. *European Journal of Engineering Education, 42*(6): 1196–1219.

Dannels, D. (2000). Learning to be professional: Technical classroom discourse, practice, and professional identity construction. *Journal of Business and Technical Communication*, *14*(1), 5–37.

Dehing, F., Jochems, W., & Baartman, L. (2013). 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), 1–10.

De Graaff, E. (1995). Models of problem-based learning. Paper presented at the Fourth World Conference on Engineering Education, Saint Paul, MN. In E. Rex Krueger & F. A. Kulacki (Eds.), Restructuring engineering education for meeting world needs (Vols. 1–4). *Technology Based Engineering Education Consortium*, The William C. Norris Institute.

DeVellis, R. F., & Thorpe, C. T. (2021). *Scale development: Theory and applications.* Sage Publications.

Direito, I., Tilley, E., & Mitchell, J. E. (2018, June). Gender differences in first-year students' expectations towards a new engineering multidisciplinary curriculum. *Paper presented at 2018 International Conference of the Portuguese Society for Engineering Education (CISPEE)* (pp. 1–5). IEEE, Aveiro, Portugal.

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction, 13*(5), 533–568.

Du, X. (2006). Gendered practices of constructing an engineering identity in a problem-based learning environment. *European Journal of Engineering Education*, *31*(1), 35–42.

Du, X., de Graaff, E., & Kolmos, A. (2009). *Research on PBL practice in engineering education*. BRILL.

Du, X., Ebead, U. Sabah, S. Ma, J., & Naji, K. K. (2019). Engineering students' approaches to learning and views on collaboration: How do both evolve in a PBL environment and what are their contributing and constraining factors? *EURASIA Journal of Mathematics, Science and Technology Education, 15*(11), em1774.

Du, X., Naji, K. K., Ebead, U., & Ma, J. (2021). Engineering instructors' professional agency development and identity renegotiation through engaging in pedagogical change towards PBL. *European Journal of Engineering Education, 46*(1), 116–138.

Du, X., Su, L., & Liu, J. (2013). Developing sustainability curricula using the PBL method in a Chinese context. *Journal of Cleaner Production, 61*(9), 80–88.

Edström, K., & Kolmos, A. (2014). PBL and CDIO: Complementary models for engineering education development. *European Journal of Engineering Education, 39*(5), 539–555.

Eliot, M., & Turns, J. (2011). Constructing professional portfolios: Sense-making and professional identity development for engineering undergraduates. *Journal of Engineering Education, 100*(4), 630–654.

Erikson, E. H. (1968). *Identity: Youth and crisis (No. 7)*. Norton & Company.

Eteläpelto, A., Vähäsantanen, K., Hökkä, P., & Paloniemi, S. (2013). What is agency? Conceptualizing professional agency at work. *Educational Research Review*, *10*(1), 45–65.

Ewan, C. (1988). Becoming a doctor. In K. Cox & C. Ewan (Eds.), *The medical teacher* (pp. 83-87). Churchill Livingstone.

Felstead, I. (2013). Role modelling and students' professional development. *British Journal of Nursing, 22*(4), 223–227.

Fleming, L. N., Smith, K. C., Williams, D. G., & Bliss, L. B. (2013). Engineering identity of black and Hispanic undergraduates: The impact of minority serving institutions. *Paper presented at the 2013 ASEE Annual Conference & Exposition* (pp. 23–510).

Foor, C. E., Walden, S. E., & Trytten, D. A. (2007). "I wish that I belonged more in this whole engineering group": Achieving individual diversity. *Journal of Engineering Education, 96*(2), 103–115.

Garcia-Robles, R., Diaz-del-Rio, F., Vicente-Diaz, S., & Linares-Barranco, A. (2009). An eLearning standard approach for supporting PBL in computer engineering. *IEEE Transactions on Education, 52*(3), 328–339.

Gee, J. P. (2000). Chapter 3: Identity as an analytic lens for research in education. *Review of Research in Education, 25*(1), 99–125.

Gijbels, D., Dochy, F., Van den Bossche, P., & Segers, M. (2005). Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of Educational Research, 75*(1), 27–61.

Godwin, A. (2016). The development of a measure of engineering identity. *Paper presented at 2016 ASEE Annual Conference & Exposition*, New Orleans, Louisiana, USA.

Godwin, A., & Kirn, A. (2020). Identity-based motivation: Connections between first-year students' engineering role identities and future-time perspectives. *Journal of Engineering Education, 109*(3), 362–383.

Godwin, A., & Potvin, G. (2017). 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), 439–462.

Godwin, A., Potvin, G., Hazari, Z., & Lock, R. (2016). Identity, critical agency, and engineering: An affective model for predicting engineering as a career choice. *Journal of Engineering Education*, *105*(2), 312–340.

González-González, C. S., García-Holgado, A., de los Angeles Martínez-Estévez, M., Gil, M., Martín-Fernandez, A., Marcos, A., & Gershon, T. S. (2018, April). Gender and engineering: Developing actions to encourage women in tech. *Paper presented at the 2018 IEEE Global Engineering Education Conference (EDUCON)* (pp. 2082–2087), Canary Islands, Spain.

Gratchev, I., & Jeng, D. S. (2018). Introducing a project-based assignment in a traditionally taught engineering course. *European Journal of Engineering Education, 43*(5), 788–799.

Guerra, A. (2017). Integration of sustainability in engineering education. *International Journal of Sustainability in Higher Education, 18*(3), 436–454.

Hassan, H., Domínguez, C., Martínez, J. M., Perles, A., Capella, J. V., & Albaladejo, J. (2015). A multidisciplinary pbl robot control project in automation and electronic engineering. *IEEE Transactions on Education, 58*(3), 167-–172.

Hatmaker, D. M. (2013). Engineering identity: Gender and professional identity negotiation among women engineers. *Gender, Work & Organization*, *20*(4), 382–396.

Hazari, Z., Sadler, P. M., & Sonnert, G. (2013). The science identity of college students: Exploring the intersection of gender, race, and ethnicity. *Journal of College Science Teaching*, *42*(5), 82–91.

Hernandez-Martinez, P. (2016). "Lost in transition": Alienation and drop out during the transition to mathematically demanding subjects at university. *International Journal of Educational Research*, *79*(1), 231–239.

Higgs, J. (1993). Physiotherapy, professionalism and self-directed learning. *Journal of the Singapore Physiotherapy Association*, *8*(14), 8–11.

Holland, D. C., Lachicotte Jr, W., Skinner D., & Cain, C. (1998). *Identity and agency in cultural worlds*. Harvard University Press.

Hosseinzadeh, N., & M. R. Hesamzadeh. (2012). Application of Project-Based Learning (PBL) to the teaching of electrical power systems engineering. *IEEE Transactions on Education, 55*(4), 495501.

Hugo, R. J., Brennan, R. W., & Gu, P. (2012, July). Quantitative indicators for assessing the effectiveness of Project-Based Learning experiences. *Paper* *presented at the 8th International CDIO Conference*. Brisbane: CDIO Organization.

Jääskelä, P., Poikkeus, A. M., Vasalampi, K., Valleala, U. M., & Rasku-Puttonen, H. (2017). Assessing agency of university students: Validation of the AUS Scale. *Studies in Higher Education, 42*(11), 2061–2079.

Johnson, B., & Ulseth, R. (2016). Development of professional competency through professional identity formation in a PBL curriculum. *Paper presented at the 2016 Frontiers in Education Conference,* Singapore.

Johnson, B., Ulseth, R., Smith, C., & Fox, D. (2015, October). The impacts of project-based learning on self-directed learning and professional skill attainment: A comparison of project-based learning to traditional engineering education. *Paper presented at 2015 IEEE Frontiers in Education Conference (FIE)* (pp. 1–5). IEEE.

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2), 139–151.

Jones, B. D., Paretti, M. C., Hein, S. F., & Knott, T. W. (2010). An analysis of motivation constructs with first-year engineering students: Relationships among expectancies, values, achievement, and career plans. *Journal of Engineering Education*, *99*(4), 319–336.

Kajfez, R. L. & McNair, L. D. (2014, June). Graduate student identity: A balancing act between roles. *Paper presented at 2014 ASEE Annual Conference & Exposition*, Indianapolis, Indiana.

Knight, D., Sullivan, J. F., Kotys-Schwartz, D. A., Myers, B. A., Louie, B., Luftig, J. T., & Hornback, J. M. (2013, June). The impact of inclusive excellence programs on the development of engineering identity among first-year underrepresented students. *Paper presented at 2013 ASEE Annual Conference & Exposition,* Atlanta, Georgia.

Kolmos, A. (1996). Reflections on project work and problem-based learning. *European Journal of Engineering Education, 21*(2), 141–148.

Kolmos, A. (2017). PBL curriculum strategies: From course based PBL to a systemic PBL approach. In *PBL in Engineering Education* (pp. 1–12). Brill Sense.

Kolmos, A., Fink, F. K., & Krogh, L. (2004). The aalborg model-problem-based and project-organized learning. In *The Aalborg PBL Model-Progress, Diversity and Challenges* (pp. 9-18). Aalborg: Aalborg University Press

Kolmos, A., & Holgaard, J. E. (2010). Responses to problem based and project organised learning from industry. *International Journal of Engineering Education, 26*(3), 573–583.

Kolmos, A., & de Graaff, E. (2015). Problem-based and Project-based Learning in engineering education: Merging models. In A. Johri and B. M. Olds (Eds.), *Cambridge handbook of engineering education research (CHEER)* (pp.141–161). Cambridge University Press.

Kolmos, A., de Graaff, E., & Du, X. (2009). Diversity of PBL–PBL learning principles and models. *Research on PBL Practice in Engineering Education* (pp. 9–21). Brill.

Kolmos, A., Du, X., Holgaard, J. E., & Jensen, L. P. (2008). *Facilitation in a PBL environment*. Aalborg University Press.

Kolmos, A., Holgaard, J. E., & Clausen, N. R. (2021). Progression of student self-assessed learning outcomes in systemic PBL. *European Journal of Engineering Education, 46*(1), 67–89.

Kolmos, A., Holgaard, J. E., & Dahl, B. (2013). Reconstructing the Aalborg Model for PBL. *International Research Symposium in PBL*. Aalborg University Press.

Krippendorff, K. (2018). *Content analysis: An introduction to its methodology*. Sage Publications.

Lappenbusch, S., & Turns, J. (2007, June). What portfolio construction efforts reveal about students' search for engineering identity. *Paper presented at 2007 Annual Conference & Exposition* (pp. 12–1608).

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Lehmann, M., Christensen, P., Du, X., & Thrane, M. (2008). Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education *European Journal of Engineering Education, 33*(3), 283–295.

Long, J., Rajabzadeh, A. R., & MacKenzie, A. (2017). Teaching teamwork to engineering technology students: The importance of self-reflection and acknowledging diversity in teams. *Proceedings of the 2017 Canadian Engineering Education Association (CEEA)*.

MacQueen, K. M., McLellan, E., Kay, K., & Milstein, B. (1998). Codebook development for team-based qualitative analysis. *Cam Journal, 10*(2), 31–36.

McCrum, D. P. (2017). Evaluation of creative problem-solving abilities in undergraduate structural engineers through interdisciplinary problem-based learning. *European Journal of Engineering Education, 42*(6), 684–700.

Marra, R. M., Jonassen, D. H., Palmer, B., & Luft, S. (2014). Why problem-based learning works: Theoretical foundations. *Journal on Excellence in College Teaching, 25*(3–4), 221–238.

Merriam, S. B. (1998). *Qualitative research and case study applications in education. Revised and expanded from "Case study research in education."* Jossey-Bass Publishers.

Meyers, K. L., Ohland, M. W., Pawley, A. L., Silliman, S. E., & Smith, K. A. (2012). Factors relating to engineering identity. *Global Journal of Engineering Education*, *14*(1), 119–131.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Sage Publications.

Miller, G. A., & Wager, L.W. (1971). Adult socialization, organizational structure, and role orientations. *Administrative Science Quarterly, 16*(2), 151–163.

Ministry of Higher Education and Science. (2013). Danish Agency for Science, Technology, and Innovation. Retrieved from http://fivu.dk/en/

Morelock, J. R. (2017). A systematic literature review of engineering identity: Definitions, factors, and interventions affecting development, and means of measurement. *European Journal of Engineering Education*, *42*(6), 1240–1262.

Morton, C. S., Huang-Saad, A., & Libarkin, J. (2016, June). Entrepreneurship education for women in engineering: A systematic review of entrepreneurship assessment literature with a focus on gender. *Paper presented at the 2016 ASEE Annual Conference and Exposition*, Ohio, USA.

Mourshed, M., Farrell, D., & Barton, D. (2013*). Education to employment: Designing a system that works*. McKinsey Center for Government.

Ota, E., & Punyabukkana, P. (2016, October). Effects of bilateral problem-based learning program for engineering students: Case of a joint course with japan and Thailand. *Paper presented at the Frontiers in Education Conference* (pp.1–9). Erie: Wiley IEEE Press.

Patrick, A. D., Prybutok, A. N. & Borrego, M. J. (2018). Predicting persistence in engineering through an engineering identity scale. *International Journal of Engineering Education, 34*(2a), 351–363.

Perrenet, J. C., Bouhuijs, P. A., & Smits, J. G. (2000). The suitability of problem-based learning for engineering education: Theory and practice. *Teaching in Higher Education, 5*(3), 345–358.

Pierrakos, O., Beam, T. K., Constantz, J., Johri, A., & Anderson, R. (2009, October). On the development of a professional identity: Engineering persisters vs engineering switchers. *Paper presented at the Frontiers in Education, 39th IEEE Annual Conference*, Texas, USA.

Pierrakos, O., Curtis, N. A., & Anderson, R. D. (2016). How salient is the identity of engineering students? On the use of the Engineering Student Identity Survey. *Paper presented at 2016 IEEE Frontiers in Education Conference*, Singapore.

Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education, 95*(2), 123–138.

Prybutok, A., Patrick, A., Borrego, M., Seepersad, C. C., & Kirisits, M. (2016). Cross-sectional survey study of undergraduate engineering identity. *Paper presented at 2016 ASEE Annual Conference & Exposition*, New Orleans, Louisiana.

Qattawi, A. A., Venhovens, P. J., & Brooks, J. (2014, June). Rethinking automotive engineering Education–Deep orange as a collaborative innovation framework for Project-Based learning incorporating Real-World case studies. *Paper presented at the 2014 ASEE Annual Conference & Exposition* (pp. 1024-1052), Indiana, USA.

Reis, A. C. B., Barbalho, S. C. M., & Zanette, A. C. D. (2017). A bibliometric and classification study of Project-based Learning in Engineering Education. *Production*, 27(spe), e20162258.

Savin-Baden, M. (2014). Using Problem-based Learning: New constellations for the 21st century. *The Journal on Excellence in College Teaching, 25*(3&4), 197–219.

Simcock, A., Ives, R., Bronson, P., Mphande, C., & Shi, J. (2007). The phased introduction of PBL in the engineering undergraduate programs at Victoria University. *Paper presented at the 2007 ASEE Annual Conference* (pp.672-689). Wichita, KS: ASEE Prims.

Spaulding, W. B. (1969). The undergraduate medical curriculum (1969 model): McMaster university. *Canadian Medical Association Journal, 100*(14), 659–664.

Spinks, N., Silburn, N., & Birchall, D. (2006). *Educating engineers for the 21st Century: The industry view*. London: The Royal Academy of Engineering.

Stevens, R., Johri, A., & O'Connor, K. (2015). Professional engineering work. Johri, A., & Olds, B. M. (Eds.). *Cambridge handbook of engineering education research*. 267–283. Cambridge University Press.

Tajfel, H., Turner, J. C., Austin, W. G., & Worchel, S. (1979). An integrative theory of intergroup conflict. *Organizational identity: A reader*, *56*(65), 33–47.

Tan, C. P., Van der Molen, H. T., & Schmidt, H. G. (2016). To what extent does problem-based learning contribute to students' professional identity development? *Teaching and Teacher Education, 54*(1), 54–64.

Terrón-López, M. J., García-García, M. J., Velasco-Quintana, P. J., Ocampo, J., Vigil Montaño, M. R., & Gaya-López, M. C. (2017). Implementation of a project-based engineering school: Increasing student motivation and relevant learning. *European Journal of Engineering Education, 42*(6), 618–631.

Thomas, R. E. (1997). Problem-based learning: Measurable outcomes. *Medical Education, 31*(5), 320–329.

Tonso, K. L. (2006). Student engineers and engineer identity: Campus engineer identities as figured world. *Cultural Studies of Science Education*, 4(1), 273–307.

Tonso, K. L. (2015). Engineering identity. In Johri, A., & Olds, B. M. (Eds.), *Cambridge Handbook of Engineering Education Research* (pp. 267–283). Cambridge University Press.

Trytten, D. A., Wong Lowe, A., & Walden, S. E. (2012). "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), 439–468.

Turner, J. C., & Reynolds, K. J. (2011). Self-categorization theory. *Handbook of theories in social psychology, 2*(1), 399–417.

UNESCO. (2017). *Sustainable development goals*. http://en.unesco.org/sdgs.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wenger, E. (1999). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press.

Weidman, J. C., Twale, D. J., & Stein, E. L. (2001). Socialization of graduate and professional students in higher education: A perilous passage?. *ASHE-ERIC Higher Education Report*, *28*(3), Jossey-Bass.
Williams, M., & Ringbauer, S. E. (2014, June). PBL field deployment: Lessons learned adding a problem-based learning unit to a traditional engineering lecture and lab course. *Paper presented at the 2014 ASEE Annual Conference & Exposition* (pp. 954-974), Indiana, USA.
Wilkerson, L., & Gijselaers, W. H. (1996). *Bringing problem-based learning to higher education: Theory and practice*. Jossey-Bass.
Yadav, A., Subedi, D., Lundeberg, M. A., & Bunting, C. F. (2011). Problem-based learning: Influence on students' learning in an electrical engineering course. *Journal of Engineering Education, 100*(2), 253–280.
Zastavker, Y. V., Ong, M., & Page, L. (2006, October). Women in engineering: Exploring the effects of project-based learning in a first-year undergraduate engineering program. *Paper presented at the Frontiers in Education 36th Annual Conference* (pp. 1–6). IEEE.
Zhou, C. (2012). Integrating creativity training into problem and project-based learning curriculum in engineering education. *European Journal of Engineering Education, 37*(5), 488–499.
Ziyatdinova, J. N., & Sanger, P. A. (2015). Project-based learning for creating the 21st-century engineer. *Higher Education in Russia, 4*(3), 92–97.

APPENDICES

Appendix A. The interview protocol in the qualitative study

BACKGROUND AND DESCRIPTIVE QUESTIONS

1. Basic information (name, subjects, semesters)
2. In this semester, how was your group formed?
3. How did your team choose the topic of your project?

INTERNAL SOURCES

1. Are you interested in engineering? Please elaborate more on your interest.
2. What makes engineering interesting for you?
3. What drove you to choose to study engineering?
4. What makes becoming an engineer important/meaningful for you? Why?
   Probe: What learning activities can help you achieve this goal?
5. How do you understand the work of engineers?
6. In your opinion, what skills or knowledge are necessary for engineers?
   Probe: How do you assess yourself in aspects of those skills/knowledge?
   In what way do you think PBL and teamwork can help you develop those competences?
7. Could you evaluate your performance in this project? / Are you satisfied with your own performance in teams?
   Probe: Could you elaborate on this? / Could you give an example?
8. Do you see yourself as a future engineer? Why?

EXTERNAL SOURCES

1. In your current study, what influences/enhances your motivation in learning engineering?
   Probe: Do you think teamwork in PBL influences your motivation to learn engineering? If so/not, how/why not?
2. What kinds of project could make you feel more like an engineer?
3. What do you expect to gain from this project? Are those expectations being fulfilled?
4. Could you describe briefly how you collaborated with your team members/supervisors to finish the project?
5. Based on those teamwork experiences, what factors do you think could influence your choice of future jobs?

Probe: Do you think PBL/teamwork can help you prepare for future jobs? If so/not, how/why not?

6. For you, what is important for successful teamwork?

Probe: What do you think about your teamwork in this project?

7. Do you have the opportunity to work with industry/companies? If so, please elaborate on the connection to industry.

Probe: How do you think these interactions with companies influence you?

8. What do you learn from teamwork?

Probe: In what way does teamwork contribute to/constrain your study of engineering?

9. What challenges do you meet in this project? How do you deal with these challenges?

10. 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?

CONCLUDING QUESTIONS

1. (For students who haven't experienced PBL before) Could you compare the differences between this PBL experience and your prior learning experience regarding developing engineering identity?

2. Do you have anything else to say about today's topic?

Appendix B. Survey of engineering students' professional identity development in PBL

Dear participant,

This survey consists of 30 questions about your views on the effects of the PBL courses and programs. We are particularly interested in how you think **PBL has supported you in developing your self-perceived identity as an emerging engineer**. In this survey, PBL includes problems, projects, teamwork, and possible collaboration with external stakeholders.

Please read the questions carefully and answer them as accurately as you can. In this survey, there are no right or wrong answers. Your answers should be those that can best describe your personal experience.

At the bottom of the window, you can see your progress in the survey, and you can move back and forth between questions. It will take around 15 minutes to complete the survey. All your answers will be kept confidential.

Your responses will be saved automatically. If you close the window by accident, you can re-access the survey via the link you have received. Thank you for your time and participation.

BACKGROUND INFORMATION

1) What gender do you identify yourself as?

❑ Male

❑ Female

❑ Prefer not to answer

2) What is your age? ___________

3) What is your nationality? ____________

4) Which degree are you studying for?

❑ Bachelor's degree – First year
❑ Bachelor's degree – Second year
❑ Bachelor's degree – Third year
❑ Bachelor's degree – Fourth year
❑ Bachelor's degree – Fifth year
❑ Master's degree – First year
❑ Master's degree – Second year
❑ Master's degree – Third year

5) Which program are you studying now? ________________________

PBL ENVIRONMENT AND ENGINEER IDENTITY

6) To what extent do you see yourself as a future engineer? Please rate from 1 to 5 showing the extent from low to high.

❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ Not sure yet

7) Based on your personal experience within a PBL environment, to what extent have the following aspects helped you to develop a sense of becoming an engineer? Please rate from 1 to 5 showing the extent from no support to strong support.

1. A mentor/role model from a company I have worked with in PBL enhances my wish to become an engineer	1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑	Not applicable ❑
2. I feel prepared for real engineering work due to my PBL experience	1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑	Not applicable ❑
3. I believe my PBL experience helps me overcome difficulties in the learning process	1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑	Not applicable ❑
4. Through my PBL experience, I develop interdisciplinary skills	1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑	Not applicable ❑
5. By experiencing PBL, I become more concerned about the contributions of engineers towards the sustainable development of the society	1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑	Not applicable ❑
6. PBL supervisors enhance my wish to become an engineer	1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑	Not applicable ❑
7. I feel prepared to manage my time well by experiencing PBL	1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑	Not applicable ❑

8. By experiencing PBL, I find it interesting to connect engineering content with humanity and society content	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
9. Through my PBL experience, I enjoy working with people from diverse backgrounds	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
10. I anticipate a promising engineering career due to my PBL experience	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
11. I enjoy being challenged by solving real-life problems in PBL	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
12. Through working on projects, I develop abilities to negotiate among different stakeholders	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
13. I am able to apply theories to engineering practice while studying through a PBL approach	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
14. Collaboration with peers in PBL makes me feel like I am working in an engineering team	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
15. I am able to take responsibilities actively during PBL processes	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
16. I learn engineering content well while studying through a PBL approach	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
17. I develop the ability to solve conflict through my PBL experience	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
18. Opportunities to work on projects with/for engineering companies make me feel like an engineer	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
19. I learn to identify, analyze, and solve real-life problems by experiencing PBL	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
20. Getting support from engineering companies for my projects makes me feel like I am part of the professional community	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑

21. Through working on problems/projects, I become more aware of the engineering ethics	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
22. I learn to conduct engineering design (a model, product, etc.) by experiencing PBL	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
23. I plan to pursue the engineering profession because of opportunities to do innovative work	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
24. PBL suits my personal learning preferences	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
25. Studying in PBL makes me feel more interested in engineering contents	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
26. Studying in a PBL environment makes me feel like a professional engineer	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
27. In PBL, I have the opportunity to work on projects to improve people's quality of life	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
28. Through my PBL experience, I feel more confident in communicating with others (peers, supervisors, and other stakeholders)	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
29. Through my PBL experience, I feel more confident in my teamwork skills	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑
30. I develop leadership skills by experiencing PBL	1 ❑	2 ❑	3 ❑	4 ❑	5 ❑	Not applicable ❑

8) Do you have any further comments on the resources from the PBL learning environment that you feel contribute to your desire to become an engineer?

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9) Do you have any further comments on what factors could constrain your desire to become an engineer?

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