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Measuring the Authenticity of Engineering Learning in Community of Practice: An Instrument Development and Validation

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Measuring the Authenticity of Engineering Learning in Community of Practice: an Instrument Development and Validation

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Abstract: Authentic engineering learning means that students learn in authentic environments with rich, real-world, immersive, and engaging tasks, which was regarded as an effective way to align engineering concepts and principles with ill-structured and complex workplace engineering problems. The purpose of this research paper is to describe the development and validation process of instruments to measure the authenticity of engineering learning. In the qualitative research stage, a thorough literature review about authentic engineering learning and qualitative interviews in some different engineering communities of practice were performed to collect and form a total of 26 original items, followed by discussions with professional engineers and engineering students were organized to clarify the statement of every item. In the quantitative research stage, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) based on the data we gathered from engineering universities or other institutions in China were conducted to explore the factor structure of authenticity in engineering learning. The results of factor analysis indicated that the instrument we developed had acceptable internal consistency (Cronbach’s alpha) and could extract three sub-constructs: context authenticity, task authenticity, and impact authenticity. This study provided a new measure for engineering education researchers to deeply explore the construct of effective engineering learning environments.

Key Words: authenticity; engineering learning; community of practice; instrument development

INTRODUCTION

Engineers are entrusted by the public to apply their professional knowledge and competencies to innovate, design, and implement solutions for societal needs [1]. But in recent years, many engineering students have reported they have difficulties in applying their professional engineering knowledge and skills in real-world contexts [2]–[4], and lacking preparation for solving engineering workplace problems [5], [6], which has become global issues for engineering education. Some higher engineering education institutions have made steps to overcome these challenges. For example, MIT implemented the NEET initiative, concentrating on five different learning threads and project-based learning mode, which provide students authentic contexts to address the real-world engineering challenges [7], [8]. Other engineering education institutions like Singapore University of Technology and Design, University College London, Charles Sturt University and TU Delft (see [9]), and The Pennsylvania State University’s Learning Factory [10] have also launched some new engineering learning programs. In China, similar reforms and transformations have also been

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implemented by governments in the field of Science, Technology, Engineering, and Mathematics (STEM), like New Engineering Education Plan implemented by the MOE of China [11], [12]. Almost all reform and transformation of engineering education mentioned above has shown common characteristics: shorten the distance between professional engineering knowledge and the real-world by emphasizing the important role of authentic engineering environments in engineers' training process, which can be generalized as "authentic engineering learning".

In practice, there are many authentic engineering learning examples. In our previous research, we investigated the concrete learning process of a bionic robot design club in a China university [13], which can be seen as one type of authentic engineering learning happening in communities of practice. In this club, members from different disciplines work collaboratively and iteratively to design, test, and manufacture new functions of bionic robots, and try to make the robots more competent for the RoboCup Tournament. Meanwhile, they also modify or optimize their function design to meet the authentic needs of industries. Obviously, the robot club's ultimate learning outcome is concrete and workable artifacts, and students simulate the roles of the engineering professionals to master engineering knowledge and develop professional abilities during these design and manufacturing processes, which indicates this kind of engineering learning process is different from the normal learning in the classroom. Another typical example of authentic engineering learning is the industry-partnered projects in learning factories. In these projects, partners from industries would put up some specific pre-defined problems or ill-structured problems as learning triggers, and students are expected to provide newly defined problems and relevant solutions. During the learning process in learning factories, students focus on a comprehensive understanding of problem situations and concepts and design specific products to meet real market demands [14].

Moreover, authentic learning can enhance students' personal competencies. Under authentic learning, students have the chance to participate in real-world simulated work, acquire complex information, engage in deep inquiry and ongoing reflection about the "real problems" during the collaborative learning process, which facilitates the higher-order thinking, such as critical thinking, reasoning skills, and engineering creativity. Further, authentic engineering learning provides dynamic and interactive engineering scenarios that involve interdisciplinary knowledge and multidisciplinary collaboration, helping students to become familiar with, understand, and solve real, unstructured, complex engineering problems. Students could gain experience in applying professional engineering knowledge and skills in the real world, able to solve problems in engineering sites, which will significantly and continuously enhance their employability.

THEORETICAL FRAMWORK

This research is based on two inter-connected theories from learning sciences [15]: situated engineering learning theory and authentic learning framework.

Situated Engineering Learning Theory

Based on behaviorism, cognitivism, constructivism, etc. [15], [16], some researchers put forward the situated learning theory in 1990s, pointing out that context and activity in which knowledge is developed and deployed are not separable from learning and cognition, meanwhile learning and cognition are fundamentally situated [17]. The key points of situated learning include [13]:

- *Knowledge is situated, which is embedded in specific contexts, showing distributive characteristics;*
- *Learning is a process of practice, and practice is a necessary stage for effective learning to occur;*
- *Learning not only involves the acquisition of knowledge, but also a process in which learners establish their own professional identity.*

Based on the situated learning theory, Johri et al. [18] further proposed a situated engineering learning framework to reveal the mechanism of engineering learning. In Johri and Olds' work, the framework contains three dimensions: the first is social & material context, which means that engineering is highly dependent on representations and physical materials; the second is activities & interactions, which emphasizes engineering usually benefits from project-based and collaboratively team-organized work; and the last dimension named participation & identity, which indicates that engineers often have a strong sense of engineering identity in communities of practice [18]. Community of practice is an important part in situated learning theory, which refers to the informal learning organizations or learning contexts composed of learners with similar professional experience and shared enthusiasms, like students leagues, engineering clubs, professional laboratories, competition teams, etc. [19]. The current research is a part of a larger project concentrating on the effect of communities of practice in engineering learning and the cultivation of engineering students' practical ability. As a result, the following investigations of authentic engineering learning rooted in the context of communities of practice. In other words, the instrument of authentic engineering learning we developed in this research work is applicable to engineering learning happening in communities of practice.

Authentic Learning Framework

One of the foundational ideas of the learning sciences is that students can obtain a deeper knowledge if they engage in similar activities as professional experts, which indicates active participation in authentic practice can improve learning outcomes. The authentic practice has gradually become one of the key points of international frontier engineering learning research [20], [21]. For example, the National Science Education Standards and the Next Generation Science Standards require students to engage in the authentic practice of scientific inquiry to construct explanations and prepare arguments to justify those explanations [22], [23]. The National Academy of Engineering (NAE) also mentioned in the engineering education for 2020 that engineering students (need) to better integrate engineering courses and academic experience with the challenges and opportunities that graduates face in the workplace [24], [25]. NAE noted in its report on K-12 engineering education research that engineering research is closely related to asking real questions and participating in real engineering practice, too [26].

Authentic learning means learning activities that are centered on rich, real-world, immersive, and engaging tasks and learning environments where students are motivated to learn in rich, relevant, and real-world contexts [27]. Many ways can lead to authentic learning, like using role-playing exercises, problem-based activities, case studies, and participation in communities of practice. The learning environments are inherently multidisciplinary [28]. Nine critical characteristics of authentic learning have been identified by Herrington and Oliver [29] based on situated learning theory, such as Authentic Context, Authentic Activities, Expert Performances, and the Modelling of Processes, etc.. As a summary of the conceptual research, Strobel et al. [30] analyzed 1058 engineering education literature related to authenticity through a systematic literature review and proposed a four dimensions concept framework based on Brab et al.'s research work [31], which includes context authenticity, task authenticity, impact authenticity, as well as personal and value authenticity.

Authentic learning has a long history in engineering fields like apprenticeship [28], in which the learners could finish some real-world tasks and solve ill-defined problems. The features of work-place engineering problems, such as ill-structured, complex, conflicting goals, multiple solution methods, beyond engineering success standards or constraints, need a more effective learning process like authentic learning [5]. Real engineering problems are open-ended problems from real industrial activities, which can provide sufficient motivational support and learning contexts for students' learning in specific topics, and provide students with similar experiences to those they face in the industry and challenges [32], [33]. Previous studies have investigated different kinds of authentic engineering learning such as real engineering problem solving (AEP) [33], the creation of real practical situations (Bulte et al., 2006), completing real engineering projects, etc. [34]. For empirical research, existing studies have used methods such as regression analysis and random forest to verify the relationships between authentic engineering learning and student engagement [35], professional identity or learning interest [36] , student-perceived learning outcomes [37], reasonable assumptions and problem-solving abilities [32], engineering learning self-efficacy [38] and so on.

RESEARCH PURPOSE

The current study was situated in the engineering learning in communities of practice. Communities of practice were seen as an effectively collaborative learning situations with a group of learners sharing professional knowledge and common career enthusiasm. In our previous study, we found community of practice is an important engineering learning context and engineering learning happening in communities of practice usually focused on solving the authentic engineering problems such as design or make engineering artefacts in authentic environments, namely engineering learning happening in communities of practice was driven by authentic tasks [13]. Despite a growing number of quantitative studies that have identified the key characteristics of authentic learning [37], [39], there is limited research to investigate what's the operational definition of every specific dimension of authentic engineering learning in the context of community of practice. Besides, how to measure engineering learning authenticity accurately in community of practice is still a research gap.

Briefly, the purposes of this paper are twofold: Firstly, this paper will make clear the operational definitions for authentic engineering and put forward some appropriate items to form an instrument; Secondly, this research will study the validity and internal consistency of the instrument we have developed. The development of the instrument followed recommendations for instrument development by Netemeyer et al.[40], focused on construct design and initial evidence of validity [41].

RESEARCH PROCEDURES

This study adopted a mixed-method research design, which was carried out in two sequent stages: qualitative research stage and quantitative research stage (Figure1). In the qualitative research stage, we made clear operational definitions generated original survey items for each dimension of authentic learning based on Brab et al.'s [31] and Strobel et al.'s [42] framework and revised the items with the help of interviewing data from five different kinds of engineering communities of practice. In the quantitative research stage, in order to provide validity evidence for initial scale, exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and criterion-related validity (CRV) test were carried out respectively, and the internal consistency test was carried out too on the reliability of the instrument.

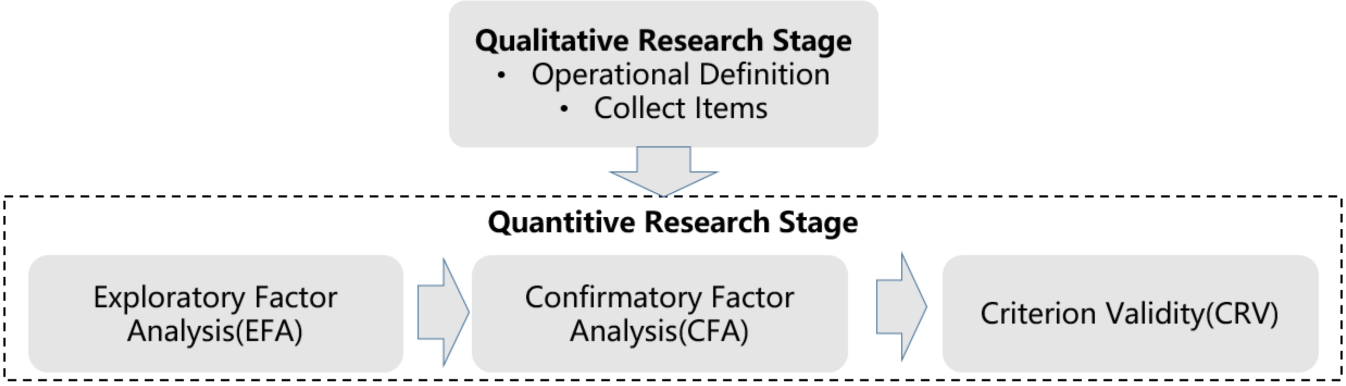

Figure1. Two-stage Research Procedures

FINDINGS

Qualitative Research Findings

In the qualitative stage, we referred to the key definitions and characteristics for each type of authenticity in engineering learning proposed by Strobel et al.[30] and generated the original survey items. For example, the key definitions for context authenticity are "*be similar to the real-world work environment or future professional situations*" or "*be a situation similar to 'in-the-wild*'" and the key characteristics of context authenticity are "*be open in forming and solving the problems and outcomes*" or "*be a complex problem-solving context and interdisciplinary context*". We modified this statements into original survey items like "*The engineering learning projects or activities I participated in can simulate a real engineering work environments*" or "*The engineering learning projects or activities I participated in are similar to professional engineering situations*". Then, to test the content validity of the original items, we conducted semi-structured interviews with engineering professionals, teachers, and students from five different kinds of engineering communities of practice (see also Wang et al.,[13]) . The questions used in semi-structured interviews were like "*what do you think of the context/activity/impact authenticity in engineering learning*?" and "*what makes a context/activity/impact authentic in terms of your own engineering learning experience*?". Based on the data collected in the interviews, we preliminarily clarified the operational definitions for each authentic engineering learning dimension (Table1.). Besides, we found the context authenticity, task authenticity, and impact authenticity were clear and easy to understand for engineering professionals, teachers and students, but the personal/value authenticity are unclear in our pilot interviews. As a result, we neglected this vague dimension in the following research stage.

Table1. Triple Dimensions of Authenticity in Engineering Learning

Dimension	Operational Definitions
Context Authenticity	The engineering learning context is highly similar to the real-world working

(CA)	environments or professional work situations
Task Authenticity (TA)	The engineering learning activities (including activity processes and procedures) are similar to real-world activities aimed at solving ill-structured engineering problems.
Impact Authenticity (IA)	The outcomes or products of engineering learning can be applied in outside school contexts.

With help of the key definitions and characteristics for each type of authenticity and the data we gathered from semi-structured interviews, we finished the 28 initial Likert-7 items. Afterward, to check the clarity and readability of each items, we performed two rounds of revisions: firstly, we invited 5 engineering teachers and engineering graduate students to read and give feedback about the items, focusing mainly on the fit between each item and the operational definitions; secondly, we invited 9 doctoral students in engineering fields and engineering education fields to finish the survey and put up their modification suggestions. At last, we deleted 2 items, modified 22 items and reached an initial measuring scale consisting of 26 items was formed in the last.

Exploratory Factor Analysis(EFA)

The purpose of the EFA study is to explore how well the items we collected relative to each dimension of authenticity in engineering learning. All 123 questionnaires containing all 28 items were distributed to engineering students with at least one completed experience of engineering artefact design in communities of practice. The questionnaires were distributed through a school BBS platform at XX University, a famous engineering education institution in China. Responses were removed based on the criteria of those who did not complete 100% of the survey, and 5 invalid questionnaires were removed, while 118 valid questionnaires were retained in our analysis. The sample information was presented in Table 2. Among the valid respondents, the proportion of male participants is slightly higher than female participants (53.4% Vs. 46.6%), which was similar to the gender ratio in this university (59% Vs. 41% for males and females separately). And the participants mainly were under master's degree (53.4%). In terms of the disciplines of participants, more than half of the participants (50.8%) were from Civil Engineering (16.9%), Chemical and Material Engineering (14.4%), Computer Science and Engineering (10.2%) as well as Electronics Engineering (9.3%).

Table2. Demographic Distribution of Participants in EFA Study

Group	**Subgroup**	**Total n (%)**	**Group**	**Subgroup**	**Total n (%)**
Gender	Male	63（53.4%）	Discipline	Optical Engineering	8（6.8%）
	Female	55（46.6%）		Civil Engineering	20（16.9%）
Degree	Bachelor	31（26.3%）		Hydraulic Engineering	2（1.7%）
	Master	61（53.4%）		Dynamics Engineering	5（4.2%）
	Doctorial	24（20.3%）		Electronics Engineering	11（9.3%）
Discipline	Chemical and Material Engineering	17（14.4%）		Electrical Engineering	6（5.1%）

	Environmental Science and Engineering	7（5.9%）		Control Science and Engineering	5（4.2%）
	Mechanical	7（5.9%）		Computer Science and Engineering	12（10.2%）
	Biomedical Engineering	8（6.8%）		Others	10（8.5%）

The mean value of all 26 items was calculated as 4.496 and only two of the 26 items had elevated means (5.093 and 5.136 on a 7-point scale), the skewness ranged from -1.094 to 0.072, and kurtosis ranged from -0.779 to 1.593, indicating the data were not normally distributed but met the criteria of 3.0 and 10.0 established by Kline for EFA [43]. The Kaiser-Meyer-Olkin (KMO) value of total items was 0.884, and the Bartlett sphericity test was significant (1788.967), indicating that the items of the scale were appropriate for the EFA study. EFA was conducted with principal component analysis and retained 16 factors whose loadings >0.6 and extracted the top 3 factors (cumulative factor loadings is 55%). The overall Cronbach's α for the remaining 16 items was 0.910, which is greater than the reference value of 0.8 recommended by Clark & Watson[44], [45] for developing a new scale. The correlations among items in each dimension were all above 0.3 and the standardized correlations among three factors were from 0.328 to 0.525, meeting the criteria proposed by [46].

Table3. Summary of Factor Loadings in EFA and Cronbach's alpha (α)

Factor	**Survey Item**	**Factor Loading**		
Context Authenticity（α=.878）	**CA 1**: The engineering learning projects or activities I participated in can simulate a real engineering work environments.	**.735**	.267	.034
	CA 2: The engineering learning projects or activities I participated in are similar to professional engineering situations.	**.629**	.035	.347
	CA 3: The engineering learning projects or activities I participated in hava complete task-based working environments.	**.712**	.262	.030
	CA 4: The engineering learning projects or activities I participated in allow me to finish hands-on tasks.	**.671**	.214	-.098
	CA 5: The engineering learning projects or activities I participated in provide complex engineering scenarios.	**.714**	.281	.126
	CA 6: The engineering learning projects or activities I participated in provide working environments that can replace the real world to some extent.	**.766**	.182	.107
	CA 7: The engineering learning projects or activities I participated in are collaborative work environments.	**.602**	.303	.234
	TA 2: I need to solve ill-structured problems in	-.016	.279	**.776**

Task Authenticity （α=.815）	engineering learning projects I participated in.			
	TA 3: I need to solve interdisciplinary problems in engineering learning projects I participated in.	.233	.163	**.714**
	TA 4: I need to provide open-ended solutions to problems in engineering learning projects I participated in.	.144	.147	**.779**
Impact Authenticity （α=.895）	**IA 1**: In the engineering learning projects I participated in, the ultimate goal is to design/manufacture complete products.	.203	**.581**	.041
	IA 2: In the engineering learning projects I participated in, I have solved some long-standing engineering problems	.140	**.750**	.373
	IA 3: In the engineering learning projects I participated in, the products I designed can be applied to real-world situation.	.347	**.747**	.104
	IA 4: In the engineering learning projects I participated in, the products I designed can have a certain impact on the development of technology/industry, etc.	.215	**.821**	.190
	IA 6: In the engineering learning projects I participated in, the engineering products I designed can be used for markets clients after polishing.	.236	**.778**	.210
	IA 7: In the engineering learning projects I participated in, I can provide feasible solutions for real customers.	.163	**.759**	.172

Table4. Standardized Factor Correlations

Standardized Correlations	**Context Authenticity (CA)**	**Task Authenticity (TA)**	**Impact Authenticity (IA)**
Context Authenticity (CA)	1		
Task Authenticity (TA)	0.328	1	
Impact Authenticity (IA)	0.525	0.481	1

Confirmatory Factor Analysis(CFA)

The purpose of the CFA study is to validate the theoretical factor structure of authenticity in engineering learning. Questionnaires containing 16 items based on EFA results were distributed to engineering students with at least one experience of completing engineering products in communities of practice from more than 50 engineering institutions in China through a web platform. Students completed the questionnaires online by clicking a link in an email and agreeing to participate in the study. Overall, 264 questionnaires were collected, among which 8 invalid questionnaires were eliminated because of the incomplete answer, and 256 valid questionnaires were retained. Among valid respondents, the proportion of male participants is higher than female participants (59.4% VS. 40.6%), and more than half of the participants were under bachelor's degree (132 or 51.6%). Furthermore, most participants (98.4%) were from 985 or 211 engineering institutions, which were top universities in China.

Table5. Demographic Distribution of Participants in CFA Study

Group	**Subgroup**	**Total n (%)**
Gender	Male	152（59.4%）
	Female	104（40.6%）
Degree	Bachelor	132（51.6%）
	Master	99（38.7%）
	Doctorial	25（9.8%）
Institution	985 institutions	161（62.9%）
	211 institutions	91（35.5%）
	General undergraduate colleges	3（1.2%）
	Others	1（0.4%）

The mean value of the 16 items was 5.04, and fifteen of the 26 items had elevated means (5 on a 7-point scale). The skewness ranged from -1.300 to -0.426, and kurtosis ranged from -0.155 to 2.058, indicating the data were not normally distributed but met the criteria of 3.0 and 10.0. The results of the CFA analysis are shown in Table7: all standardized factor loadings for 16 items exceeded 0.6, indicating that the three factors can explain more than 60% variance of the data; the item reliability (SMC) is greater than 0.36, indicating that the reliability of each factor is good; the composition reliability (CR) is greater than 0.7, indicating that the internal consistency of each facet is good; the convergent validity (AVE) is greater than 0.5, indicating that each facet item has good convergent validity (Table7).

Table6. Summary of CFA Results

		Estimation				Standardized Factor Loadings	Item Reliability	Composition Reliability	Convergent Validity
		Unstd.	S.E.	t	P				
CA	CA 1	1				.765	.585	.882	.518
	CA 2	.813	.077	10.573	***	.669	.448		
	CA 3	1.070	.085	12.651	***	.788	.621		
	CA 4	.836	.077	10.840	***	.685	.469		
	CA 5	.941	.079	11.858	***	.743	.552		
	CA 6	.800	.080	9.952	***	.633	.401		
	CA 7	.913	.077	11.810	***	.740	.548		
TA	TA2	1				.689	.475	.742	.500
	TA3	1.118	.147	7.595	***	.766	.587		
	TA4	.861	.112	7.665	***	.641	.411		
IA	IA1	1				.780	.608	.910	.628
	IA 2	1.035	.073	14.149	***	.826	.682		
	IA 3	.989	.071	13.887	***	.813	.661		

	IA 4	1.002	.070	14.327	***	.834	.696		
	IA 6	.871	.071	12.351	***	.738	.545		
	IA 7	.933	.073	12.753	***	.758	.575		

Since we found that the correlated coefficients among the triple dimensions were high (>0.8), implying that a higher-order variable may exist. Competitive models (first-order one-factor model, first-order three-factor model with no correlation among the factors, first-order three-factor model with correlations among factors, and three-factor model with a second-order *Authenticity*) were generated to make decisions about which model was congruent with the theoretical framework. The results showed that the goodness-of-fit indexes of the three-factor model with a higher-order *Authenticity* and the first-order model with correlations were similar, and most of them can meet the recommended values, and the former was more concise (Figure2.).

Table7. Comparison of CFA Fit Indices

	X^2	df	X^2/df	SRMR	CFI	AGFI	TLI	RMSEA
first-order one-factor model	216.912	104	2.086	.041	.953	.859	.945	.065
first-order three-factor model (no correlation)	662.364	104	6.369	.039	.766	.714	.730	.145
first-order three-factor model (correlated)	150.109	101	1.486	.033	.979	.906	.976	.044
second-order three-factor model	150.109	101	1.486	.033	.930	.906	.976	.044
Suggested Value	-	-	<3	<.08	>.8	>.8	>.8	<.08

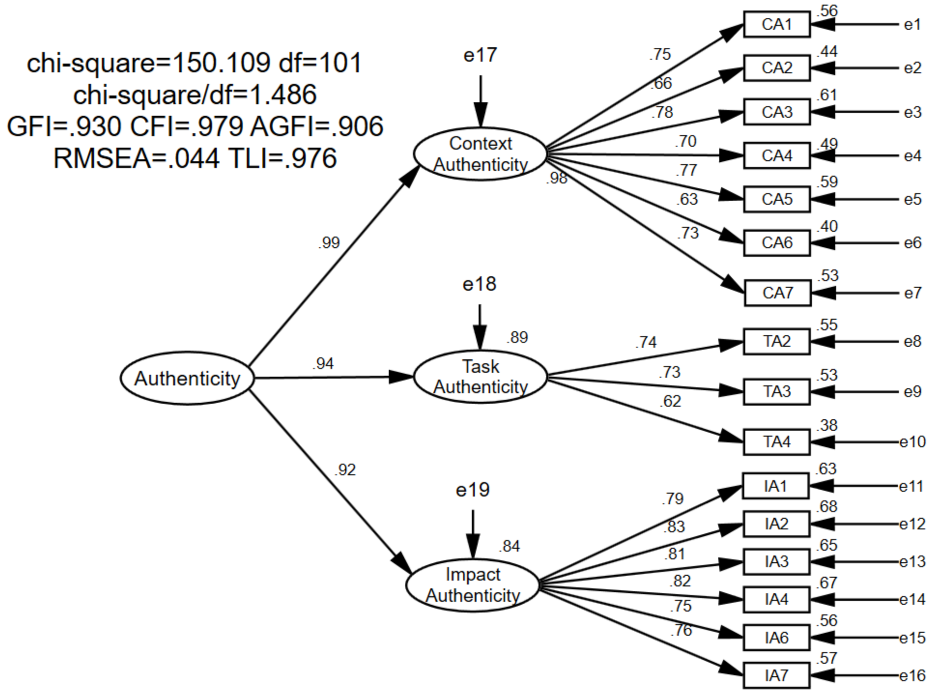

Figure2. Second-order Confirmatory Factor Analysis Model with Standardized Loadings

Criterion Validity(CRV)

Cronbach and Meehl indicated that the investigator was primarily interested in some criterion that he wished to predict in criterion validity [47]. As past research has emphasized that authentic learning such as learning in robotic teams can promote individuals' active self-knowledge construction, higher-ordering thinking, and diversity in solving problems [30], [48], [49], so we used engineering creativity [50] [51], engineering students' complex problem-solving ability [52], and engineering students' critical thinking [53] as outcome variables in this study. The results of regression analysis suggested that the authenticity in engineering learning has a significant impact on engineering students' creativity (B = 0.906, $p<0.000$), ability to solve complex engineering problems (B = 0.838, $p<0.000$) as well as critical thinking (B = 0.951, $p<0. 000$), further confirming that the measurement we developed in the current study has an ideal criterion validity.

Table8. Results of Regression Analyses for Criterion Validity

	Engineering Creativity	Complex Engineering Problem-solving Ability	Critical Thinking
B	0.906***	0.838***	0.951***
S.E.	0.078	0.071	0.076
C.R.	11.692	11.882	12.461

DISSCUSION

The purpose of this study was to develop an instrument to measure the authenticity of engineering learning. Referring to situated learning theory and authentic learning framework, the instrument we explored and developed was based on Brab et al.'s and Strobel et al.'s conceptual model about authentic learning: context authenticity, task authenticity, and impact authenticity. Validity evidence was gathered throughout the two successive research stages. In the first qualitative research stage, we make clear the operational definitions of each construct and generated original survey items based on existing literature and data from our interviews. To improve the content validity of the items, we invited teachers and students from engineering majors to revise the items, guaranteeing the fit between each survey item and the operational definition of each construct. At last, 26 Likert-7 items emerged as our basis for EFA and CFA study.

The quantitative research stage contains three phases: EFA, CFA, and criterion validity certification (CRV). In the EFA phase, we gathered 118 valid responses from engineering students in a single university. Based on the results of exploratory factor analysis, we retained 16 factors (7, 3, and 6 items for context authenticity, task authenticity, and impact authenticity respectively) with the criterion that factor loading >0.6, eliminating 10 items due to poor performance in EFA. In the next phase, 16 items were utilized in a CFA study with 256 valid participants to confirm whether the factor structure consistent with the theoretical model. All results of CFA analysis containing standardized factor loadings, item reliability, composition reliability, and convergent validity had a great performance, meaning that the three-factor structure of authentic engineering learning was stable and acceptable. Considering the high correlation coefficients among different factors, we compared goodness-of-fit for different models and found that a higher order factor, *Authenticity*, along with three first-order factors be aligned to the theoretical authentic learning structure. In the last phase, we made regression analyses with authenticity in engineering learning as the independent variable, and the outcome variables were engineering creativity, complex engineering problem-solving ability, and critical thinking. The results of regression analyses indicated that the instrument we developed had an accepted criterion validity.

Our findings demonstrated that the structure of authenticity in engineering learning contains three sub-constructs: context authenticity, task authenticity, and impact context, and we can use 16 items to measure it. Although the development of instruments in this paper is a pilot study, it has some important implications for future research. First, the instrument can be used to evaluate the authenticity level for engineering learning in communities of practice. Besides, many new engineering initiatives such as PBL and Experiential learning have focused on the creation of authentic learning contexts. So future research can use the instrument to make a further understanding of the authenticity in different kinds of engineering learning situations. Additionally, previous research have demonstrated the importance of authentic learning in some design-based learning environments like engineering education [30], but little research aims to investigate the causal mechanism behind the surface phenomena. The instrument to measure authenticity in engineering learning can help researchers bridge these gaps as it can help transfer the practical conducts into theoretical construct or measurement variables in some empirical research.

LIMITATIONS

As a pilot research, there were still some limitations in our work. Firstly, we didn't consider the individual/value authenticity dimension proposed by Strobel et al. [30] because we found it was a vague construct in our pilot interviews with engineering teachers and students. However, individual/value authenticity was still a very important profile for the structure development as Herrington said "It is the cognitive authenticity rather than the physical authenticity that is of prime importance in the design of authentic learning environments [27]". In the following research, there is a need to collect proper items and add this dimension to the construct structure.

Secondly, we referred to Holloway et al. work [6], [41], [54], [55] in terms of the process and method of developing a valid and credible scale. But we didn't perform group analysis among different groups (such as different engineering disciplines, different degrees, etc.) since the limited sample in EFA and CFA. The perceptions of context authenticity, task authenticity, and impact context of engineering students in different gender or discipline may have significant differences. The differences among different groups have many practical implications for engineering educators and engineering education policy-makers. For example, we noticed students in Control Science and Engineering tended to have higher scores for context authenticity, task authenticity, and impact context than students in other majors because they can design and manufacture authentic products in learning factories.

Lastly, the current research has not been able to explain the mechanism of the relationship between authentic engineering learning and outcome variables, such as engineering creativity, complex engineering problem-solving ability, and critical thinking in this research. Therefore, some deeper research needs to be conducted to answer the question "why authentic engineering learning can benefit engineering students in improving their abilities like engineering creativity, complex engineering problem-solving ability, and critical thinking?"

CONCLUSIONS

The recent reforms and transformations in worldwide engineering education such as NEET at MIT, ITP at UCL, PBL at Alborg University as well as New Engineering Education Plan implemented by China's MOE have a common characteristic: authenticity plays an important role in engineering learning. However, although many qualitative engineering education studies have recognized the importance of authenticity, there is a lack of valid and acknowledged ways to measure it precisely. To bridge this research gap, this study comprehensively used a mixed research method consisting of both qualitative research and quantitative research stages, to develop a valid and reliable way to measure authenticity in engineering learning rooted in communities of practice. We performed a qualitative study to make clear the operational definitions of authenticity and its every dimension in the context of engineering learning. Then EFA and CFA were conducted successively based on data we gathered from experienced engineering students in XX University and other engineering institutions in China. Results of EFA and CFA supported the structure of authenticity, namely authenticity in engineering learning contains three sub-constructs: context authenticity, task authenticity, and impact authenticity. Regression analyses were performed to verify the criterion validity, and the results demonstrated the authenticity in engineering learning measured by our instrument can predict engineering students' creativity, complex problem-solving ability as well as critical thinking well. The results of this study indicate in the design of engineering learning environments, we need to pay full attention to three dimensions of authenticity: contexts, tasks, and impacts.

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