Ju and Zhu
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RESEARCH

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Exploring senior engineering students' engineering identity: the impact of practice-oriented learning experiences

Tongjie Ju[1] and Jiabin Zhu[1*]

Abstract

Background Engineering identity reflects students' acceptance and recognition of engineering, which has a great influence on their willingness to enter and stay in the engineering field. Existing studies have shown that curricular and co-curricular practice-oriented experiences may be helpful for developing students' engineering identity. However, the actual impact of various practice-oriented learning experiences remained to be further examined. This quantitative study aims to explore the impact of three types of practice-oriented learning experiences (capstone experiences, technological innovation and entrepreneurship competitions, and engineering-related internships) in the development of engineering talents' engineering identity. A theoretical framework of engineering identity, which consists of three dimensions, that is, Interest, Performance/Competence and Recognition, was adopted to guide the research.

Results Through responses from 160 senior engineering students at a leading research intensive Chinese university, the study explored the relationships between engagement in practice-oriented learning experiences and engineering identity. Senior capstone design was found to be associated positively with students' development of engineering identity and recognition by others. Participating in two or more technological innovation and entrepreneurship competitions associated positively with students' development of engineering identity, performance/competence and recognition. Meanwhile, internships did not show any statistically significant effect on engineering identity. Moreover, by analyzing the potential mediating effect, we found that recognition played a complete intermediary role between senior capstone design and engineering identity. In addition, recognition and performance/competence mediated the relationship between twice or more technological innovation and entrepreneurship competitions and engineering identity.

Conclusions These findings add to our current understanding about the role of different practice-oriented learning activities on students' development of engineering identity. These findings point to the importance of learning activities, including technological innovation and entrepreneurship competitions and senior capstone design, on the development of engineering identity. Moreover, the results highlighted the important role of students' engagement in multiple authentic engineering projects throughout the curriculum and their gaining recognitions through these project experiences. Based on these findings, practical suggestions are proposed to help nurture students' engineering identity. In addition, future qualitative investigations about the underlying mechanisms are recommended to facilitate the understanding of students' development of engineering identity.

*Correspondence:
Jiabin Zhu
jiabin.emily.zhu@gmail.com
Full list of author information is available at the end of the article

Keywords Engineering identity, Capstone design, Technological innovation and entrepreneurship competition, Internship

Introduction

Engineers are essential talents for countries to keep up with the new round of technological revolution. However, there is an engineering brain drain in many countries, and students who have completed engineering degrees do not necessarily engage in engineering or related professions (Lichtenstein et al., 2009; Zhang & Li, 2015). Compared with other professional talents, engineering talents requires a lot of technical development; students need to go through challenging training processes to become professional engineers. The loss of engineering talent can be unfavorable and disadvantageous for technological and economic development; therefore, to retain potential engineering talents becomes a compelling issue for nations and states (National Academies of Sciences, Engineering, and Medicine, 2016). Relevant studies have shown that students with a higher score in engineering identity-related measurement are more likely to persist in studying engineering and/or work as engineers after graduation (Choe & Borrego, 2020; Verdín, 2021). However, the current status of engineering identity of engineering undergraduates is not quite promising. Based on interviews with students from a U.S. technical public university, prior research pointed out that, despite taking nearly 4 years of engineering-related courses and activities, senior engineering students can still be unsure of what it means to be an engineer and what kind of work an engineer needs to do (Matusovich et al., 2009). In this regard, more and more scholars begun to pay attention to different ways to improve students' engineering identity.

Prior researchers pointed out that various curricular and co-curricular experiences can help students develop their engineering identity, such as engineering-related courses (Lappenbusch & Turns, 2007), community practice activities based on project-based learning (Du, 2006), and reflection on existing engineering practice (Eliot & Turns, 2011). Through contact with the engineering field, students can deepen their understanding of engineering and thus strengthen their engineering identity. This study seeks to further explore the factors that can impact the development of students' engineering identity by examining the impact of students' engagement in different practice-oriented activities on their engineering identity.

Literature review

Engineering identity

Identity means a self-construction in a particular context and is a process of constant development and self-reflection (Johnson et al., 2011). Engineering identity reflects students' acceptance and recognition of engineering, which is of great significance to whether students are willing to enter and stay in the engineering field. When students had a strong sense of engineering identity, they would regard themselves as future engineers, thus encouraging them to major in engineering (Matusovich et al., 2010). After majoring in engineering, students' engineering identity would continue to affect their learning. Engineering identity served as a compass for students to complete their studies (Stevens et al., 2008). A lack of identification with engineering and engineers often drove students to switch from engineering majors to other majors (Tonso, 2014). Identification with engineering would encourage students to further identify with the engineering profession (Downey & Lucena, 2003), which might enhance the willingness of students to choose engineering-related jobs after graduation, thus promoting students to choose to stay in the engineering field for employment.

In view of the importance of engineering identity, multiple authors seek to clarify the definitions of engineering identity. According to Gee's multiple identity theory, identity is defined as "being recognized as a certain 'kind of person,' in a given context" (Gee, 2000, p. 99). Thus, identity is changeable and potentially measurable by defining the constructs embedded in a specific identity. Existing research on the frameworks of engineering identity can be summarized into four main categories (Morelock, 2017). The first kind argues that engineering identity is a combination of different aspects of identity, such as academic identity, school identity and occupational identity. The second theme suggests that engineering identity refers to perceptions of self or engineering profession (Beam et al., 2009; Mann et al., 2009). For example, Beam et al. (2009) defined engineering identity as perceptions of self in relation to the engineering profession. The third one shows that engineering identity can be defined via multiple components including cognitive, affective and performance variables (Eliot & Turns, 2011; Godwin, 2016). The forth category describes engineering identity as specific actions or decisions, for example, building relationships with engineering professional community (Peters & Pears, 2013).

Influencing factors on engineering identity

In view of the importance of engineering identity, scholars also studied the factors that can influence engineering identity to take effective measures to promote the development of students' engineering identity (Chen et al., 2023; Choe & Borrego, 2019; Meyers et al., 2012; Verdín et al., 2018). The influencing factors of engineering identity mainly include gender (Meyers et al., 2012), interest in mathematics, physics and science (Verdín et al., 2018), contact with engineering-related personnel (Downey & Lucena, 2003; Stevens et al., 2008), and engineering-related experiences (Beam, et al., 2009; Lappenbusch & Turns, 2007).

Amongst the various factors, the increase of engineering-related experience can contribute to the development of students' engineering identity. Before participating in formal engineering education, students who had participated in engineering-related activities had a higher level of engineering identity than students who had not been exposed to the engineering field (Beam, et al., 2009). Formal engineering education experience can serve as an important platform for students to develop their engineering identity. For example, when students acquired basic engineering knowledge and skills through engineering courses, their engineering identity could be strengthened (Lappenbusch & Turns, 2007). Moreover, as pointed out by Godwin and Lee (2017) based on quantitative data from a large, public US university, students' engineering identity reached the highest level in their senior year. Similarly, Delatte et al. (2010) pointed out that the introduction of real engineering cases in the course had helped students to establish their engineering identity. Meanwhile, students' encountering with difficulties in the learning process of engineering courses might have a negative impact on their engineering identity or may instead strengthen their engineering identity when students were ready to overcome the difficulties (Fleming et al., 2013).

Previous studies had also shown that practice-oriented learning activities with the characteristics of project-based learning (PBL) and the integration of real engineering environment had a positive impact on students' engineering identity (Chen et al., 2023; Du, 2006; Tan et al., 2016). Project-based learning helps students develop a sense of responsibility and work style as engineers in a practical engineering environment (Du, 2006). Tan et al. (2016) found that through the learning experience which incorporated real engineering environments, students could understand the scope and nature of engineers' work and the different aspects of their work. Chen et al. (2023) pointed out that in a project-based learning environment, factors such as students' internal interest and external support can contribute to their engineering identity development. During engineering students' undergraduate studies, multiple platforms may embody the features of PBL. Such platforms can include cornerstone courses (Marshall, et al., 2018), capstone design experiences (Marques et al., 2017), technological innovation and entrepreneurship competitions (Bland et al., 2016), service-learning activities (Carberry et al., 2013), internships (Kramer & Usher, 2012), and some other courses or learning programs that have incorporated authentic engineering projects into the in- and out-of-class activities.

Amongst the different PBL platforms, this study focuses on students' participations in senior capstone design, technological innovation and entrepreneurship competition, and internship, because students are often engaged in authentic, complex engineering projects in these activities. In addition, prior research have demonstrated potential correlations between the engagement of said activities and the development of students' engineering identities (Bland et al., 2016; Dunlap, 2005; Kramer & Usher, 2012; Litzinger et al., 2011; Marques et al., 2017), which will be further elaborated as follows.

Senior capstone design

Senior capstone design is an culminating activity that usually takes place during the last year of undergraduate studies. It aims to train and test students' abilities to solve practical problems by comprehensively applying knowledge and skills they have learned. Students' soft skills such as communication, collaboration and negotiation skills are exercised and developed in the process of completing senior capstone design projects (Marques et al., 2017). Dunlap (2005) interviewed 31 computer undergraduates who completed senior capstone design projects and found that students' software development capability was improved through capstone projects, thus strengthening their confidence to becoming a software engineer. In University-Industry collaborative capstone projects, students had the opportunity to truly understand the value of what they had learned via practice and developed their engineering identity through teamwork in real projects (Mann, et al., 2009). Thus, in this study, we hypothesize that finishing senior capstone design projects positively relates to the engineering identity of senior engineering students.

Technological innovation and entrepreneurship competition

Technological innovation and entrepreneurship competitive activities offer multiple opportunities to improve students' professional skills and attributes. It provides engineering students with a platform to participate in authentic engineering tasks. Students participated in the planning and designing processes, solved complex problems, and cooperated with teams during the competition (Bland et al., 2016; Huang et al., 2021). In the process of solving real engineering problems, engineering students applied their professional knowledge and skills to practical or application-oriented problems (Litzinger et al., 2011). When participating in competitions, students thought and acted-like professional engineers, which could promote the development of students' professional ability so as to prepare for their future careers (Bland et al., 2016). Although studies have not directly proved that technological innovation and entrepreneurial competition can promote the development of engineering identity, multiple scholars have pointed out that students develop professional abilities through such competitions. Since the students' professional performance/competence constitutes an important part of their engineering identity (Godwin, 2016), we hypothesize that experience in technological innovation and entrepreneurship competition positively relates to senior engineering students' engineering identity.

Internship

As one of the most common platforms for students to engage in authentic engineering contexts, internship has become an essential part of engineering students' training. Internship contributes to the improvement of multiple abilities and serves as one of the most effective ways to integrate work and learning (Kramer & Usher, 2012). Studies on the relationship between internship and engineering identity have not reached a consensus. Dehing et al. (2013) found that not all students' engineering identity improved after internship. Moreover, for different students, the impact of internship was different. Students with lower engineering identity were more likely to demonstrate development in their engineering identity through the internship (Dehing et al., 2013). In addition, engineering identity was positively correlated with students' willingness to work in enterprises. Meanwhile, students with internship experiences were more inclined to work in enterprises (Choe & Borrego, 2020). To a certain extent, this indicated that internship may had a certain impact on engineering students' engineering identity. Based on these studies, we hypothesize that internship experience positively relates to senior engineering students' engineering identity.

To summarize, prior studies have explored some possible impact of practice-oriented experiences on engineering identity. Nevertheless, it requires further effort to examine the effect of such learning experiences on the different components of engineering identity. Moreover, most of the studies were conducted in a western context. Concerning the importance of engineering identity, it is of unique relevance to explore the impact of relevant experiences on engineering identity across different contexts.

In terms of Chinese engineering education, prior research have delineated active education innovations that are taking place in various Chinese universities and engineering colleges (Li et al., 2014; Zha, 2008; Zhu et al., 2020). In particular, practitioners in leading Chinese universities are engaging in piloting teaching and learning innovations, such as design-oriented PBL, outcome-based learning at both the university level and individual class level (Gu et al., 2014; Zhang, 2011; Zhang, et al., 2018). Existing research have started to explore the outcomes of such teaching and learning innovations, including the said practice-oriented learning activities (Zhang, et al., 2018, 2021); however, empirical studies remain scarce as to the impact of such learning activities on the development of students' engineering identity. This current study seeks to contribute to the on-going research on the impact of relevant activities during the undergraduate studies on students' engineering identity in a Chinese context.

Engineering identity frameworks

As mentioned in the literature review section, multiple strands of frameworks on engineering identity were proposed (Morelock, 2017). In this research, we adopted a framework proposed by Godwin and colleagues (2016, 2017, 2020), as presented in the third category of Morelock's literature synthesis, to explore the components of students' engineering identity using the three specific dimensions of the framework, including, interest in engineering, performance/competence, and recognition. Meanwhile, we adopted the second category of frameworks (Morelock, 2017), describing engineering identity as perceptions of self in relation to the engineering profession (Beam, et al., 2009) to capture the overall status of students' engineering identity.

In specific, the framework by Godwin and colleagues (2016, 2017, 2020) can be traced back to the on-going studies on science identity and physical identity (Carlone and Johnson, 2007; Hazari et al., 2010). According to Godwin and her colleges' work (2016, 2017, 2020), interest refers to students' personal desire or curiosity to explore in engineering. Performance/competence refers to the belief of students concerning how well they can achieve learning and understanding regarding engineering content and how well they can carry out engineering practice. Recognition refers to students' internalized belief that they can be recognized by peers, parents or teachers that they can do well in the engineering field. We chose this framework because of its strength in operationalizing the components of engineering identity and its applications in multiple studies amongst engineering students, demonstrating its validity in exploring the concept of engineering identity (Godwin & Lee, 2017; Godwin & Kirn, 2020; Choe & Borrego, 2020). Therefore, in this study, we applied this framework of engineering identity to explore the impact of practice-oriented learning activities on the different components of engineering identity.

For the overall engineering identity, defined as perceptions of self in relation to the engineering profession according to Beam et al. (2009), we adopted an engineering identity measure that was operationalized and validated by prior researchers (Choe and Borrego, 2019; Choe et al., 2017; Plett et al., 2011).

Proposed hypotheses

Based on the reviewed literature concerning the influencing factors on engineering identity and guided by the above-mentioned frameworks, three hypotheses along with their sub-hypotheses are proposed as follows.

H_1 Senior capstone design experience positively relates to senior engineering students' engineering identity and its components (Interest, Performance/Competence, and Recognition).

H_2 Technological innovation and entrepreneurship competition experience positively relates to senior engineering students' engineering identity and its components (Interest, Performance/Competence, and Recognition).

H_3 Internship experience positively relates to senior engineering students' engineering identity and its components (Interest, Performance/Competence, and Recognition).

Methodology

Sampling

Senior engineering students were recruited from two engineering schools (A and B) of a leading Chinese research intensive university H, a prior "985" and current " Double first-Class" university, where active engineering education innovations were taking place. It should be noted that the "985" (1998) project, along with the subsequent "Double first-class" project (2015), was initiatives launched by the Chinese government to enhance the academic and research quality of key Chinese universities by a focused investment of resources and multiple preferential policies (Chinese MoE, 2008; Chinese MoE et al., 2017). There were 39 Chinese universities being designated as "985" project universities (Chinese MoE, 2008, 2015). The classification was valid before the subsequent "Double first-class" project announced a list of 42 selected universities as "World-class Universities-in-Construction" in 2017 (Chinese MoE et al., 2017) which included most of the "985" universities.

The on-going innovative educational activities that were taking place in University H included providing students with in-class activities (such as design experiences), and extracurricular activities (such as technological innovation and entrepreneurship competitive activities) that are project-based and geared toward developing both students' technical and professional skills. School A and School B were chosen, because the two branch engineering colleges have larger enrollment in University H than other engineering colleges.

The survey language was Mandarin. The original English version of the survey items was translated into Mandarin and back-translated into English to verify the accuracy of translation. The survey was also beta-tested among engineering students before the official administration. The survey was administered in May 2021, which was in the middle of the Spring semester, via gatekeepers of the respective schools. The online survey (administered via www.wjx.cn) started with participants giving informed consent before they can proceed to the survey.

The survey link was distributed to all senior engineering students from the two schools with a total of 766 students, among whom 160 valid survey responses were collected. The response rate was 20.89%. The 160 participants were from six engineering majors, such as mechanical engineering, electrical and computer engineering, energy and power engineering and industrial engineering. Males constituted 80.0% of the sample and females 20.0%. The percentage of female participants roughly reflected the overall presentation of female students in these schools (varied from about 10% to about 20% across different majors).

Survey instrument

This study adopted a survey instrument which consists of three parts, that is, items for engineering identity, items exploring students' learning experiences, and items for collecting demographic information.

In the first part, survey items was compiled on the basis of a number of previous quantitative surveys for the three dimensions of interest, performance/competence and recognition (Godwin, 2016; Choe & Borrego, 2020, 2019). According to Choe and Borrego (2019), identification with engineering is different from identification with math or science, the former concerns not only identification with the engineering discipline but also with the engineering profession. Therefore, the compiled survey included both items that represent identifications with engineering disciplinary and items that represent identifications with engineering profession (Godwin, 2016; Choe & Borrego, 2020, 2019). In addition, to finalize the choice and wording of items, survey items were tested during the beta-testing phase via two rounds of cognitive interviews among engineering students (nine person-times in all). In this process, a participant would think-aloud when responding an item to ensure that a listed item can reflect the intended purposes of that item (Ryan et al., 2012). Follow-up questions were also asked to clarify what they thought about certain wordings.

Meanwhile, an engineering identity measure with four questions that were operationalized and validated by prior researchers (Choe and Borrego, 2019; Choe et al., 2017; Plett et al., 2011) was adopted to measure the overall status of students' engineering identity.

The initial survey had 29 items. A Five-point Likert scale was used ("Strongly disagree", "Disagree", "uncertain", "Agree", "Strongly agree") for the items.

The second part measured students' participation in practice-oriented learning activities, including senior capstone design, technological innovation and entrepreneurship competition and engineering-related internship.

The third part investigated demographic information, including gender, major, GPA, and whether they have close family members engaged in engineering-related professions. The choice of control variables was informed by prior findings, which illustrated the importance of gender, GPA, and close contact with engineering-related personnel as related to students' engineering identity (Koul, 2018; Meyers et al., 2012; Stevens et al., 2008).

Validity and reliability

Exploratory factor analysis (EFA) was used to explore the structure validity of the survey. The four items used to measure the overall status of engineering identity and, therefore, considered as a separate construct from the other items on the three dimensions of engineering identity. The four items were adopted directly from the items used by Choe and Borrego (2019). Using exploratory factor analysis (EFA), Choe and Borrego (2019) reported results of the structural validity of the four items (single factor) along with Cronbach's Alpha of 0.83, falling within the acceptable range (Brace et al., 2012). Using EFA, we obtained a similar result (single factor) with a Cronbach's Alpha of 0.854. The rest items on interest, performance/competence and recognition were a compilation of existing questionnaires (Godwin, 2016; Choe & Borrego, 2020, 2019). The structure of these items was also explored with EFA.

For EFA, the value of Kaiser–Meyer–Olkin (KMO) was 0.918 and the Bartlett's Test of sphericity was significant ($p < 0.001$), both of which met the standard for factor analysis. The extraction method was principal component analysis (PCA). The rotation method was Varimax. Based on the result, four items were deleted because of low factor loading (less than 0.40) (Field, 2009). A second exploratory factor analysis was performed. Factor loadings of all the items in the second factor analysis are listed in Table 1.

The results showed four factors. Factor one represents the dimension of interest; factor two represents the dimension of performance/competence. Factor three concerns recognition from friends, peers and family members, while factor four represents recognition from advisors. Still, both factors three and four represent the dimensions of recognition. In this case, the results of EFA agree largely with the three dimensions of the engineering identity framework (Godwin, 2016). For the items (No. 7 and 8 in factor two) that were cross-loaded into two factors, we designated the dimension as performance/competence as defined in the original literature (Godwin, 2016). The source of final items in this survey are described in Table 2.

Cronbach's alpha was calculated to ensure the reliability of the instrument. The Cronbach's alpha coefficients for items in each dimension were found to be within the acceptable range of larger than 0.70 (Brace et al., 2012), that is, 0.927 (Interest), 0.910 (Performance/Competence), 0.871 (Recognition) and 0.854 (Engineering identity), respectively.

Variables

Three control variables were included in this study: gender, GPA, and whether students had close family members that were engaged in engineering-related professions. Descriptive statistics are shown in Table 3.

Independent variables consisted of engineering students' engagement in practice-oriented learning experiences, including senior capstone design, technological innovation and entrepreneurship competition and engineering-related internship. Percentages of respondents are shown below in Table 4. It should be noted that senior capstone design is a compulsory element for all senior engineering students, that is, students in their fourth year. At the time of survey administration, May 2021, which was in the middle of a Spring semester, there were still many students who were in the middle of their capstone design projects. For such students, we denote them as "not yet completed" as compared to those who have completed their senior design projects at the time of this study. In addition, very few students have engaged in technological innovation and entrepreneurship competition or engineering-related internship more than twice among the sampled students. Therefore, we only reported three groups (No such experience, Once, Twice or More) for these learning activities.

Table 1 Factor loadings

	Items	Component 1/2/3/4	Predefined dimension[a]
	Factor one		
1	I think engineering is interesting	0.799///	I
2	I feel good when I am doing engineering	0.784///	I
3	I like doing engineering	0.779///	I
4	I think engineering is fun	0.776///	I
5	I find fulfillment in doing engineering	0.772///	I
6	I enjoy learning engineering	0.722///	I
7	I am interested in learning more about engineering	0.695///	I
	Factor two		
1	Designing a system, a part/component of a system, or a process based on realistic constraints	/0.794//	P
2	Creating prototypes to test an idea	/0.794//	P
3	Designing and conducting experiments to test a research idea	/0.757//	P
4	Building and testing systems to learn more about how they work	/0.709//	P
5	Improving a design to make it more efficient (faster, better, cheaper)	/0.549//	P
6	Identifying technical solutions that are as simple as possible	/0.534//	P
7	I am confident that I can understand engineering outside of class	0.532/0.493//	P
8	I am confident that I can understand engineering in class	0.450/0.433//	P
	Factor three		
1	My peers view me as an engineer	//0.844/	R
2	Other students in my program see me as an engineer	//0.756/	R
3	My friends see me as an engineer	//0.746/	R
4	My family sees me as an engineer	//0.710/	R
	Factor four		
1	My advisor expects me to continue my career as an engineer	///0.865	R
2	My advisor sees me as an engineer	///0.693	R

I Interest, *P* performance/competence, *R* recognition

[a] Pre-defined dimension refers to the dimension from previous quantitative surveys (Godwin, 2016; Choe & Borrego, 2020, 2019)

Four dependent variables were constructed in this study: interest, performance/competence, recognition and engineering identity.

Data analysis

To explore the relationship between practice-oriented learning activities and engineering identity for senior engineering students, this study conducted multiple linear regression. Three kinds of practice-oriented learning experiences were treated as independent variables. Engineering identity and the three components of engineering identity, that is interest, performance/competence, and recognition, were treated as dependent variables.

Mediating effect was explored between practice-oriented learning experiences and engineering identity. We adopted a Bias-corrected bootstrap method to test the mediating effect (Taylor et al., 2008), in which null hypothesis was rejected if the 95% confidence interval of an effect value does not include zero. All analyses were conducted via SPSS V24.

Results

Relationships between practice-oriented learning activities and engineering identity

Engineering identity

The regression model with both control variable and independent variables (participation in multiple practice-oriented learning experiences) on engineering identity resulted in an $F(10, 149)$ of 2.074 ($p < 0.05$) and an adjusted determination coefficient (R^2) of 0.063. Compared with the regression model with only control variables, the (ΔR^2) was 0.040, which means that participation in the learning activities explained 4.0% variation of engineering identity. In specific, compared with students who had not completed senior design, students who had completed senior design have a higher level of engineering identity ($\beta = 0.224$, $p < 0.01$). Compared with students who had not participated in the competition, students who had participated in competitions twice or more have a higher level of engineering

Table 2 Adjusted items for engineering identity

Dimension	Items	Source
Interest	I am interested in learning more about engineering	Godwin (2016)
	I enjoy learning engineering	
	I find fulfillment in doing engineering	
	I like doing engineering	Choe and Borrego (2020)
	I feel good when I am doing engineering	
	I think engineering is fun	
	I think engineering is interesting	
Performance/competence	I am confident that I can understand engineering in class	Godwin (2016)
	I am confident that I can understand engineering outside of class	
	Creating prototypes to test an idea	Choe and Borrego (2020)
	Designing a system, a part/component of a system, or a process based on realistic constraints	
	Building and testing systems to learn more about how they work	
	Designing and conducting experiments to test a research idea	
	Improving a design to make it more efficient (faster, better, cheaper)	
	Identifying technical solutions that are as simple as possible	
Recognition	My advisor sees me as an engineer	Choe and Borrego (2019)
	My advisor expects me to continue my career as an engineer	Choe and Borrego (2019); Choe and Borrego (2020)
	Other students in my program see me as an engineer	
	My friends see me as an engineer	
	My family sees me as an engineer	
	My peers see me as an engineer	
Engineering identity	I consider myself an engineer	Choe and Borrego (2019); Choe et al. (2017)
	I am proud to be an engineer	
	Being an engineer is an important reflection of who I am	
	I feel strong ties to other engineers in my discipline	

Table 3 Descriptive statistics of control variables

Variable name	Coding	Number	Percentage (%)
Gender	0 = Female	32	20.0
	1 = Male	128	80.0
Whether there were close family members that were engaged in engineering-related professions	0 = No	77	48.13
	1 = Yes	83	51.87
GPA	0 = Over 3.7	36	22.5
	1 = 1–2.7	4	2.5
	2 = 2.7–3.2	29	18.1
	3 = 3.2–3.7	91	56.9

identity ($\beta = 0.178$, $p < 0.05$) (Table 5). In sum, the regression results partially supported H_1 and H_2.

This study further explored the effect of practice-oriented learning activities on each dimension of engineering identity. These regression models regarded three kinds of practice-oriented learning activities as independent variables, and treated interest, performance/competence and recognition as dependent variables, respectively.

Interest dimension The regression results were not significant. Participation in the practice-oriented learning activities did not show any effect on the engineering interest among the sampled students in a significant way.

Table 4 Descriptive statistics of independent variables

Variable name	Coding	N	%
Senior capstone design	0 = Not yet completed	127	79.4
	1 = Completion	33	20.6
Technological innovation and entrepreneurship competition	0 = No such experience	105	65.6
	1 = Once	35	21.9
	2 = Twice or more	20	12.5
Engineering-related internship	0 = No such experience	48	30.0
	1 = Once	93	58.1
	2 = Twice or more	19	11.9

Performance/competence dimension The regression model with both control variable and independent variables (participation in multiple practice-oriented learning experiences) on performance/competence resulted in an *F(10, 149)* of 2.602 ($p < 0.01$) and an adjusted determination coefficient (R^2) of 0.092. Compared with the regression model with control variables, the (ΔR^2) was 0.069, which means that participation in the learning activities explained 6.9% variation of performance/competence. In specific, compared with the students without technological innovation and entrepreneurship competition experience, the students who had two or more competition experiences performed better in performance/competence ($\beta = 0.315$, $p < 0.001$) (Table 6). In sum, the regression results partially supported H_2.

Recognition dimension The regression model with both control and independent variables resulted in an *F (10, 149)* of 2.352 ($p < 0.05$) and an adjusted (R^2) of 0.078. Compared with the regression model with control variables, (ΔR^2) was 0.049, which means that participation in the learning activities explained 4.9% variation of recognition. Moreover, results of regression indicated that, compared with students who had not completed senior design, students who had completed senior design have a

Table 5 Multiple linear regression result on engineering identity ($N = 160$)

Variables			Beta(β)	SE	95%CI
Control variables	Gender (reference group: female)	Male	0.053	0.174	[− 0.228, 0.459]
	Whether close people engaged in engineering-related profession (reference group: no)	Yes	− 0.004	0.138	[− 0.279, 0.266]
	GPA (reference group: over 3.7)	1–2.7	0.110	0.172	[− 0.205,0.0.474]
		2.7–3.2	− 0.162	0.597	[− 2.084, 0.274]
		3.2–3.7	0.112	0.282	[− 0.323, 0.288]
Independent variables	**Senior Capstone Design (reference group: not yet completed)**	**Completed**	**0.224****	**0.172**	**[0.144, 0.823]**
	Technological Innovation and Entrepreneurship Competition (Reference group: no such experience)	Once	0.052	0.171	[− 0.228, 0.449]
		Twice or more	**0.178***	**0.217**	**[0.041, 0.900]**
	Engineering-Related Internship (reference group: no such experience)	Once	− 0.010	0.155	[− 0.323, 0.288]
		Twice or more	− 0.092	0.236	[− 0.717, 0.218]

*$p < 0.05$, **$p < 0.01$

The significance values (bold) are indicated in the last line in each of the table

Table 6 Multiple linear regression result in performance/competence dimension (N = 160)

Variables			Beta(β)	SE	95%CI
Control variables	Gender (reference group: female)	Male	0.101	0.142	[− 0.098, 0.462]
	Whether close people engaged in engineering-related profession (reference group: no)	Yes	− 0.023	0.112	[− 0.254, 0.189]
	GPA (reference group: over 3.7)	1–2.7	0.074	0.140	[− 0.201, 0.352]
		2.7–3.2	− 0.178	0.486	[− 1.782, 0.139]
		3.2–3.7	0.028	0.230	[− 0.401, 0.508]
Independent variables	Senior Capstone Design (reference group: not yet completed)	Completed	0.126	0.140	[− 0.052, 0.501]
	Technological Innovation and Entrepreneurship Competition (reference group: no such experience)	Once	0.067	0.140	[− 0.158, 0.394]
		Twice or more	**0.315****	**0.177**	**[0.338, 1.038]**
	Engineering-related internship (reference group: no such experience)	Once	− 0.014	0.126	[− 0.269, 0.229]
		Twice or more	0.018	0.193	[− 0.340, 0.421]

**$p < 0.001$

The significance values (bold) are indicated in the last line in each of the table higher level of recognition ($\beta = 0.210$, $p < 0.01$). Students who had participated in competitions twice or more times had a higher level of recognition than those who had no such experience ($\beta = 0.218$, $p < 0.01$) (Table 7). In sum, the regression results partially supported H_1 and H_2.

Mediating variable between practice-oriented learning experiences and engineering identity

According to the results of multiple linear regression analysis, senior capstone design had a significant positive effect on students' engineering identity ($p < 0.01$) and recognition ($p < 0.01$). Meanwhile, participating in twice or more technological innovation and entrepreneurship competitions was positively related to students' engineering identity ($p < 0.05$), performance/competence ($p < 0.001$) and recognition ($p < 0.01$). According to the engineering identity framework (Godwin, 2016; Choe & Borrego, 2020), performance/competence and recognition can effectively promote the development of engineering identity. Thus, there were significant correlations between these variables, which met the premise of mediating effect analysis.

Mediating effect of recognition in the relationship between senior capstone design and engineering identity

Recognition played a complete intermediary role between senior capstone design and engineering identity, which meant the effect of senior capstone design on engineering identity was entirely due to recognition (Fig. 1). The 95% confidence interval of the total effect of senior capstone design on engineering identity was entirely above zero (0.1440, 0.8226), indicating that the total effect was significant. The 95% confidence interval of the direct effect included zero (− 0.0853, 0.4135), which meant the direct effect was insignificant. The 95% confidence interval of the indirect effect excluded zero (0.0734, 0.5473), which showed the indirect effect was significant.

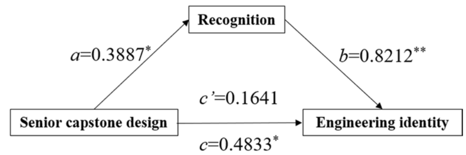

Fig. 1 Mediating effect of recognition in the relationship between senior capstone design and engineering identity. *$p < 0.01$, **$p < 0.001$; *a* is effect of senior capstone design on recognition; *b* is effect of recognition on engineering identity; *c'* is direct effect of senior capstone design on engineering identity; *c* is total effect of senior capstone design on engineering identity

Mediating effect of recognition and performance/competence in the relationship between twice or more technological innovation and entrepreneurship competitions and engineering identity

Recognition and performance/competence entirely mediated the relationship between twice or more technological innovation and entrepreneurship competitions and engineering identity (Fig. 2). The 95% confidence interval of the total effect of technological innovation and entrepreneurship competition on engineering identity excluded zero (0.0220, 0.8592), which showed the total effect was significant. The 95% confidence interval of the direct effect contained zero (− 0.4238, 0.1260), which indicated the direct effect was not significant. In terms of recognition, the 95% confidence interval of the indirect effect did not include zero (0.0627, 0.4427), which showed that the indirect effect was significant. In terms of performance/competence,

Table 7 Multiple linear regression result in recognition dimension ($N = 160$)

Variables			**Beta(β)**	**SE**	**95%CI**
Control variables	Gender (reference group: female)	Male	0.128	0.148	[− 0.053, 0.532]
	Whether close people engaged in engineering-related profession (reference group: no)	Yes	0.10	0.117	[− 0.216, 0.247]
	GPA (reference group: over 3.7)	1–2.7	− 0.013	0.146	[− 0.302,0.275]
		2.7–3.2	− 0.235*	0.507	[− 2.130, − 0.125]
		3.2–3.7	0.007	0.240	[− 0.460, 0.488]
Independent variables	**Senior Capstone Design (reference group: Not yet completed)**	**Completed**	**0.210****	**0.146**	**[0.100, 0.677]**
	Technological Innovation and Entrepreneurship Competition (reference group: no such experience)	Once	0.067	0.146	[− 0.166, 0.410]
		Twice or more	**0.218****	**0.185**	**[0.129, 0.859]**
	Engineering-related internship (reference group: no such experience)	Once	− 0.032	0.132	[− 0.309, 0.211]
		Twice or more	− 0.112	0.201	[− 0.656, 0.139]

*$p < 0.05$, **$p < 0.01$

The significance values (bold) are indicated in the last line in each of the table

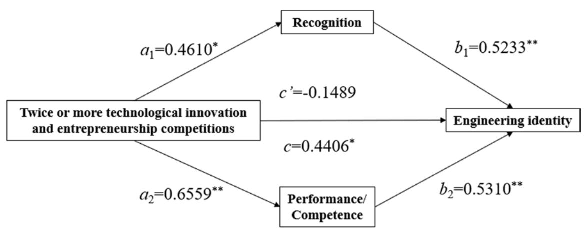

Fig. 2 Mediating effect of recognition and performance/competence in the relationship between twice or more technological innovation and entrepreneurship competitions and engineering identity. *$p < 0.05$, **$p < 0.001$; a_1 is the effect of twice or more technological innovation and entrepreneurship competitions on recognition, a_2 is effect of twice or more technological innovation and entrepreneurship competitions on performance/competence; b_1 is the effect of recognition on engineering identity, b_2 is effect of performance/competence on engineering identity; c' is the direct effect of twice or more technological innovation and entrepreneurship competitions on engineering identity; c is the total effect of twice or more technological innovation and entrepreneurship competitions on engineering identity

the 95% confidence interval of the indirect effect also excluded zero (0.1530, 0.5688), which showed that the indirect effect was significant.

Discussion

The study explored the relationships between engagement in practice-oriented learning experiences and engineering identity through responses from 160 senior engineering students from a leading Chinese university. According to our analyses, students who have completed senior capstone design was found to have a higher level of recognition and engineering identity. In addition, compared with the students who had not engaged in technological innovation and entrepreneurship competition, the students who had participated in competitions twice or more had better performance in the aspects of engineering identity, performance/competence and engineering recognition. In specific, the study has contributed to the on-going research on engineering identity in both theoretical and practical aspects.

Theoretically, existing different lines of definitions or understandings on engineering identity have offered multiple lenses to examine the concept (Morelock, 2017). The study has adopted two frameworks on engineering identity, with one on the overall engineering identity and the other on its components (Interest, Performance/Competence and Recognition). The adoption of both frameworks has allowed us to investigate the relationships among these various constructs, which has helped our understanding of the pathways or impact factors for developing engineering identity. Similar designs using multiple strands of frameworks on engineering identity might be useful to explore the various factors and/or pathways that might affect students' engineering identity development.

Practically, our findings have extended current research in the following ways.

First, this study further clarified the important role of senior capstone design on students' engineering identity development. Prior studies have pointed out the usefulness of senior design experiences in developing students' professional skills, such as team-working and communication skills, and strengthening their confidence to become future engineers (Dunlap, 2005; Johri & Olds, 2011; Lutz & Paretti, 2017; Mann et al., 2009; Marques et al., 2017). In particular, Mann et al. (2009) found that senior capstone design could enable engineering students to truly understand the value of what they learn and cultivate their abilities, which was conducive to the development of engineering identity. Meanwhile, engineering students self-reported the development of engineering identity as one of the outcomes after engagement in capstone design courses (Lutz & Paretti, 2017). In this study, we also found that students who completed their senior capstone design demonstrated a higher level of their overall engineering identity and recognition compared to those who have not yet completed the senior design. Moreover, the results found that recognition acted as a full mediator between completion of senior capstone design and engineering identity, further illustrating the important role of recognition for the development of engineering identity.

Second, the findings of this study highlighted the important role of technological innovation and entrepreneurship competitions on engineering students' development of engineering identity. Students engaged with twice or more competitions demonstrated a higher score on their overall engineering identity and components of engineering identity, that is, performance and recognition. In addition, performance/competence and recognition fully mediated the effect of twice or more technological innovation and entrepreneurship competitions on engineering identity. Such technological innovation and entrepreneurship competitive activities often emphasize solving ill-structured, complex engineering problems for real users/customers. It offers a unique platform to strengthen students' various abilities or skills, including engineering expertise, hands-on skills, communication skills, teamwork skills and many other professional skills and attributes (Bland et al., 2016; Schoepf et al., 2020). Nevertheless, we did not observe any significant result for students who engaged in only one such experience. We speculate that this finding might point to the importance of accumulating such experiences on authentic engineering project work. Prior findings have shown that discontinuous project experience was not helpful to the maintenance of students' professional skills (Kotys-Schwartz et al., 2010). Our findings suggest that multiple engagement in such learning activities can be meaningful for engineering students versus a one-time exposure. Moreover, additional research will be necessary to explore the specific process in which design competitions can contribute to students' skill development.

Last but not least, the effect of internship on engineering identity was not significant. Previous studies have found that there were individual differences in the impact of engineering-related internships on engineering identity, and not all students' engineering identity was improved after internship (Dehing, 2013). In this study, students' engineering-related internship experiences were affected by COVID-19. Some students who had internship experiences cannot practiced in enterprises in person. This may partially explain the insignificance of such experiences in our study.

Implications for practices

Our results point to the important role of recognition for nurturing engineering identity in both technological innovation and entrepreneurship competitions and senior capstone design activities. Therefore, we suggest that engineering faculty members pay more attention to various opportunities, where students could gain recognitions from the professional community in the process of these learning activities. For example, communicating with students in professional terms and seeing students as future engineers might offer such opportunities for recognitions. In addition, providing platforms with real engineering projects might offer students opportunities to communicate with customers, which can serve as an additional channel for professional recognitions. Other possible measures can include organized events for final products exhibition. Such events, when open to the local community, would provide extra sources of recognition from peers, faculty members, industrial representatives, and even family members. Moreover, additional qualitative research can be conducted to explore the specific kinds of recognition that are helpful for improving students' engineering identity in the process of evaluation and assessment.

In addition, our findings highlights the critical role of multiple engagement in authentic engineering projects throughout the engineering program for developing engineering identity. Some leading engineering schools or universities globally, such as Olin College and Delft University of Technology, have designed engineering programs with a feature of emphasizing continuous engagement in authentic engineering project experiences throughout the curriculum via both curricular and extracurricular activities (Graham, 2018). However, as Graham further pointed out, good practice like these can be "often confined to 'pockets'" within an institution, instead of being promoted institution-wide (p. 29). To facilitate the diffusion of such innovative educational practices, raising the awareness of multiple stakeholders could be essential, including that of policy makers, universities administrators, engineering faculty members and industrial representatives, to provide ample opportunities for engineering students' involvement in authentic engineering project experiences.

Limitation

It should be noted that the sample size of this study was small ($n = 160$). Due to the small size, the sample may not be sufficient enough to explore the effect from various levels of engagement in different learning activities. For example, with a larger sample, one might be able to explore the specific effect from participating in competitive activities for more than twice.

In addition, all engineering student were recruited from two engineering schools at a research-intensive Chinese university. Findings from this sampled participants can be meaningful for students from similar engineering disciplines and/or similar Chinese universities but may be not applicable to student populations in other disciplines and/or other types of Chinese universities. Therefore, the results will need to be further tested amongst students from other types of universities.

It should also be noted that we only studied the instances of learning activities instead of number of hours spent. It might be helpful to incorporate this factor and some other factors (such as students' educational, cultural and disciplinary backgrounds) for further exploration on identity formation.

Moreover, students engagement in competitive learning activities can be self-selected in nature, indicating that they might have a high level of engineering identity in the first place. There is a possibility that the students who responded to the survey might be more motivated or have a higher level of self-confidence as future engineers than those did not respond to the survey. Therefore, correlational results obtained through regression analyses in this study cannot be interpreted as causal relationships. Future study may also include a research design with pre- and post-studies to further investigate the impact from engagement in these learning activities. Together, the findings of this work will need to be treated with caution and be further tested with more diverse samples.

Conclusion

This study explored the relationships between practice-oriented learning experiences and senior engineering students' engineering identity. Our results provided evidence toward the effect of practice-oriented learning experiences on students' engineering identity development. Further research will be needed to verify the results in different contexts. In addition, it will be beneficial to explore the specific mechanisms of how such experiences can contribute to students' engineering identity development in a qualitative manner.

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Author contributions
The first author conducted the data collection and data analyses. The corresponding author was responsible for the design of the study. Both authors were engaged in the writing of the manuscript.

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Availability of data and materials
All survey data are available from the corresponding author upon request.

Declarations

Competing interests
There are no competing interests for this manuscript.

Author details
[1]School of Education, Shanghai Jiao Tong University, Chen Rui-Qiu Bldg, Room 229, 800 Dongchuan Road, Shanghai 200240, China.

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