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The Characteristics of Engineering Learning in Communities of Practice: An Exploratory Multi-case Study

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Abstract: The Emerging Engineering Education (3E) transformation has been implemented in China to meet the society's needs of high-quality talents in science, technology, engineering and mathematics (STEM) fields. The transformation has stimulated some new forms of engineering learning which were organized in communities of practice such as engineering studio, engineering laboratory in some universities. However, little is known about the characteristics of engineering learning in communities of practice. In the paper, we would like to bridge this gap and make some deep explorations about these new forms of engineering learning under the guideline of situated engineering learning framework. Following the principles of the purposeful and theoretical sampling method, We selected four different types of engineering communities of practice at Zhejiang University. We made some iterative semi-structured interviews with students in these communities and used an inductive as well as constant comparative approach to analyze the qualitative materials we gathered from interviews. At last, we identified four salient themes about the characteristics of engineering learning in communities of practice from our analysis: (a) authentic-task driven, (b) collaborative inquiry, (c) reflective-design process, (d) engineering identity. Future we will build on this study and develop some valid instruments to measure these characteristics in order to clarify the relationship between community of practice and engineering students' learning effect.

Keywords: community of practice; engineering learning; authentic-task driven; collaborative inquiry; reflective-design process; engineering identity

INTRODUCTION

As the largest developing economy in the world, China is facing a lot of challenges in terms of emerging industries and new technologies. As a result, China is calling for increasing the quantity and quality of engineering students to meet society's needs. To achieve a better sustainable economic and social development, China's government has implemented some major strategies in the field of Science, Technology, Engineering and Mathematics (STEM). Still, the critical factors in great need are engineering and technology talents. So the reform of China's engineering education is the key to solutions for these challenges, as a result, China's higher education management departments point out a new engineering education reforming direction: Emerging Engineering Education transformation (3E transformation)[1]. Emerging Engineering Education emphasizes students' practicability, crossover, and comprehensive understanding of subjects more[2]. Now as a most essential transformative experiment in engineering talent cultivation, the Emerging Engineering Education has attracted much research attention and MOE has set up some specific supportive research funds and projects to accelerate the cultivation of application-oriented, interdisciplinary and skilled engineering talents.

Stimulated by the Emerging Engineering Education policy, leading engineering universities in China have explored new ways of engineering education. New forms of engineering learning have emerged such as engineering studios, engineering laboratories, research experience or engineering competitions for engineering undergraduates, etc., which have a common feature: organized by a group of students with similar interests. These new practical experiments in the engineering learning field are very important for meeting the needs of skilled engineering talents, but there is still a lack of a suitable theoretical framework to examine and explain such new engineering learning phenomena properly. Policymakers and engineering education managers would like to extend these new types of engineering learning but without enough empirical evidence to prove their advantages over conventional engineering learning in classrooms. For this question, we designed and implemented a comprehensive research plan to enhance our understanding of the relationships as well as identified the mechanisms between these new forms of engineering learning in communities of practice and the engineering student's competence development, and also to develop a theory that will allow future research examine these phenomena more precisely. This manuscript is part of a more comprehensive and larger project which aims to clarify the characteristics of engineering learning in communities of practice within the situation of Emerging Engineering Education transformation in China.

RESEARCH QUESTION

The purpose of this study is to enhance our understanding of engineering learning in communities of practice and build a robust foundation for the comprehensive research plan mentioned above. To frame and guide our research, this paper focuses on the following research questions: what are the characteristics of engineering learning in communities of practice? What's the specific meaning of each characteristic we identified from qualitative analysis. Existing literature on the themes of situative engineering learning such as PBL or PjBL has proposed some insightful concepts or modes which have some implications for this work. For example, practical engineering activities and interpersonal interactions are seen as the important factors affecting engineering students' innovation, design, and leadership[3]. However, we would like to deepen and broaden our horizons for these findings within the context of community of practice and in the background of China's Emerging Engineering Education.

THEORETICAL PERSPECTIVES

Situated Engineering Learning

There is being a transformation in learning science research from behaviourism or cognitivism to situative learning theory. During the past few decades, researchers and scientists in learning science have put up a series of learning theories and instructional principles based on behaviourism and cognitivism, which have deeply enhanced the understanding of students' complex learning practices and the design of teaching and learning environments[4]. However, with the in-depth development of learning research, more and more learning researchers and educational practitioners have been concerned that behaviourism and cognitivism theories couldn't explain some complex learning phenomena happening in the real world thoroughly. Meanwhile, researchers have found that the learning theories such as behaviourism and cognitivism could cause serious learning problems like inert knowledge in school education[5][6]. Since the 1990s, learning researchers tried to bridge these gaps by putting forward a new learning metaphor named situative learning theory and developing a better understanding of how people learn through this new research lens[7]. Situative learning theory turned the focus of learning from individual information processing to dynamic interaction between individual characteristics and external factors such as society, history and culture, etc. In a comprehensive conclusion, Johri and Olds summarized the different characteristics and critical viewpoints of behaviourist, cognitivism and situative learning theories[8].

Table1. Different Learning Theories Characterized by Johri and Olds[8]

Learning Theories	Contents
Behavioristic Learning	• Knowing could be characterized only in terms of observable connections between stimuli and responses. • Learning was the formation, strengthening, or weakening of those connections through reinforcement.
Cognitive Learning	• Knowledge was seen as a structure consisting of different concepts. • Learning was the acquisition of abilities such as reasoning, planning, solving problems, and comprehending language. • Learning is affected by intrinsic motivation.
Situative Learning	• Knowledge is distributed among people and their environments, including objects, artifacts, tools, books, and the communities of which they are a part" . • Learning is seen as meaningful participation in a community of practice with an understanding of "the constraints and affordances of social practices and of the material and technological systems of environments" . • Emphasis on the role of the environment on an individual's conception of knowing and how they learn; knowledge is not something an individual possesses or stores in the brain but is present in all that they do.

Situative learning theory is more dynamic than behavioristic or cognitive learning theories. The key viewpoints of situative learning theory are: (a). Knowledge is situative, which can be distributed among the interactions and embedded in the physical environments or contexts, so the social and material contexts are vital for learners' knowledge absorption; (b). Learning implies meaningful understanding through practical activity, and practical work with tools or materials as well as interactions among different learners are essential for understanding complex problems, and (c). Learners can construct their professional identity from a novice to an expert along with their participation in practical activities, which means learning is a process of legitimate peripheral participation in communities of practice[9]. Johri and Olds have extracted the most common opinions about situative learning (also named situative cognition) theory and divided them into three dimensions such as social&material context, activities&interactions and participation&identity[8].

Engineering education fits the definition of situated learning well. Engineering education research is an interdisciplinary research field[10] while engineering learning is an overlapped research category with engineering education and learning science. The mainly question the engineering learning researchers are interested in is “how do people learn engineering ?” Moreover, engineering learning emphasizes the importance of designing and manufacturing practice[11], representations process[12], material tools and social interactions[8], etc. As a result, the situative learning theory can serve a better understanding of how people learn engineering, especially in some authentic practical environments.

Community of Practice

Community of practice(CoPs) is one of the important constructs of situative learning theory, which has a history of more than 30 years since it was first put forward in Lave and Wenger’s book *Situated Learning: Legitimate Peripheral Participation* [9]. In situative learning theory, community of practice refers to some informal learning organizations or learning contexts composed of learners with similar professional experience and shared enthusiasms who are willing to make efforts for common goals[9]. In communities of practice, learning was viewed as a process of meaning negotiation and identity recognition among different professional individuals, which was named *Legitimate Peripheral Participate(LPP)*.

In 1999, Wenger further proposed that community of practice refers to a group of learners who have common enthusiasm for something and learn how to complete their shared professional goals better through interpersonal interactions or cooperation. Community of practice in Wenger’s book *Communities of practice: Learning, meaning, and identity* includes three critical composed elements: mutual engagement, joint enterprise and shared repertoire, which could promote the cooperation and negotiation among different learners in communities of practice[13].

In 2002, Wenger pointed again that the community of practice means a group of learners who have common enthusiasms on some professional topics and can deepen their domain knowledge and expertise through continuous interactions as well as practical activities[14], and the author further clarified the main elements of communities of practice: (a). Domain, which means the professional fields and the boundary of meaning negotiation in certain communities of practice[15]; (b).Community, a social structure within which interpersonal interactions and cooperation among different learners can happen; and (c). Practice, a process of sharing, developing and maintaining specific professional knowledge with different learners in a community of practice[14].

In conclusion, the community of practice is a construct of situative learning theory which means a group of learners with shared professional knowledge and collective learning enthusiasm. The members of communities of practice can share their knowledge with each other freely and create novel knowledge or artefacts during the process of participating in practical activities, which means that community of practice can help learners further understand professional knowledge, develop practical ability and build their professional identity[16].

Table3. Linkage between Community of Practice and Situated Engineering Learning

	Key Characteristics of a Community of Practice	Dimensions of Engineering Learning
1	Sustained mutual relationships — harmonious or conflictual	Activities & Interactions

2	Shared ways of engaging in doing things together	Activities & Interactions
3	The rapid flow of information and propagation of innovation	Activities & Interactions
4	Absence of introductory preambles, as if conversations and interactions were merely the continuation of an ongoing process	Activities & Interactions
5	Very quick setup of a problem to be discussed	Activities & Interactions
6	Substantial overlap in participants' descriptions of who belongs	Participation & Identity
7	Knowing what others know, what they can do, and how they can contribute to an enterprise	Social & Material Context
8	Mutually defining identities	Participation & Identity
9	The ability to assess the appropriateness of actions and products	Activities & Interactions
10	Specific tools, representations, and other artefacts	Social & Material Context
11	Local lore, shared stories, inside jokes, knowing laughter	Social & Material Context
12	Jargon and shortcuts to communication as well as the ease of producing new ones	Activities & Interactions
13	Certain styles recognised as displaying membership	Participation & Identity
14	A shared discourse reflecting a certain perspective on the world	Social & Material Context

Source: compiled from Amin, et al., 2006[17].

METHODS

The purpose of this research work is to investigate the main characteristics of engineering learning in communities of practice within the situation of Emerging Engineering Education transformation in China using a multi-case study adopted by Eisenhardt and Graebner[18]. Participants' opinions or responses in different communities of practice were collected through semi-structured interviews implemented by two authors of this study together. And all materials collected from the semi-structured interviews were coded to establish an iteratively modified codebook. For the confused but important responses found in the coding process, we implemented some added focused interviews with the learners in communities of practice and made more detailed notes about the engineering learning process happening in different types of communities of practice.

Semi-structured Interview

The open questions of semi-structured interviews were designed mainly based on the three dimensions of situated learning theory (Social & Material Context, Activities & Interactions, Participation & Identity). And the following principles were also abided during the questions design process: Firstly, all questions must be open but aimed to capture the characteristics of engineer students' learning process in the context of communities of practice, so the questions were concentrated on interviewees learning activities (including the know-how of engineering disciplines and the practical experiences such as engineering artefacts design process), their social & material learning context, as well as their interactions with peers; Secondly, the questions were modified iteratively during the interview process, so the development of the questions was a dynamic process in order to capture the most important features of engineering learning activities; Finally, every semi-structured interview was performed by two of the researchers together and the first interviewer put up questions to interviewees while the other interviewer would take detailed notes about the answers they got from the interviewees. After every interview, two interviewers would discuss the responses and notes they obtained as soon as possible in order to avoid ignoring or misunderstanding any important information.

Semi-structured interviews for each case in this study were performed in more than one round: In the first round, two researchers contacted the leaders or founders of the targeted communities of practice by e-mail and invited them to attend our research interview, and also informed them that we want to make a group- interview with other community members; In the following round(s), we only invited one student a time to attend the personal focused interview and discuss some vague or important problems we got from the first round mainly. Through these two or more rounds of semi-structured interviews, we could get more detailed information about every open question. After the semi-structured interviews, we totally got 4 group interview records and 12 personal interview records as our raw qualitative analysing material.

Open questions in the semi-structured snterviews are like these:

- "Describe an innovative engineering design process or a creative artefact or some activities like these."
- "In what ways do you think you have changed in terms of your learning style before and after participating the community of practice?"
- "Use three words to describe the atmosphere of your community of practice."
- "What do you think of the learning effect in communities of practice compared with the engineering learning in the classroom? How do you evaluate engineering learning in communities of practice? And why?"
- "How do you evaluate engineer as a profession?"
- "……"

Cases

Following the principles of purposeful and theoretical sampling methods[19], we chose four different types of communities of practice at Zhejiang University (China) as our research cases. The cases must meet the following criteria: (a.) they must be representative communities of practice with the features like mutual engagement, joint enterprise and shared repertoire [13]; (b.) they must be organized by engineering students (whether undergraduate or graduate students); (c.) they must have at least 5 members in order to meet the standard as the community of practice is "a group of people with similar professional experience and shared enthusiasms"[9]; (d.) they must have designed or manufactured at least one practical engineering artefact.

At last, we recruited four communities of practice as our analytical cases. The first case named Robo is a professional engineering student league with about 20 undergraduate or graduate students mainly from the College of Control Science and Engineering (others from the College of Mechanical Engineering and College of Computer and Software). Robo concentrated on designing small size robots and has taken part in World RoboCup Competitions many times. More specifically, this professional league designed some innovative functions for small size robots and once got first place in RoboCup2018. The second case named ET is an engineering competition team with only 5 undergraduate students from the College of Energy Engineering. Their interest is to extract carbon from used lunch boxes, and at present, they have designed prototype products successfully and prepared their products for the market. The ACEE is an experimental honour class with about 50 engineering students from almost all engineering disciplines at Zhejiang University. ACEE provided many interesting project-based courses and advanced manufacturing equipment for students which could drive them to learn the most frontier engineering knowledge through teamwork. The MTS is a professional studio concentrated mainly on mechanical design and about 20 undergraduate or graduate students from the School of Mechanical Engineering joined it voluntarily. With a lot of mechanical equipment like 3D printers, MTS would put up some creative engineering design ideas and encourage its members to transfer these ideas into reality jointly.

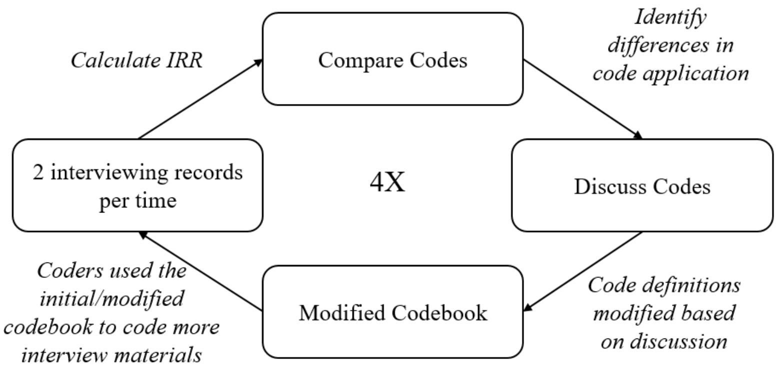
Table4. Research Cases

CoP	Type	Discipline(s) (the members from)	Population	Participants
Robo	Professional League	Control Science and Engineering , Electronical Engineering, Mechanical Engineering	20	5
ET	Competition Team	Energy Engineering	5	2
ACEE	Honor Class	Civil Engineering, Electric Engineering, Mechanical Engineering, Computer Engineering, …	50	3
MTS	Professional Studio	Mechanical Engineering	20	2
Total	-	-	95	12

Analysis

To identify the characteristics more accurately, we use computer-enhanced coding technology (The software used in this study is MAXQDA2018) to avoid destroying the original meaning of the raw data we gathered from interviews. Referring to Faber's method[20], we divide the data analysis into the following stages:

(1) Codebook Development. In the first phase, we used open coding and constant comparison methods to capture the original meaning from semi-conducted interviews and develop our codebook[21]. The first and third authors of this paper performed the open coding process independently, and we recruited a graduate engineering student to help us understand the meaning of some professional terms in engineering design processes. Before coding, both coders read the guidelines of coding principles in qualitative research and also read the literature reviews about the keywords of this research like situated learning and community of practice, thus the coders can both know the foundational concepts of this study and have a common understanding for the engineering learning (especially understand the three dimensions of situated engineering learning: social&material context, activities&interactions as well as participation&identity proposed by Johri and Olds[8]). This approach helped coders to focus on the key concepts while being open to new ideas and theories that emerged from the data[20]. Open coding is an iterative process: Firstly, two coders started coding with 4 group interviewing records independently and identified the key phrases and words from these raw materials using Vivo coding way mostly; Secondly, compared the two codebooks and calculate inter-rater reliability (IRR) value by "the number of same codes / the number of different codes"; Thirdly, two coders discussed the different codes with each other and modified some differences. For the remaining different codes, two coders discussed them with the second author of this paper and the graduate helper or consulted other researchers in the more comprehensive research team. Thirdly, two coders reached a consensus on all codes and developed the initial coding book, which was used to code more interviewing materials. Then repeated the coding and discussion processes until the IRR value exceed 0.8. At last, we make "4X" iterations to code the total of 16 interviewing materials and found the IRR value can be higher than 0.8 stably (Figure1) which means that the final codebook can reach acceptable reliability.



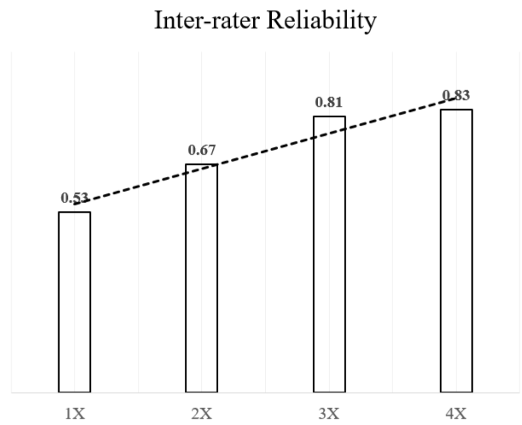


Figure1 Coding Book Development and IRR (Referring to Faber's method[20])

Table5. Codes, definitions, and example from the semi-structured interviews

Code	Definition	What it is	Examples
Tasks to be achieved	Learning through doing real tasks.	Students in CoPs will understand new concepts or knowledge through doing some realistic tasks	"*He (the team leader) generally assigned some tasks with very clear targets to us. For example, he could describe an interesting function and need us make that true through programming*"
Constructive conflicts	Conflicts which can bemefit learning among community members	Some disagreements which can stimulate the new design ideas or novel understanding	*"If there are some disagreements for the design scheme, we usually disscuss the alternative ways and test all possible initiative, then chose the best one"*
Iterative Tests	A circle of design and modification.	Test novel functions or ways many times during the design process	*"We tried many ways and methods to make our robots more stable"*
Recognition by engineering commumity	Acceptance from other community members.	Others give some praises for one's excellent engineering work	*"Engineer is a great image in my heart and I want to be accepted by engineers community"*

(2) Category Development. In the second phase, we first referred to the three dimensions of situated engineering learning, grouped the codes into four categories through an axial coding process based on the connections and relationships among the codes and mapped specific themes to these categories with the meaning emerging from similar coders[22][20]. This iterative process was performed by the first author and the second author of this paper. Firstly, two authors read codes in the codebook and grouped the codes into initial categories by the relationships among codes they felt independently. Secondly, the two authors compared the categories they found and discussed the different opinions about the codes which were divided into different groups. For example, the two authors have different opinions about the categories of "Encouragements from other members" and "Recognition by engineers community", and through the discussion, they identify the key differences between these two codes as well as the categories they belonged to respectively (Table 6.). For some codes the two authors didn't reach a consensus about their categories, so they discussed these codes with the larger research group to make more clarified classifications and refined the categories. At last, we made sure there were four categories for all codes in the codebook and identified the themes by comparing interactions between the meaning within different categories (Table6.).

Table6. Categories of codes

Codes	Authentic-task Driven	Collaborative Inquiry	Reflective Design	Engineering Identity
Tasks	X			
Shared goals	X			
Complex problems	X			
Clear working plans	X			
Collective design		X		
Constructive conflicts		X		
Communication		X		
Experiments with others		X		
Encouragements from other members		X		
Sharing ideas		X		
Tools or scaffoldings				
Iterative Tests			X	
Revisions of the design schemes			X	
Debug			X	
Constant comparisons			X	
Trials with many ways or materials			X	
Optimization			X	
Recognition by engineers' commumity				X
Interests for engineering work				X
Ambition to be an engineer				X

Quality Consideration

We make sure the quality consideration of this research in two phases referring to the Quality Framework: making the data and handling the data[23]:

In the phase of making data, we established the research quality in the following ways: (a.) The questions of the semi-structured interview were designed iteratively with the main dimensions of situated learning theory; (b.) In terms of the ambiguous or vague ideas emerging from the coding process, we made some focus interviews and an open-ended survey after the semi-structured interview; (c.) Furthermore, we gathered more information and materials about the cases we interviewed from their web pages, news reports and publications. (d.) Different resources of data can be verified mutually in order to meet the principle of triangulation in the case study[24].

In the phrase of handling data, we considered the research quality through the following measures: (a.) In both the code's development and categories development phrases, we performed open coding and axial coding through two researchers independently and calculated the IRR value during the open coding process; (b.) We made an iterative coding process during which constant comparisons and discussions were performed until reached a consensus.

FINDINGS

Based on the situative learning theory (specifically the three dimensions of situative engineering learning induced by Johri and Olds, 2011[8]) and the semi-structured interviewing data gathered from four different engineering communities of practice at Zhejiang University, we identified four typical themes for characteristics of engineering learning in communities of practice preliminarily : (a.) authentic-task driven, (b.) collaborative inquiry, (c.) reflective design process, and (d.) engineering identity. In the following sections, we would describe the meaning of each of the themes detailedly.

Authentic-task Driven

The first theme that appeared in the semi-structured interviews was ***authentic-task driven*** which means that the communities of practice would provide a lot of practical opportunities for engineering students to finish authentic engineering tasks. Different from engineering learning in classrooms, learning in communities of practice is tasks oriented and students in communities of practice were surrounded by a lot of authentic as well as complex engineering problems that needed to be solved. So in terms of the characteristics of engineering learning in communities of practice, students often mentioned the importance of the authenticity of tasks during their learning process. As one student we interviewed stated: "*On the first day I joined this robot design team, the leader assigned me a programming problem with the language C, but I didn't know how to handle this puzzle properly beginning; For this, I read some relevant books and tutorial videos during the next 2-3 months to master the necessary skills*". Another student in the same community mentioned: "*Authenticity is a vital difference between learning in our team and learning in the classroom. We have more useful equipment and more authentic environments like true laboratories or factories. For me, completing real engineering tasks or solving puzzling engineering problems is a shortcut (for the mastery of engineering knowledge). Just like climbing stairs, you can climb one floor at a time and you also can go to the ninth floor directly using elevators. There is no doubt that the latter one is better*".

Additionally, based on authentic tasks, communities of practice usually set shared goals or make clear working plans for a long period. The shared goals within communities of practice usually emphasize designing and manufacturing real engineering products. And through the shared goals, learners in communities of practice can be devoted to their engineering work. For example, an interviewee mentioned "*our (team's) ultimate goal is to make high-level robots and win the robots competition. Therefore, what we need to do every day is to test the operating system bugs of our robots and then fix them as soon as possible*". Meanwhile, learners in communities of practice would make some detailed planning to guide them to finish their collective tasks. Some interviewees have mentioned during semi-structured interviews that "*We will make a plan for the next year or several years after each competition, including making a route-map, It is important for everyone in the team to see your results and the actual operation of your coding. So in this process, it is important to describe the problems clearly and solve them in your plans*".

Although the authenticity has been explored by existing engineering education research (see Strobel et al., 2013[25]), the *authentic-task driven* is a salient theme for engineering learning in communities of practice because it is related to the "activities" dimension in situative engineering learning theory on the one hand, and it benefited engineering students' professional practice well as it can help engineering students to learn how to more effectively apply their technical knowledge to the practical work they will face on the other hand.

Collaborative Inquiry

Another theme emerging from the analysis is ***collaborative inquiry***, meaning that engineering students in communities of practice would manage their projects by working and interacting closely with others. Collaborative inquiry concentrated on the importance of interpersonal co-operations like sharing ideas with learning partners or doing experiments with other students. The interviewees repeatedly expressed the viewpoints that: "*We have the opportunity to get together and communicate every day or every week. If we have difficulties, we can solve them together. That's how we learned* ", "*(We) can constantly emerge new ideas in the process of collaboration with others*", which reflects that the communities of practice have created safe environments that allow the sharing of informal views, so the members of the communities of practice are willing to trust each other and share their innovative ideas as well as get encouragements mutually. Likewise, there were a lot of "constructive conflicts" we found in communities of practice, which means although the members in communities of practice have different ideas, solutions or conflicts for some specific engineering problems, they can meet consensus and get better ways by comparing the different ideas in practical application contexts. As an interviewee stated: "*When there are different solutions (presented by different students), we usually make comparisons between these different ways and find a better one through practical experiments*". So the constructive conflicts made students think about practical engineering problems deeply and beyond the theoretical boundary.

Besides the interpersonal interactions, there are man&machine cooperations in communities of practice too. Different from the learning in the disciplines of mathematics or science, engineering learning happens in the process of learners participating in material interactions (Material context in situative engineering learning means that engineering learners are surrounded by other people, objects or artefacts and tools play a mediated role in our learning process in the work of Johri and Olds, 2011[8]), which means engineering students can enhance their understanding of professional engineering knowledge in the repeated interaction with some equipment, tools, materials, and engineering products/artefacts. As one student in our interviews stated, "*I learned a lot of things through operating the equipment, but I can't explain it well. This experience is also very important. The feeling of 'getting started with the equipment is very important*".Various technologies, tools and equipment in engineering learning are important factors to make a deep understanding of engineering knowledge, that is, when engineering students interact with different types of materials or different types of meaning knowledge and deep understanding can emerge[26]. In our case, an experienced captain in Robo mentioned that "*These technical documents and videos only give you a rough understanding of the practical knowledge, and the details need to be explored in your own practice with the machine* ".

Furthermore, we identified that there are some external representations in communities of practice. With the support of 'scaffoldings', engineering learners in communities of practice usually use a series of representational technologies and tools (such as problem whiteboard, database, notepad, etc.) to make the thinking processes visualized. External representations can promote concept transformation and knowledge construction, and help learners in communities of practice to achieve a deep level of understanding of professional engineering knowledge. Just like most learners in our research mentioned in the interviews that "*Visualization is an important way to express engineering ideas*".

Table7. The Dimensions and Evidence of Collaborative Inquiry

Characteristics	Dimensions	Evidence
Collaborative Inquiry	Interpersonal Cooperation	• *We have the opportunity to get together and communicate every day or every week. If we have difficulties, we can solve them together. That's how we learned.*
	Man&Machine Cooperation	• *I learned a lot of things through operating the equipment, but I can't tell. This experience is also very important. The feeling of "getting started" with the equipment is very important.*
	External Representation	• *Visualization is an important way to express engineering ideas.*

Collaborative inquiry is related to the social&material context and interaction dimensions of situative engineering learning, which is vital for engineering learning as the previous studies have revealed that engineers dedicate 16% of their time toward design, coding, calculations, and simulations while they 'spend about 60% of their time on communication activities and socio-technical work[27]. What's more, many engineering students are facing some social interaction problems nowadays, as research indicated "the majority of coursework in engineering education today focuses on technical knowledge and skills of mathematics, science, and engineering as well as new graduates generally feel prepared for the technical aspects of practice, but many have difficulty transitioning to the socio-technical practices and culture of the workplace[28] ”.

Additionally, to explore the collaborative inquiry deeply, we conducted a longitudinal study for three innovative engineering design works (arc-path prediction, parallel design of robot structure and symmetrical design for robots) in our research case “Robo”. It can be seen that the three dimensions of collaborative inquiry are significantly repeated in different robotic function innovations, which revealed partly that collaborative inquiry is helpful for soluting complex engineering problems and promoting the innovative design of engineering products (Table8.).

Table8. The Relationship between Collaborative Inquiry and Innovative Engineering Design

Innovative engineering design	Interpersonal Cooperation	Man&Machine Cooperation	External Representation
Path Prediction	YES. The strategy group carries out trajectory prediction and path optimization design, followed by the simulation group.	YES. The origin of the problem is to observe the deviation between the real path of the ball and the predicted path.	YES, A visualization program that can map three-dimensional problems on two-dimensional plane is designed to help solve the "distortion" problem.
Parallel Structure	YES. Changing the serial structure of robot to parallel structure involves not only the modification of hardware, but also the debugging of software, which is almost "full cooperation"	YES. In the process of decoupling the robot, it is found that the parallel structure is more stable than the series structure.	YES. In the process of parallel structure design, a large number of hand drawn drafts of parallel structure design of each part of the robot are formed.
Symmetrical Design	YES. The general idea and design details, such as the angle of the wheel, are determined in the weekly regular meeting.	YES. Many experiments have found that the asymmetric robot will drift when moving, which increases the difficulty of control.	YES. A database that can reflect the long-term running state of symmetrical robot and asymmetric robot is established.

Reflective-design Process

The third theme derived from the semi-structured interview is ***reflective-design process***, which means that the communities of practice would stimulate engineering students’ reflective thinking and encouraged them to make iterative comparisons among different engineering experiments, design ideas, and engineering productions as much as they can. Through the iterative design process, learners tend to have a deep understanding of professional knowledge because they can actively construct their meaning on the basis of their own experience.

The ***reflective-design process*** is related to the material context and activity dimensions of situative engineering learning. On the one hand, the reflection means there are continuous iterations of engineering design, and the engineering design is iterative interactions among different theoretical knowledge, practical experience, industrial technology and engineering skills. We found that engineering students participating in the communities of practice in our interviews often emphasized "optimization" or "debug" processes, as an interviewee mentioned: "*We tried many, many methods, that is, I mudded through the original problems again*", and "*A lot of (engineering) work is based on the optimization again and again*". Reflection is one way of metacognition and a high-order thinking mode. In the context of communities of practice, learners can have more opportunities to reflect on the design of engineering products and improve themselves according to the actual operation effect. For example, learners in communities of practice told us: "*If you encounter a large number of bugs during the test, you will write them down every day, and a piece of A4 paper will be full*". For more detailed information, we made some focus interviews about the keywords like "reflection", "iteration" and "insight". Every interview can be seen as an experiment to verify the conclusions that continuously iterations such as revisions of the design schemes or iterative tests can promote the design of engineering products, and help learners get a deep understanding of engineering knowledge and skills in this process (Table9.).

Table9. The Evidence of Multiple Group Interviews about Reflective-design Process

Interviewees	Reflection	Iteration	Insight
1	*Reflection can help me accurately understand and clearly express my views. In particular,some framework knowledge needs continuous reflection to form.*	*Iterative process is very important. Continuous iteration helps me understand other people's code logic.*	
2	*Reflection occurs in all links. Only by reflecting on the function and logic of the product can we innovate.*	*Compared with hardware, software iteration has lower cost and higher frequency. This iteration uses new knowledge and expands the scope of knowledge.*	*Some specific problems need to be solved by their own inspiration, and the source of inspiration needs the accumulation of basic mathematical knowledge.*
3	*Reflection helps me clarify whether my ideas are moving forward or backward compared with those of my predecessors.*	*For me, iteration means a spiral of knowledge and ability.*	*Sometimes you suddenly have a great idea, but if you don't have enough to store or dabble in, it's difficult to produce innovative ideas.*

Engineering Identity

The last salient theme about the characteristics of engineering learning in communities of practice is ***engineering identity***. Identity is a vital construct in the theory of communtiy of practice and it explained the effect of social context on students' learning and development as learning is seen as a process of identity transformation from novices to experts[9][29]. Many studies on engineering identity use the communities of practice model as their analytical framework[30]. Meanwhile, existing research has pointed out that engineering identity presents a useful construct for predicting engineering students' persistence and competence [30][31][32].

It is well known that engineers' identification with their profession is central to learning and crucial for persistence in the field[29][33]. Previous studies have found that engineering identity contains at least three dimensions: recognition, interest and competence/performance[34]. However, in this study, we only identified the former two dimensions. For recognition, some interviewees with practical engineering design experiences would tend to recognize themselves as a real engineer to some degree within our study and express their desires to be accepted or recognized by the engineers' community as indicated by their responses "*(The) reason we joined this team is that we want to be an engineer. And (now) we feel us as real engineers in university and we do same work (with the real engineers)*". Furthermore, engineering identity is related to engineering students' interest in engineering design work. One interviewee told us that: "*An obvious difference (between the communitie of practice and engineering classroom) is the works there are more interesting*".

Communities of practice indeed helped engineering students enhance their understanding of professional knowledge and cultivate students' ambitions to be an engineer. Existing literature has provided some evidence to prove the relationship between engineering identity and engineering students' learning efficiency. For example, identity-based motivation holds the view that identity got from practical activities can influence one's action strategy and learners tend to make decisions coordinated with their identity and experience, so it is possible to use engineering identity to predict the learning motivation and career choices[35]. Furthermore, engineering identity is a robust predictor for engineering persistence. For example. Patrick and Prybutok used logistic regression to study the self-report data of 474 students majoring in mechanical and civil engineering and found that the interest dimension in engineering identity can significantly predict students' engineering persistence[36].

DISSCUSION

For new types of engineering learning or situative engineering learning, prior studies have focused on PBL or PjBL mostly (see: Chen et al., 2021[37]; Edström and Kolmos, 2014[38]; Mills and Treagust, 2003[39]), but some more broad visions should be included in this research field because not all situative engineering learning is organized by the PBL or PjBL forms. The emerging engineering education transformation in China has provided a nice opportunity to enrich the research in this field and the community of practice in situative learning theory[9] has provided an insightfully theoretical lens to investigate such new learning phenomena in engineering disciplines. Based on these fundamental observational phenomena, we put up "engineering learning in communities of practice" as our research target and identified its four typical characteristics: (a)authentic-task driven, (b)collaborative inquiry, (c)reflective-design process, (d)engineering identity. On the one hand, the four characteristics indicate that engineering learning in communities of practice can integrate engineering knowledge, professional practice and interpersonal collaboration to address complex engineering problems or to design some artefacts such as tools, devices or programs. On the other hand, engineering identity in communities of practice contains dual dimensions like recognition and interest in engineering works, which indicates that the communities of practice can inspire engineering students' motivation in their authentic design activities and have a meaningful and flexible understanding of their professional engineering knowledge.

For the theme of "***authentic-task driven***", the studies concentrated on the PBL method have emphasized that "problem is the starting-point of the learning process", and "activity-based learning is a central part of the PBL learning process, requiring activities involving research, decision-making and writing"[40], and the problems in PBL usually are "ill-defined and/or complex problems" [41]. Likewise, engineering learning in communities of practice also thinks highly of the effect of complex problems or projects, but it emphasizes authenticity more. Authenticity is a central part of engineering learning in communities of practice which means the students should apply their knowledge to practical environments and design or manufacture real engineering artefacts. Authenticity builds a bridge between the learning in universities and workplaces and helps engineering students understand the engineering concepts and principles as well as apply them in real engineering contexts.

For the theme of "***collaborative inquiry***", prior studies on PBL or PjBL have put up some useful principles like "In PBL, students work in collaborative groups and learn what they need to know in order to solve a problem" and "collaborative problem-solving groups are a key feature of PBL"[42] as well as "(Project-based learning) promotes a collaborative learning environment that can enhance students' social and problem-solving skills"[43]. Besides the similar findings, we found in our study that collaborative inquiry is not only about interpersonal interaction, but also contains the dimensions like man&machine cooperation as well as an external representational tool used in engineering learning. As a result, to create a cooperative learning environment, educational policymakers or engineering education researchers should pay more attention to the technology, tools, and other material contexts to support engineering students' learning in terms of collaborative inquiry.

For the third theme "***reflective-design process***", related studies have revealed that "reflection is fundamental to learning and that it provides a basis for future action", and "project-based learning can set the stage for reflective practice and reveal deeper aspiration and construct shared understanding"[44]. Likewise, "reflection guided by SRL theory was seen to have the potential to improve students' frequency of feedback views"[45]. But in our study, we found that engineering students' reflection is a mixed process with engineering design, which means that high-quality reflection could be stimulated to happen through practical design processes like "debug" or "experiments" in communities of practice. Meanwhile, engineering learning in communities of practice could benefit from the collective reflection process during which different design methods can be compared mutually to select the best one. As a result, future research and educational policy should attach importance to the iterative design process and the dynamic reflective thinking of engineering students.

For the last salient theme "***engineering identity***", many studies in recent years have noticed the importance of engineering identity in predicting students' interest, motivation[32], professional persistence[36] and career choice[31]. In our study, we found that communities of practice are a suitable context for helping engineering students construct their self-efficacy, cultivate their ambitions to be real engineers and enhance their interest in current and future engineering tasks. During the process of emerging engineering education transformation, universities should invest in and encourage students to build various communities of practice in which participate in the practical engineering design work and achieve the transformation from novice to expert engineers.

LIMITATIONS

Given the purpose of this study to better understand the characteristics of engineering learning in communities of practice with the background of emerging engineering education transformation in China, we should investigate as many types of communities of practice as possible in different contexts. However, this paper used the theoretical sampling method and selected only four engineering communities of practice as the research cases, and these cases in our research are all located in Zhejiang University, so the participants of this study are very limited for some more broad applications of the research findings. Besides, this study is a qualitative as well as exploratory study which does not carry out any empirical research based on statistical data, so how to measure the key characteristics or the main constructs and their specific dimensions properly we found in case analysis remains an important question to be solved. Considering the constructs we found in this study like authenticity and collaboration have been identified much in PBL and PjBL studies, so what are the similarities and differences between engineering learning in PBL or PjBL and engineering learning in communities of practice that need to be further clarified.

CONCLUSIONS

Under the background of the Emerging Engineering Education transformation in China, this draft found some new forms of engineering learning such as engineering studios, engineering laboratories, research experience or engineering competitions for engineering undergraduates, etc., which have different features and are playing an essential role in cultivating high-quality engineering talents. But how to build more efficient engineering learning environments and stimulate the engineering students' motivation to achieve deep engineering learning are remained to be answered. Our research team designed a comprehensive research plan to investigate the specific mechanism between engineering learning in communities of practice and engineering students' deep learning quality. This qualitative study exhibited the first part of this comprehensive research aiming to investigate the characteristics of engineering learning in communities of practice. With the guideline of situative engineering learning theory (especially the three-dimension characterized by Johri and Olds, 2011[8]), we identified four characteristics of engineering learning in communities of practice based on four different types of communities in Zhejiang University: authentic-task driven, collaborative inquiry, reflective-design process and engineering identity. In the future, we will develop a valid instrument to measure the key characteristics of engineering learning in communities of practice based on the findings of this study and further design some empirical studies to make the relationships between engineering learning in communities of practice and engineering students' deep learning efficiency more clear, and put up some practical policy implications to promote the development of engineering learning quality under the ground of Emerging Engineering Education transformation in China.

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REFERENCES

[1] Y. Zhou and F. Zheng, "Study of Engineering Talent Cultivation in Emerging Engineering Education," *Transformations in Business & Economics* ,vol. 20, no. 1, p. 17, 2021.
[2] Y. Jia, K. Xiao, L. Ren, and L. Huo, "Research on practice teaching mode for undergraduate in the age of emerging engineering education," *The International Journal of Electrical Engineering & Education*, p. 002072091986741, Aug. 2019.
[3] M. V. Jamieson and J. M. Shaw, "Teaching engineering innovation, design, and leadership through a community of practice," *Education for Chemical Engineers*, vol. 31, pp. 54–61, Apr. 2020, doi: 10.1016/j.ece.2020.04.001.
[4]W. Tomic, "Behaviorism and cognitivism in education," *Psychology*, vol. 30, no. 3/4, pp. 38–46, 1993.
[5]A. Renkl, H. Mandl, and H. Gruber, "Inert knowledge: Analyses and remedies," *Educational Psychologist*, vol. 31, no. 2, pp. 115–121, 1996.
[6] M.L.Yao, "From Cognition to Situation: The Change of Learning Mode," *Educational Reasearch (China)*, vol. 02, pp. 60-64, 2003.
[7] J. S. Brown, A. Collins, and P. Duguid, "Situated Cognition and the Culture of Learning," *Educational researcher,* vol. 18, no. 1, pp. 32-42, 1989.
[8] A. Johri and B. M. Olds, "Situated Engineering Learning: Bridging Engineering Education Research and the Learning Sciences," *Journal of Engineering Education*, vol. 100, no. 1, pp. 151–185, Jan. 2011, doi: 10.1002/j.2168-9830.2011.tb00007.x.
[9]J. Lave and E. Wenger, Situated learning: Legitimate peripheral participation. *Cambridge university press*, 1991.
[10]A. Van den Beemt et al., "Interdisciplinary engineering education: A review of vision, teaching, and support," *Journal of engineering education*, vol. 109, no. 3, pp. 508–555, 2020.
[11] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, "Engineering design thinking, teaching, and learning," *Journal of engineering education*, vol. 94, no. 1, pp. 103–120, 2005.
[12]W. M. McCracken and W. C. Newstetter, "*Text to diagram to symbol: Representational transformations in problem-solving*," in 31st Annual Frontiers in Education Conference. Impact on Engineering and Science Education. Conference Proceedings (Cat. No. 01CH37193), 2001, vol. 2, pp. F2G-13.
[13] E. Wenger, Communities of practice: Learning, meaning, and identity. *Cambridge university press*, 1999.
[14] E. Wenger, R. A. McDermott, and W. Snyder, Cultivating communities of practice: A guide to managing knowledge. *Harvard business press*, 2002.
[15]E. L. Lesser and J. Storck, "Communities of practice and organizational performance," *IBM systems*

journal, vol. 40, no. 4, pp. 831–841, 2001.
[16] C. Xiang, Engineering learning: model change and theoretical interpretation, *Research on higher engineering education (China)*, vol. 04, pp. 55–63, 2015.
[17]A. Amin and J. Roberts, "Communities of practice? Varieties of situated learning," *Dynamics of Institutions and Markets in Europe research paper*, 2006.
[18] K. M. Eisenhardt and M. E. Graebner, "Theory building from cases: Opportunities and challenges," *Academy of management journal*, vol. 50, no. 1, pp. 25–32, 2007.
[19]I. T. Coyne, "Sampling in qualitative research. Purposeful and theoretical sampling; merging or clear boundaries?," *Journal of advanced nursing*, vol. 26, no. 3, pp. 623–630, 1997.
[20] C. J. Faber et al., "Undergraduate engineering students' perceptions of research and researchers," *Journal of Engineering Education*, vol. 109, no. 4, pp. 780–800, 2020.
[21]J. Saldaña, The coding manual for qualitative researchers. *sage*, 2021.
[22]K. Charmaz, Constructing grounded theory: A practical guide through qualitative analysis. *sage*, 2006.
[23]J. Walther, N. W. Sochacka, and N. N. Kellam, "Quality in interpretive engineering education research: Reflections on an example study," *Journal of Engineering Education*, vol. 102, no. 4, pp. 626–659, 2013.
[24]B. G. Glaser and A. L. Strauss, The discovery of grounded theory: Strategies for qualitative research. *Routledge*, 2017.
[25]J. Strobel, J. Wang, N. R. Weber, and M. Dyehouse, "The role of authenticity in design-based learning environments: The case of engineering education," *Computers & Education*, vol. 64, pp. 143–152, 2013.
[26]E. Sørensen, The materiality of learning: Technology and knowledge in educational practice. *Cambridge University Press*, 2009.
[27]S. R. Brunhaver, R. F. Korte, S. R. Barley, S. D. Sheppard, R. Freeman, and H. Salzman, "Bridging the gaps between engineering education and practice," *US engineering in a global economy*, pp. 129–163, 2018.
[28] M. Eraut, "Transfer of knowledge between education and the workplace," *Expertise development: The transition between school and work*, pp. 52–73, 2003.
[29]C. McCall, L. D. McNair, and D. R. Simmons, "Advancing from outsider to insider: A grounded theory of professional identity negotiation in undergraduate engineering," *Journal of Engineering Education*, vol. 110, no. 2, pp. 393–413, 2021.
[30]B. E. Hughes et al., "Entering the community of practice: changes in engineering students' engineering identities and perceptions of the field," *European Journal of Engineering Education*, vol. 46, no. 6, pp. 968–986, 2021.
[31] A. Godwin, G. Potvin, Z. Hazari, and R. Lock, "*Understanding engineering identity through structural equation modeling*," in 2013 IEEE Frontiers in Education Conference (FIE), 2013, pp. 50–56.
[32] A. Godwin and A. Kirn, "Identity-based motivation: Connections between first-year students' engineering role identities and future-time perspectives," *Journal of Engineering Education*, vol. 109, no. 3, pp. 362–383, 2020.
[33]K. L. Tonso, "Engineering identity," *Cambridge handbook of engineering education research*, pp. 267–282, 2014.
[34]A. Godwin, G. Potvin, Z. Hazari, and R. Lock, "Identity, critical agency, and engineering: An

affective model for predicting engineering as a career choice," *Journal of Engineering Education*, vol. 105, no. 2, pp. 312–340, 2016.
[35]D. Oyserman and M. Destin, "Identity-based motivation: Implications for intervention," *The Counseling Psychologist*, vol. 38, no. 7, pp. 1001–1043, 2010.
[36] A. D. Patrick and A. N. Prybutok, "Predicting persistence in engineering through an engineering identity scale," *International journal of engineering education*, vol. 34, no. 2a, 2018.
[37] J. Chen, A. Kolmos, and X. Du, "Forms of implementation and challenges of PBL in engineering education: a review of literature," *European Journal of Engineering Education*, vol. 46, no. 1, pp. 90–115, 2021.
[38]K. Edström and A. Kolmos, "PBL and CDIO: complementary models for engineering education development," *European Journal of Engineering Education*, vol. 39, no. 5, pp. 539–555, 2014.
[39]J. E. Mills and D. F. Treagust, "Engineering education—Is problem-based or project-based learning the answer," *Australasian journal of engineering education*, vol. 3, no. 2, pp. 2–16, 2003.
[40]E. De Graaf and A. Kolmos, "Characteristics of problem-based learning," *International journal of engineering education*, vol. 19, no. 5, pp. 657–662, 2003.
[41] B. Galand, M. Frenay, and B. Raucent, "Effectiveness of problem-based learning in engineering education: a comparative study on three levels of knowledge structure," *International Journal of Engineering Education*, vol. 28, no. 4, p. 939, 2012.
[42]C. E. Hmelo-Silver, "Problem-based learning: What and how do students learn?," *Educational psychology review*, vol. 16, no. 3, pp. 235–266, 2004.
[43]F. Martínez, L. C. Herrero, and S. De Pablo, "Project-based learning and rubrics in the teaching of power supplies and photovoltaic electricity," *IEEE Transactions on Education*, vol. 54, no. 1, pp. 87–96, 2010.
[44]K. Ayas and N. Zeniuk, "Project-based learning: Building communities of reflective practitioners," *Management learning*, vol. 32, no. 1, pp. 61–76, 2001.
[45]H. A. Diefes-Dux and L. M. Cruz Castro, "Reflection types and students' viewing of feedback in a first-year engineering course using standards-based grading," *Journal of Engineering Education*, vol. 111, no. 2, pp. 283–307, 2022.