International Journal of Engineering Education Vol. 38, No. 3, pp. 786–798, 2022
Printed in Great Britain
0949-149X/91 $3.00+0.00

Big Data + Business Administration: Applying Problem-Based Learning to Enrich the Design of Interdisciplinary Education*

LANXIA ZHANG[1], CHUNFANG ZHOU[2], and XINBO SUN[3]
[1] Department of Organizational Management, School of Business Administration; PBL Teaching Innovation and Research Center, Northeastern University, China. E-mail: lxzhang@mail.neu.edu.cn
[2] Center for Research in Science Education and Communication, Department of Mathematics and Computer Science, University of Southern Denmark, Denmark. E-mail: chzh@imada.sdu.dk
[3] Department of Organizational Management, School of Business Administration; PBL Teaching Innovation and Research Center, Northeastern University, China. E-mail: xbsun@mail.neu.edu.cn

In this paper, we explore how to apply Problem-Based Learning (PBL) to enrich the design of interdisciplinary education programs and facilitate the integration of big data engineering education into business contexts. Theoretically, we take social constructivism as the theoretical root of PBL, which highlights principles of student-centered learning, active learning, learning by doing, group learning, teachers' facilitation of the learning process, etc. In designing an education program, it is necessary to align diverse elements of PBL, including (1) objectives and outcomes; (2) types of problems, projects, and lectures; (3) progression, size, and duration; (4) students' learning; (5) academic staff and facilitation; (6) space and organization; and (7) assessment and evaluation. This leads to a discussion of a case on developing a new Bachelor of Education program of "Big Data + Business Administration" at Northeastern University (NEU), China. The case shows how PBL is applied in practice for the development of interdisciplinary engineering education and reflects how NEU managed institutional and cultural challenges in the process of changes. This paper provides implications for better developing interdisciplinary engineering education in the future.

Keywords: interdisciplinary education; program design; problem-based learning (PBL), big data education; business education

1. Introduction

It has been increasingly recognized that the essence of engineering education is to prepare the future 21st-century workforce with the required knowledge, skills, and abilities, where students can take what they learn in the classroom to solve real-life problems in diverse contexts [1]. As there is complexity in solving any real-life problem [2], interdisciplinary engineering education has been paid more attention than ever. As Kennedy and Odell [3] suggested, the current state of engineering education has evolved into an integrated effort that removes the traditional barriers between different subjects and focuses on innovation and the applied process of designing solutions to complex contextual problems using current tools and technologies.

Accordingly, engaging students and teachers in high-quality interdisciplinary learning and teaching contexts requires efforts to make the education programs to include rigorous curriculum, instruction, assessment, and management. Meanwhile, educators, industry, and the business community should work as a team to develop curricula that will enhance this expectation [4, 5]. In addition to curricula development, collaboration between schools and professionals in the industry should include internships, mentoring, delivery of hands-on activities in the classroom, and diverse outreach activities to introduce students to careers in interdisciplinary fields to learn fundamental skills [1, 6]. This has led to a number of recent studies on how to develop interdisciplinary pedagogies and design interdisciplinary programs [7]. Among the discussed strategies, problem-based learning (PBL) is a popular approach to meet the requirements of changes from traditional single disciplinary education to interdisciplinary models [8].

PBL is an approach to learning in which students engage with complex, real-world situations that have no one "right" answer and are the organizing focus for learning. Students work in teams to confront the problem, identify learning gaps, develop viable solutions, and gain new information through self-directed learning. The diverse activities such as lectures, seminars, workshops, or laboratories support the inquiry process rather than transmit subject-based knowledge [9]. PBL has been seen by many to be synonymous with Project-Based Learning because in both contexts, student-centered learning models are encouraged, and the role of the teacher is not only to communicate knowledge, but in particular to act as a facilitator of the student learning process. There are also discus-

* Accepted 17 December 2021.

sions on differences between them: in Project-Based Learning, students are required to produce a solution or strategy to solve the problem, whereas in PBL, it also involves the management of process of organizational changes. Accordingly, Project-Based Learning is more often seen as a teaching technique rather than an overall educational strategy like PBL [9]. In this sense, stressing the interdisciplinary dimension in PBL might be a viable way to supplement the learning objectives of the formal curriculum [10, 11] that takes project-based learning as the key method in practice. In general, when developing interdisciplinary education, the relevant dimensions should be considered. These include awareness of professional and disciplinary perspectives, appreciation of disciplinary and cross-disciplinary perspectives, recognition of disciplinary limitations, interdisciplinary evaluation, ability to find common ground, reflexivity, and integrative transversal competences [8]. It is also essential to facilitate changes that aim at breaking the boundaries of traditional disciplines and institutional structures, which requires joint efforts of all participants.

This paper explores how to take PBL as an approach to design an interdisciplinary program and how to break traditional boundaries in engineering education. A case will be discussed on designing a new bachelor program on "Big Data + Business Administration" in a Chinese university. This leads to reflections on how to manage institutional and cultural challenges. Since those challenges are recognized as both contextual-specific and contextual-general, this paper has significance for developing diverse models of interdisciplinary engineering education around the world in the future.

2. Theoretical Understanding of Interdisciplinarity and Engineering Education

2.1 Interdisciplinarity in Engineering

Today, engineers are confronted with a huge amount of information and a large number of methods and approaches to be applied to problems in an ever more complex world. The engineering work lies at the interface between science and society [10]. It is about solving real-life problems using a systematic approach, subject to economic, environmental, social, and other constraints. The traditional professional profile of engineers has changed: engineers should not only master "hard knowledge and skills of engineering" but also gain understanding of the language and principles of "soft science" [2, 12]. They are expected to address environmental, regulatory, economic, and human constraints and to put forwards creative and innovative solutions that take account of these wider issues within the context of what is technically feasible [8]. In other words, engineering requires knowledge in humanities, social science, and other fields as well as abilities across those fields.

Increasingly, "interdisciplinarity" has been emphasized as one of the elements for understanding the essence of engineering practice [10]. According to Lattuca et al. [13], interdisciplinarity can be understood as a process of answering a question, solving a problem, or addressing a topic that is broad or complex to be dealt with adequately by a profession, and it draws upon different disciplinary perspectives and integrates their insights through construction of a more comprehensive and systematic perspective. From this definition, we learn that interdisciplinarity integrates disciplinary contributions and thus obscures the separate contributions of individual disciplines [2]. Undoubtedly, the process of achieving such integration requires identifying, evaluating, and rectifying differences between disciplinary insights to achieve a new understanding. Such cognitive achievement cannot be gained without synthesis of disciplinary methods, knowledge, or insights into something new [14]. For example, contextual knowledge and mathematical and computational thinking are often integral to the design process that allows engineers to run tests and mathematical models and assess the performance of a design solution before prototyping [1].

2.2 Interdisciplinary Engineering Education

The design and development of education always respond to the needs of societal changes. As suggested by Zhou and Krogh [11], educational reforms were often propelled by developments acting as many different levers such as shaping attitude, creating opportunities, changing management, and promoting shifts in policies, practices, and programs. Driven by recognition of interdisciplinarity in engineering practice, we call for a new type of engineering education by which engineers are trained to learn to combine theories, concepts, and methods from different disciplines in a single context [16]. Therefore, we can see interdisciplinary courses, curricula, and programs are proliferating in disciplinary departments in different cultures, which has offered compelling cases and evidence that interdisciplinary engineering education becomes a mainstream [4, 15].

In comparison with disciplinary learning, interdisciplinary learning is expected to provide learners with many more opportunities to relate new knowledge to previously acquired knowledge; therefore, learning becomes more effective [7]. There has also been increased interest in how to design, teach, and assess learning and teaching that explores how to enable teachers to document how students attain competence in the process of interdisciplinary problem solving and integration [10, 17]. In pursuit of designing and developing interdisciplinary education, recent studies have suggested different principles that emphasize student-centered learning [11], authentic learning [18], integrative learning [19], reflective teaching [20], collaborative practice [21], etc. These ideas have formed the basis to apply diverse models in practice, such as PBL [8], discover-based learning [22], practice-based learning [1], design-based learning [23], inquiry-based learning [24], etc. These approaches reinforce the integration of multiple sources of information and perspectives, higher-order critical thinking skills, and experience of learning by doing in group work that all require authentic learning settings. However, in traditional universities, the application of new pedagogical models and the development of interdisciplinary engineering education have to be developed carefully and proceed step by step. In other words, a process of incremental innovation is required [8]. According to Ivanitskaya et al. [25], a four-stage interdisciplinary education model is proposed:

(1) Unidisciplinarity, in which the learner focuses on one relevant discipline and acquires unidisciplinary knowledge;
(2) Multidisciplinarity, in which the learner focuses on several disciplines but addresses each one separately;
(3) Limited interdisciplinarity, in which the learner integrates several disciplines around a central topic, identifies the weaknesses and strengths of the perspectives that stem from the different disciplines, and, as a result, develops critical thinking skills; and
(4) Extended interdisciplinarity, in which the learner acquires meta-cognitive skills and is able to transfer the interdisciplinary knowledge to new subjects.

Additionally, we should recognize that the process of developing interdisciplinary education is always full of challenges for most students. Being interdisciplinary learners, students are expected to integrate information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines to craft products, explain phenomena, or solve problems in ways that would have been unlikely through single-disciplinary means [13, 25]. At the same time, in many ways, it is even more challenging for teaching and management staff, who will be crossing borders and charting new terrain where they need to make many efforts in achieving common goals [4, 7]. This further underpins the need for a systematic perspective to design and develop powerful pedagogies and appropriate management strategies that enable and ensure students and teachers to engage themselves in meaningful learning and teaching experiences in interdisciplinary contexts.

3. Designing Educational Programs with PBL

3.1 Theoretical Root of PBL

As mentioned, there has been growing recognition that PBL is one of the most innovative pedagogies in engineering education. PBL encourages students' open-minded, reflective, creative, critical, and active thinking skills [10, 18] that are all keys to gain successful interdisciplinary learning experience [11]. This has been evidenced by theories and empirical work in contemporary learning studies, which have increasingly recognized learning as a fundamental activity of being cognitive, contextual, social, and cultural [27]. Among all theories discussed, we take social constructivism as the theoretical root of PBL.

Social constructivism is a theory of knowledge in sociology and communication theory that examines the knowledge and understandings of the world that are developed jointly by individuals [10]. This theory is strongly influenced by Vygotsky's work [28] and suggests that knowledge is first constructed in a social context and then internalized and used by individuals. It highlights that reality is not something that individuals can discover because it does not pre-exist prior to their social invention of it. Humans as learners are perceivers and interpreters who construct their own interpretations of the physical world through cognitive, interpretive activities that construct mental models [27]. This sense-making process involves accommodating new ideas and phenomena with existing beliefs and the knowledge representations that have already been created [8]. The knowledge that is constructed by a learner consists not only of the ideas or content, but also knowledge about the context in which it was acquired, what the knower was doing in that environment, and what the knower intended from that environment [29]. In other words, the theory of social constructivism suggests an understanding of human thinking and knowledge that depends on an understanding of social experience, and the force of the cognitive process derives from the social interaction.

In educational contexts, social constructivism encourages the learner's own version of the truth that is influenced by his or her background, culture, or knowledge of the world that facilitates, utilizes, and rewards the learner as an integral part of the learning process [30]. These points further suggest instructors are introduced as facilitators, not as teachers. Whereas a teacher gives a didactic lecture that covers the subject matter, a facilitator helps the learner to get to his or her own understanding of the content [31]. Thus, it is advocated that to give the learner ownership of the problem and solution process, the instructors should consider learning as a reflective process instead of seeking a unique answer [10]. Diverse methods in pedagogical practice are accordingly encouraged, such as reciprocal teaching, peer collaboration, cognitive apprenticeships, and problem-based instruction [8].

3.2 *PBL as an Approach to Systematic Design*

In practice, PBL incorporates diverse appropriate educational strategies to optimize motivation, process, management, and outcomes of student-centered learning beyond just knowledge acquisition and lecture delivery [4]. This highlights PBL as a complex learning system that essentially indicates a systematic perspective to design educational programs. In the process of developing interdisciplinary education by PBL, many elements should be considered, which leads us to rethink a model suggested by Kolmos et al. [32] (Fig. 1).

As Fig. 1 shows, a typical PBL curriculum model consists of at least seven elements: (1) objectives and outcomes; (2) type of problems, projects, and lectures; (3) progression, size, and duration; (4) students' learning; (5) academic staff and facilitation; (6) space and organization; and (7) assessment and evaluation. All these elements are elementary in a curriculum that is suitable to apply to faculty-wide curriculum reform and the integrated interdisciplinary engineering program [33]. Meanwhile, all the elements should be aligned. This is based on a holistic understanding, which means if there is a change in one element, it will cause change in all the other elements as well [32]. In designing an engineering program, Table 1 shows detailed dimensions of every element.

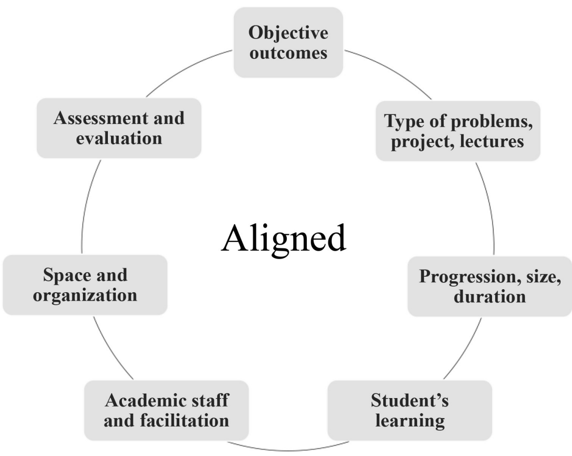

Fig. 1. Alignment of Elements of PBL.

Table 1. Meaning of Curriculum Elements in PBL

Curriculum Element	**Detailed Dimensions**
Objectives and Knowledge	• Methodological objectives of PBL • Interdisciplinary knowledge
Type of Problems, Projects and Lectures	• Open, ill-defined problems • Problem-oriented projects, innovation projects • Lectures supporting the projects
Progression, Size and Duration	• Visible and clear progression • Amount of time of projects and lectures
Students' Learning	• Supporting courses • Construction of knowledge • Collaboration for innovation
Academic Staff and Facilitation	• Training courses • Facilitator/process guide
Space and Organization	• Administration supports • Library supports • Physical space
Assessment and Evaluation	• Individual assessment • Group assessment • Formative and Summative assessment

According to the above table, we learn there is a lot to consider in a PBL implementation process and a lot of variation in PBL practice, and there might even be many more dimensions combined in elements. In contexts of traditional education, such a process also involves organizational changes that interplay between bottom-up and up-bottom and require active participation among students and staff under strong and effective leadership [4, 8]. This also calls for university–industry collaboration that requires synthesized efforts from different stakeholders in developing a co-creation platform, which involves multi-dimensional resources in one framework [34].

4. A Case: A New Bachelor Program on "Big Data + Business Administration" at Northeastern University in China

4.1 *Background on Developing "Big Data + Business Administration"*

In the area of business administration, the impact of big data becomes more and more profound. Big data plays many roles, helps enterprises to meet customers' needs, improves product design, makes quick and accurate responses, and strengthens risk management, etc. [35]. Briefly, big data has become an important strategic resource for enterprises' business development and decision-making that also shapes the trends of educational reforms around the world.

With this background, Northeastern University (NEU) in China started to develop a new four-year bachelor program entitled "Big Data + Business Administration" by a PBL approach in 2018. Since the autumn semester in 2019, the program has been opened to enrolled students. Every academic year, it is planned to include 30 students. It should be noted that in the name of the program, the character "+" does not mean to simply add the two disciplines together; it means to provide a new education that integrates knowledge of big data education into contexts of business administration. The new program mainly draws resources from two faculties at NEU: the School of Business Administration and the School of Software Engineering. In order to support and develop such an innovative initiative, a group of teaching and management staff who come from the two faculties and industries has been formed to bridge disciplines between social science and engineering and between theory and practice.

4.2 Designing "Big Data + Business Administration" with PBL

As mentioned, PBL is applied in the practice of designing the new program. The alignment of diverse elements in PBL, as described in Fig. 1 and Table 1, provides a systematic perspective to the design and basic principles to the development. Meanwhile, as mentioned, an incremental innovation process should be taken into account in a context with a long tradition of disciplinary engineering education like NEU. All these ideas help to structure the following sections.

4.2.1 Objectives and Outcomes

The overall objectives of the new four-year interdisciplinary bachelor program are to cultivate highly qualified engineers, managers, and business leaders who learn solid knowledge, international vision, local sentiment, social responsibility, professional ethics, innovative spirit, management literacy, and the ability to analyze and solve practical problems in relation to big data and business administration. Specifically, in comparison with traditional education on big data or business administration, the above overall objectives show advantages in learning outcomes that can be divided into the following aspects:

(1) Better comprehensive literacy, which includes better political literacy, better moral literacy, better humanistic literacy, and better professional literacy, etc.;
(2) More complete theories and knowledge structure, which include the basic theories and knowledge in data science, business administration, the common analysis techniques and methods for big data, the basic principles and knowledge of humanities and social science, the basic principles, and knowledge of science, etc.;
(3) Stronger learning and practical skills, which include a broader international perspective, stronger sense of innovation, stronger self-learning and continuous learning skills, and the skill to solve practical management problems depending on what has been learned, etc.;
(4) Stronger social skills, such as interpersonal skills, logical reasoning skills, teamwork skills, coordination skills, and communication skills, to solve practical problems and apply creatively what has been learned to analyze and solve practical problems in the business administration area; and
(5) Higher professional competence, which means the candidates who gets their bachelor's degree in "Big Data + Business Administration" will be qualified to engage in innovation management, strategic management, marketing management, operations management, human resource management, and financial management, etc., and will be able to support big data analysis in banks, multinational corporations, IT companies, governments, and other enterprises and institutions.

4.2.2 Progression, Size, and Duration

In order to achieve the learning objectives and obtain satisfactory outcomes, an interdisciplinary PBL model is designed and applied. At NEU, students need to gain 160 credits in their four-year study (eight semesters; one credit equals 16 study hours) to achieve the bachelor's degree. As shown in Fig. 2, there are three parts that indicate different teaching/learning activities along with students' study time. The part on business administration is organized by lectures from semester 1 to semester 7; lectures in the part on big data technology are organized from semester 1 to semester 6; and the part on the interdisciplinary projects are organized from semester 1 to semester 8.

From the curriculum structure, we can see with the progression of education in eight semesters that the study time spent on lectures decreases, while it increases gradually on projects. Before entering universities, most Chinese students have been educated with rote learning models, and freshmen are not very familiar with or even know PBL at all, so the program allocates less project time and offers them more lecture time than the senior students. When the students become more familiar with PBL, their time spent on projects will be gradually increased. Up to the eighth semester, students are expected to spend almost all the time on project

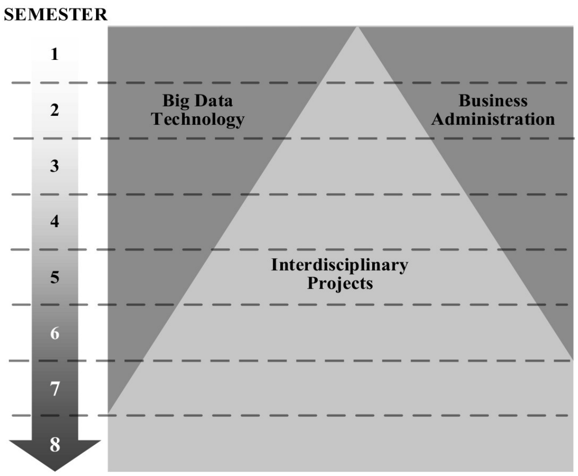

Fig. 2. Curriculum Structure of "Big Data + Business Administration".

work. Based on this basic structure of curriculum, the detailed progression process is planned that indicates different percentages of students' workload between projects and lectures.

From Fig. 3, we can see the first-year students spend 90% of study time in lectures (10% of study time on projects, accordingly), while in the fourth year, students spend approximately 90% of study time on project work (only 10% of study time in lectures). During the period of four-year study, the scale and duration of student projects are designed as continually changing from miniprojects within a single course (in the first academic year) to intercourse projects within one discipline (big data or business administration, in the second academic year), and then finally to interdisciplinary projects of "Big Data + Business Administration" (in the third and fourth academic years). Such an idea will be discussed more in section 4.2.4.

In other words, students are encouraged and facilitated to gradually master interdisciplinary learning skills deeper and deeper. At the beginning of their bachelor study, students are expected to remember and understand theories more than practice; along with the time to last year, they are expected to enhance their abilities and skills to apply, analyze, evaluate, and create by solving real-life problems in project work. At the same time, from an organizational perspective, it always takes energy and time to develop methods for monitoring and evaluating any new interdisciplinary initiatives and efforts, as well as develop new policies, new ways of working and collaboration, and infrastructure necessary to support the changes [8]. Therefore, practically, the design of the progression process allows the changes to happen from easy to more complex, which leaves opportunities for teaching staff and leadership to reflect and take action to move on incremental innovation [36].

4.2.3 Type of Lectures, Problems, and Projects

The problem framing for developing interdisciplinary projects is a collaborative effort among teaching staff and between academics and industries. The designs of project themes are centered on solving real-life problems that require students' group work. All lectures in "Big Data + Business Administration" support students' interdisciplinary projects. In some series of lectures, interdisciplinary teaching groups are formed. For example, in the course "Management of Innovation and Entrepreneurship", there are eight teachers from different departments and industries, while in the course "Practice and Business Digitalization", most lectures are given by company managers or enterprisers who share insightful cases and rich experience of working with big data technologies in their business contexts. Regarding the type of lectures, active learning has been especially designed to move away from the prevalent passive teaching style to involvement of students in the learning process [37]. This includes everything from listening practices that help students absorb what they hear, to short writing exercises in which students react to lecture

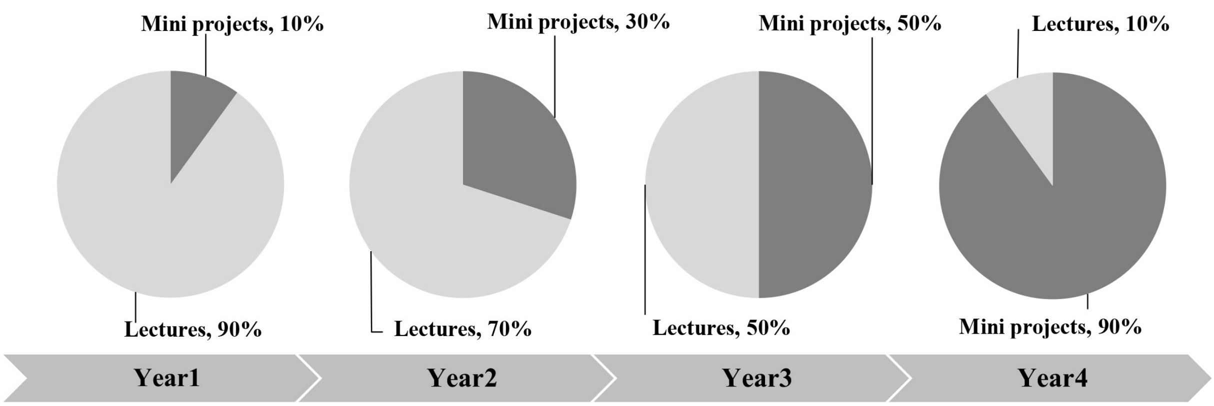

Fig. 3. Progression of Curriculum.

material, and to complex group exercises in which students apply course material to "real-life" situations and/or new problems [38]. In this sense, active learning not only involves engaging with activities, but also encourages students to reflect, analyze, share, evaluate, and communicate information [39]. A series of techniques of active learning is used in lectures [40], such as think-pair-share, collaborative learning groups, student-led review sessions, games, reactions to videos, student debates, case studies, and concept mapping.

4.2.4 Students' Learning

As mentioned, before university education, most Chinese students are used to the passive learning model; the design of lectures, progression of scales, and duration of student projects also aim at helping students to learn not only "what to learn" but also "how to learn". Along with students' active learning experience in lectures, elements of PBL are introduced gradually; for example, group discussion and peer learning are often organized among students during lectures. Relating this to what has been discussed in section 4.2.2, the gradual process of deepening learning skills in the PBL environment involves stages of (a) some PBL elements in lectures, (b) mini projects within a single course, (c) intercourse projects within a discipline, and (d) interdisciplinary projects. As shown in Fig. 4, the gradual process is driven by different stages that have been applied in the program.

Along with the gradual process of developing students' learning skills, from the first academic year to the fourth academic year, the proportion of compulsory courses continually decreases, while the proportion of elective courses continually increases. As shown in Fig. 5, in the first academic year, the proportion of compulsory courses is 62%, while the proportion of elective courses is 38%. However, in the fourth academic year, the proportion of elective courses is 100%, which means students should plan to select courses those are interesting and necessary to learn in order to support their interdisciplinary projects. The gradual increased opportunities of elective courses facilitate "student-centered learning". With more and more ownership of learning, students are expected to gain more and more learning skills, both independently and collaboratively.

It should also be noted that in the beginning of their bachelor study, students have to take a compulsory course entitled "An Introduction to PBL" (2 credits). The course includes theoretical understanding (50%) and project work (50%). In the part on theoretical understanding, students should learn what PBL is, what kinds of roles they need to play in PBL, methods of group management, methods of project management, and so on. All the theories learned should be applied in project work. For example, one of the project themes is "Internet and Human Behavior in Organizations", student project groups are organized by themselves, where each group consists of four to six members. The project groups have to seek their own research questions under given themes, make a project management plan, organize a supervision meeting, manage their group work, and complete a project report. Along with the project work, all students

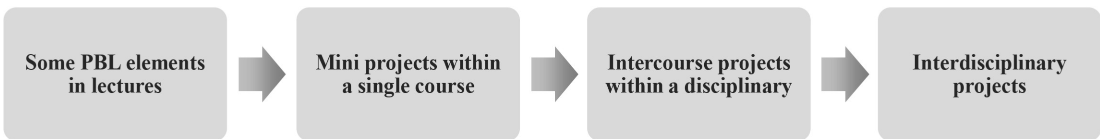

Fig. 4. Gradual Process of Developing Learning Skills.

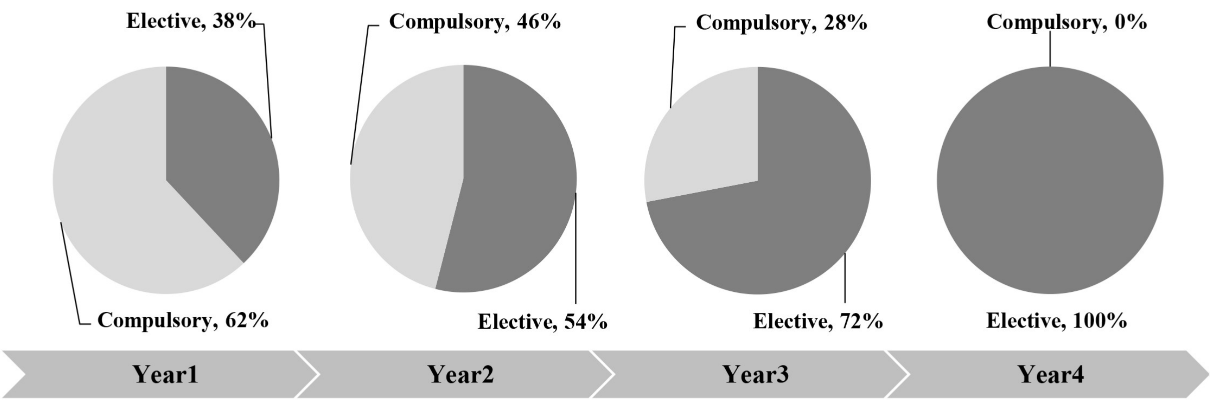

Fig. 5. Proportion of Compulsory and Elective Courses.

also need to participate in an "In-Process Seminar" that invites all groups to present their ongoing work and share their experiences with each other. Teachers in the course are also invited to participate in the seminar to ask questions, provide suggestions, and give comments to student groups for improvement. Additionally, supervisors of student groups are suggested to take the following responsibilities in facilitating students through methods for more effective group learning:

(1) Coordinate the research of group members and individual tasks and support each other in developing joint efforts;
(2) Ensure the development of common results (synthesis) and ascertain that the research ends up with common solutions;
(3) Organize the work within the group by negotiating rights and duties, by discussing the criteria to be used in the evaluation of the processes and the achieved results;
(4) Support group development by discussing the members' expectations of each other as well as concerning the interdisciplinary project, by monitoring the group's working with an eye to possible conflicts due to disciplinary socialization of the individuals involved; and
(5) Facilitate presentation skills and design and monitor internal and external communication by defining the different disciplinary and non-scientific target audiences to be addressed, defining the different media and languages needed to address the target audiences, and discussing specific assignments concerning communication within the group.

4.2.5 Academic Staff and Facilitation

As mentioned, an interdisciplinary group of teaching staff has been formed that delivers lectures and supervises student project work. However, in a traditional Chinese university, in the process of developing a new interdisciplinary program with a PBL approach, one of the biggest challenges for teaching staff is to change from "teacher-led education" to "student-centered learning". As we have discussed in theories of social constructivism, in order to ensure the quality of facilitation of students' learning, NEU has taken measures to equip teaching staff with PBL pedagogical skills. Since 2018, a series of activities on improving the university pedagogy of PBL has been organized. These activities include workshops, seminars, and expert lectures centered on themes of engineering education innovation and interdisciplinary education. Teaching staff have also been encouraged to apply for research funds to improve their daily pedagogical research and practice.

NEU has also explored opportunities to learn how to facilitate staff development in the PBL environment from other cultures. Thus, efforts have been made to develop collaboration with other universities in the global community of interdisciplinary engineering education and PBL. For example, one cross-cultural collaboration is with educational institutions in Denmark that aims to facilitate teaching staff to learn, reflect, and transfer teaching experience of PBL from Danish culture to the local context of NEU. In 2019 and 2020, two groups of teaching staff (a total of 15 individuals) visited the Danish engineering education environment and experienced a half year of cross-cultural participation in a PBL pedagogical training program in Denmark. The following are the key learning goals of participants in such a program:

(1) To gain further insight into understanding theories of teaching, learning, innovative pedagogy methods such as PBL, and philosophies of education;
(2) To master developing, planning, and carrying out suitable teaching and learning activities in interdisciplinary contexts in relation to general and specific educational objectives, the subjects, and the contexts;
(3) To be more skilled to better identify students' learning needs and to initiate learning processes among a variety of students, both individually and in groups; and
(4) To strengthen their own identities as "learning experts" instead of "learning leaders" that ensure their roles of effective supervision to realize the potential of PBL in initiating and supporting students' group and learning processes.

Besides their participation in activities of staff development, teaching staff in "Big Data + Business Administration" must also communicate ideas and share reflections with each other, learn to support each other's emotional dynamics, and foster belief and trust in each other's capabilities. Accordingly, meetings and social activities are organized regularly to keep the dynamic of the teaching group.

4.2.6 Space and Organization

Due to traditional models of education, most architecture styles at NEU have been built mainly to deliver lectures to large classes, and thus most office buildings are located by disciplines. However, a physical space may not always serve only one function. The space should be constantly redefined by the nature of the lesson activities or the lesson microgenres. At NEU, some efforts at rethinking and redesigning the functions of existing spaces, facilities, and resources have been made to align the space with the PBL environment. "Flexibility" becomes a fundamental principle of designing and redesigning spaces at NEU. It means involving multiple users and multiple potential applications, providing a diversified learning environment (physical, virtual, and mixed environments), and strengthening the possibility of space arrangement and re-arrangement. For example, activities such as group discussion, games, workshops, making posters, and student presentations have been easily arranged in large classrooms. Students are also encouraged to make good use of corridors, the library, the dining hall, dormitories, recreation areas, etc.

4.2.7 Assessment and Evaluation

In most courses at NEU, both formative assessment and summative assessment are adopted. The two methods are also applied in the new program. The formative assessment is carried out in the daily learning experience, such as by examining students' presence, performance during lectures, and homework after lectures. Through formative assessment, we can learn students' feedback in time to ensure correct directions of adjustments for more effective teaching. The summative assessment is carried out at the end of courses or project work. In the new program, individual assessment is applied in lectures, which is combined with assessment of group project reports. Diverse perspectives of evaluation are applied, such as student self-evaluation, group members' mutual evaluation, peer evaluation, and teachers' evaluation. Table 2 shows an example that involves different evaluations in the course "Philosophy of Management".

As shown in Table 2, in "Philosophy of Management", besides individual participation in lectures, students should complete two tasks in their group work: one is to finish a problem-oriented project report by which the students should learn to (1) seek and identify a problem, (2) solve the problem by the methods mastered, and (3) reflect on the learning experience from the process of problem-solving; the other one is to work on a case study under a given theme. Based on all the tasks, different perspectives of evaluation are taken into account with different percentages (the total score is 100). Different focuses of abilities and skills are examined among students in different evaluation perspectives. In between learning and assessment, "alignment" is the key principle, which means focuses and methods of evaluation are designed and practiced and should be aligned with characteristics of students' learning activities and learning objectives.

4.3 Discussion: Challenges and Management of Changes

The development of an interdisciplinary program at NEU requires an incremental innovation process in organizational changes that interplays with students, teaching staff, management staff, leaders, and collaborative partners. It requires connecting some previously unconnected resources. However, it is similar to most other Chinese universities, NEU has a long tradition of engineering education with a foundation as a discipline-based institutional system. At present, the resource allocation mode carried out in universities is still based on the relatively solidified single mature disciplines. When new research or teaching areas do not belong to the existing discipline category, the university needs to develop new strategies to allocate resources. This is one of the biggest challenges in the change towards interdisciplinary education at NEU and other Chinese universities.

There are also challenges from a cultural perspective. In the overall environment of Chinese universities, more efforts are required for developing interdisciplinary education and localization of PBL in the long term. As Zhou [8] suggested, in pursuit of "student-centered learning" pedagogies, the traditional relationships between teachers and students should be changed firstly, which means most Chinese teachers should take off their "masks of knowledge authority" given by traditional Confucianism, sit among groups of students together, and encourage students to learn to manage challenges by themselves and support each other [26]. The university management should increasingly consider what staff and students need; the needs include both "hard resources" (e.g., physical space, capital resource, and advanced equipment) and "soft resources" (e.g., methods of knowledge shar-

Table 2. Diverse Evaluation Perspectives in Course Philosophy of Management

No.	Evaluation Perspective		Percent	Focus of Abilities and Skills in Evaluation
1	Individual Attendance		10%	To examine students' basic attitude and behavior of learning
2	Peer Discussion		10%	To examine students' critical thinking and communication skills
3	Group Work	Project Report	15%	To examine students practical problem-solving skills
		Case Study	15%	To examine students interdisciplinary learning abilities and collaborative skills
4	Final Assessment		50%	To examine students' comprehensive learning abilities and skills

ing, collaboration management, and evaluation of workload of staff). Meanwhile, universities should move towards open innovation and increase interactions with multiple stakeholders and partners locally and globally. Universities will not live in "ivory towers" any longer; instead, "being entrepreneurial universities" will be a promising way to gain more research resources from corporations with industries for an increased number of applied projects [8]. This requires better application of the co-creation approach that calls for active participation of and cooperation among different partners who commonly engage in the problem-based interdisciplinary learning communities.

How do we support and facilitate interdisciplinary education and manage cultural and institutional challenges at NEU? In practice, along with the development of a new program, NEU is committed to a series of initiatives that are helpful to make the reforms broader and deeper. In spring 2020, the PBL Teaching Innovation Center was established, which aims to:

(1) Support teaching staff to design new courses and apply diverse methods of PBL;
(2) Manage cooperation between different faculties and departments that moves in the development of interdisciplinary education step by step;
(3) Organize a university pedagogy training program on PBL;
(4) Evaluate the new design, process, and outcomes of courses;
(5) Encourage research areas related to PBL and pedagogy innovation; and
(6) Develop local, national, and international networks.

The Center consists of a leadership group and five staff groups who are senior teachers with rich teaching experience in PBL and who take different management responsibilities categorized by different functions of the Center. Meanwhile, new policies have been issued that motivate teaching staff to engage in "breaking different traditional boundaries", ensure NEU builds a "healthy innovation community", and therefore improve the quality of research, teaching, and learning as well as the quality of coordination and collaboration among learners, researchers, and partners. As Kolmos and de Graaff suggested [16], in the change process towards PBL, both bottom-up and top-down strategies are necessary. There is a need for a faculty development unit. It can be a research-based education center that relates all levels in the organization (the top, middle, and bottom levels); resources enable the unit to act at all levels and promote awareness of the roles of both the faculty development units and the leaders at all levels in the university organization. Additionally, in daily management, self-reflection and self-evaluation should be two key measures along with the process of institutional changes. Doing this, on the one hand, helps to reveal both the strengths and weakness of a university's own pedagogical model and methods adopted; on the other hand, the results of reflection and evaluation further help to identify better strategies for improvement in a timely way.

5. Conclusion

In response to the growing demands of fostering qualified data scientists and engineers who are able to work in interdisciplinary business contexts, this paper discusses a case of a new bachelor program of "Big Data + Business Administration" at NEU in China and attempts to explore how PBL provides a systematic approach to design and develop the program in practice. This leads to rethinking and strategies on how to manage challenges of education reforms in traditional universities. From the case, we learn firstly that there is complexity in the practice of changes towards PBL and developing interdisciplinary education. Traditional universities should consider at least three conditions before the reforms: (1) identify a clear vision of development (e.g., motivation of changes, curriculum goals, selected pedagogies, milestones of development, and potential resources); (2) map diverse factors that hinder the reforms (e.g., staff's identity, institution structure, policy, management system, and historical and cultural issues); and (3) equip teaching, research, and management staff with the required attitude, knowledge, and skills to develop, improve, and evaluate courses, assessments, and programs. Secondly, to facilitate the application of PBL, NEU set up a center to more effectively manage reforms, organize the university pedagogy training program, and facilitate the changes from "teacher-led education" to "student-centered learning". Change is a process that does not take place within a short period of time. In pursuit of continuous improvement, it is important to be able to provide evidence of changes in the students' learning along with the changes in staff capacity. The success of education innovation in the long run depends on the ability of the staff to adapt the new methods to suit their own specific needs and the ability to constantly renew itself in practice. In short, any innovation should be highlighted as a kind of context-based practice, as it occurs in the process of shaping and matching with its context. We cannot define which model is the best without any contextual considerations; however, only the one that adapts to its context is successful. In this sense, diverse models should be encouraged that may provide opportunities for different contexts and cultures to learn from each other in the future.

Acknowledgements – This publication is supported by a number of ongoing research projects: (a) Research and Application of Pedagogy of PBL at Northestern University (NEU) (project ID PBL-JX2021ZD001, NEUJX04103, Key Program, funded by NEU, China), (b) A Complex Adaptive System Perspective to Research Incentive Mechanism of Crowdsourcing Platform (project ID 72172031, funded by the National Natural Science Foundation of China), (c) Intelligent Industrial Data Analysis and Optmization Innovation Base for Introducing Talents of Discipline to Universities (project ID B16009, funded by Plan 111, Program of the Ministry of Education of China), (d) Research on Development of Strategy of Digital Liaoning (project ID XLYC2006009, funded by the Program of XingLiao Talent Plan, 2020, Liaoning Province, China), and (e) Creativity in Technololgy Design: Developing a Sino-Danish Research Network for Future Digital Society (funded by the International Network Program, Ministry of Higher Education and Science, Denmark).

References

1. T. R. Kelley and J. G. Knowles, A conceptual framework for integrated STEM education, *IJ STEM Ed*, **3**(11), 2016.
2. C. Zhou, Integrating creativity training into Problem and Project-Based Learning (PBL) curriculum in engineering education, *European Journal of Engineering Education*, **37**(5), pp. 488–499, 2012.
3. T. Kennedy and M. Odell, Engaging students in STEM education, *Science Education International*, **25**(3), pp. 246–258, 2014.
4. C. Zhou, Developing engineering creativity in STEM programmes in chinese universities, in Z. Zhu and C. Zhou (eds), *Global Perspectives on Fostering Problem-Based Learning in Chinese Universities*, IGI Global, pp. 273–293.
5. A. A. Jensen, D. Stentoft and O. Ravn, *Interdisciplinarity and Problem-Based Learning in Higher Education: Research and Perspectives from Aalborg University*, Springer, 2019.
6. J. A. Ejiwale, Barriers to successful implementation of STEM education, *Journal of Education and Learning*, **7**, pp. 63–74, 2013.
7. D. Dezure, Interdisciplinary pedagogies in higher education, in R. Frodeman (ed),*The Oxford Handbook of Interdisciplinarity*, Oxford University Press, New York, pp. 372–386, 2010.
8. C. Zhou, *Introducing Problem-Based Learning for Creativity and Innovation in Chinese Universities: Emerging Research and Opportunities*, IGI Global, 2020.
9. C. Zhou, A. Kolmos and J. D. Nielsen, A Problem and Project-Based Learning (PBL) approach to motivate group creativity in engineering education, *International Journal of Engineering Education*, **28**(1), pp. 3–16, 2012.
10. C. Zhou and A. Kolmos, Interplay between individual and group creativity in Problem and Project-Based Learning (PBL) environment, *International Journal of Engineering Education*, **29**(4), pp. 866–878, 2013.
11. C. Zhou and L. Krogh, Developing successful group processes in interdisciplinary projects, in A. A. Jensen, D. Stentoft and O. Ravn (eds.), *Interdisciplinarity and Problem-Based Learning in Higher Education: Research and Perspectives from Aalborg University*, Springer, pp. 103–116, 2019.
12. J. Grimon and C. Roughneen, Diversity in engineering: tinkering, tailoring, transforming, in S. H. Christensen, B. Delahousse and M. Meganck (eds.), *Engineering in Context*, Academica, Denmark, pp. 197–220, 2009.
13. L. R. Lattuca, D. Knight and I. Bergom, Developing a measure of interdisciplinary competence, *International Journal of Engineering Education*, **29**(3), pp. 726–739, 2013.
14. J. J. Marquez, M. L. Martinez, G. Romero and J. M. Perez, New methodology for integrating teams into multidisciplinary project-based learning, *International Journal of Engineering Education*, **27**(4), pp. 746–756, 2011.
15. V. Talanquer, DBER and STEM education reform: are we up to the challenge? *Journal of Research in Science Teaching*, **51**(6), pp. 809–819, 2014.
16. A. van den Beemt, M. MacLeod, J. V. der Veen, A. V. de Ven, S.van Baalen, R. Klaassen and M. Boon, Interdisciplinary engineering education: A review of vision, teaching, and support, *Journal of Engineering Education*, **109**(3), pp. 508–555, 2020.
17. W. H. Newell, A theory of interdisciplinary studies, *Issues in Integrative Studies*, **25**(19), pp. 1–25, 2001.
18. K. Kaput, Evidence for student-centered learning, *Education Evolving*, https://files.eric.ed.gov/fulltext/ED581111.pdf, Accessed August 28, 2021.
19. S. Blackley and J. Howell, A STEM narrative: 15 Years in the making, *Australian Journal of Teacher Education*, **40**(7), 2015.
20. C. Zhou, How Ha-Ha interplays with Aha!: Supporting a playful approach to creative learning environments, in T. Chemi, S. G. Davy, and B. Lund (eds), *Innovative Pedagogy: A Recognition of Emotions and Creativity in Education*, Sense Publishers, Rotterdam, pp. 107–124, 2017.
21. D. Yang and S. J. Baldwin, Using technology to support student learning in an integrated STEM learning environment, *International Journal of Technology in Education and Science*, **4**(1), pp. 1–11, 2020.
22. J. Huwer and J. Seibert, A new way to discover the chemistry laboratory: the augmented reality laboratory-license, *World Journal of Chemical Education*, **6**(3), pp. 124–128, 2018.
23. A. Nguyen, L. Gardner and D. Sheridan, Data analytics in higher education: an integrated view, *Journal of Information Systems Education*, **31**(1), 2020.
24. B. R. Lim, Challenges and issues in designing inquiry on the web, *British Journal of Educational Technology*, **35**(5), pp. 627–643, 2004.
25. L. Ivanitskaya, D. Clark, G. Montgomery and R. Primeau, Interdisciplinary learning: process and outcomes, *Innovative Higher Education*, **27**, pp. 95–111, 2002.
26. C. Zhou, Students'perceptions of humor and creativity in Project-Organized Groups (POGs) in engineering design education in China, *International Journal of Chinese Education*, **4**, pp. 189–206, 2015.
27. K. Illeris, *How We Learn: Learning and Non-Learning in School and Beyond*, Routledge, London, 2007.
28. L. S. Vygotsky, *Mind in Society*, Harvard University Press, Cambridge, 1978.
29. A. Collins, Cognitive apprenticeship, in R. K. Sawyer (ed.), *Cambridge Handbook of the Learning Sciences*, Cambridge University Press, New York, pp. 47–60, 2006.
30. R. J. Amineh and H. D. Asl, Review of constructivism and social constructionism, *Journal of Social Sciences*, *Literature and Language*, **1**(1), pp. 9–16, 2015.

31. D. H. J. M. Dolmans, How theory and design-based research can mature PBL practice and research, *Adv. in Health Sci. Educ.*, **24**, pp. 879–891, 2019.
32. A. Kolmos, E. de Graaff and X. Du, Diversity of PBL - PBL learning principles and models, in X. Du, E. de Graaff, and A. Kolmos (eds.), R*esearch on PBL Practice in Engineering Education*, Sense Publishers, Rotterdam, pp. 9–21, 2009.
33. J. E. Mitchell, A. Z. Nyamapfene, K. Roach and E. Tilley, Faculty wide curriculum reform: the integrated engineering programme, *European Journal of Engineering Education*, **46**(1), pp. 48–66, 2021.
34. C. Zhou, Fostering creative problem solvers: a response to complexity of societies, in C. Zhou (ed.) *A Handbook Research on Creative Problem Solving Skills Development in Higher Education*, IGI Global, USA, 2016.
35. I. O. Pappas, P. Mikalef and M. N. Giannakos, et al, Big data and business analytics ecosystems: paving the way towards digital transformation and sustainable societies, *Inf Syst E-Bus Manage*, **16**, pp. 479–491, 2018.
36. J. Proenca and F. Jiménez-Sáez, Design of services for the incremental innovation management in SMEs, *Revista Universidad & Empresa*, **22**(39), pp.1–20, 2020.
37. M. Prince, Does active learning work? A review of the research, *Journal of Engineering Education*, **93**(3), 223–231, 2004.
38. J. L. Faust and D. R. Paulson, Active learning in the college classroom, *Journal on Excellence in College Teaching*, **9**(2), pp. 3–24, 1998.
39. M. Marrone, M. Taylor and M. Hammarie, Do international students appreciate active learning in lectures? *Australasian Journal of Information Systems*, **21**, 2018.
40. R. M. Felder and R. Brent, Active learning: an introduction. *ASQ Higher Education Brief*, **2**(4), 2009.

Lanxia Zhang, PhD, Professor in Department of Organizational Management, School of Business Administration, key member in PBL Teaching Innovation and Research Center, Northeastern University (NEU), China. Lanxia is working as an expert consultant for Liaoning SMEs, and an expert peer reviewer for many research foundations and associations in China, such as National Natural Science Foundation, China Postdoctoral Science Fund, Social Science Fund of Liaoning Province, Association of Modern Management Innovation Achievements of Iron and Steel Metallurgy and China Mining Association. Lanxia has an interdisciplinary education and cross-cultural working experience: she majored Economics in bachelor degree, National Economic Planning and Management in master degree, and Business Management in PhD degree. From May 1998 to June 1999, with support of The United Nations Population Fund, she studied Demography in International Institute for Population Sciences (IIPS), India. From December 2009 to June 2010, she worked as a visiting scholar at York University, Canada. From August 2019 to January 2020, she visited Aalborg University and studied pedogogical methodology of Problem-Based Learning (PBL) in Denmark. Lanxia's main research areas include Organization Behavior, Human Resources Management, Corporate Social Responsibility (CSR), and Strategy Management, etc., with multiple focuses on Work-family Balance, Employee's Innovative Behavior, Job Crafting, and Job Thriving, etc. Among her over 100 peer-review authored and co-authored publications, she is one of editors in *Organizational Behavior* (Tsinghua University Press, China), the author of *CSR Related with Labor Relations in China* (Published in 2013, by Economic Science Press, China), *New Management Theory Jungle* (Published in 2001, by Liaoning People's Publishing House, China). Lanxia's recent interests are PBL and higher education innovation that has led her successful work on *PBL Theory and Practice* (Published in 2021, by Economic Science Press, China).

Chunfang Zhou, PhD, Associate Professor in Department of Mathematics and Computer Science, University of Southern Denmark. She is a leadership member in Center of STEM Education and Science Communication and a member of Center of AI Science and Application. She is a board member of Danish Development Research Network (DDRN), Denmark and works as a senior consultancy in PBL Teaching Innovation and Research Center at Northeastern University (NEU), China. Chunfang has an interdisciplinary and cross-cultural educational background: she finished bachelor degree (Industry Automation and Information Engineering) and master degree (Philosophy of Science and Technology) in China; during 2008–2012, Chunfang finished PhD study on *Creativity, Learning, and Engineering Education Innovation* at Aalborg University, Denmark. Chunfang locates her research in Science, Technology and Society (STS), with a focus on creativity and innovation in learning environments. Since 2013, Chunfang has done cross-cultural contributions to creativity research between China and Denmark, especially by her leading projects of *Fostering Creativity in Higher Education: A Comparative Study on Pedagogical Strategies of Learning by Projects between Denmark and China*, (2013–2016, funded by funded by Ministry of Higher Education and Science, Denmark), *Designing, Participation and Participation of Problem-Based Learning (PBL)* (2018–2021, funded by Northeastern University, China,) and *Creativity in Technology Design: Developing a Sino-Danish Research Network for Future Digital Societies* (2019–2021, funded by Ministry of Higher Education and Science, Denmark). Chunfang has authored and co-authored over 100 peer-review publications; she is the editor of *Handbook of Research on Creative Problem-Solving Skill Development in Higher Education* (published in 2016, by IGI Global), the author of *Introducing Problem-Based Learning (PBL) for Creativity and Innovation in Chinese Universities* (published in 2020, by IGI Global), and one of editors in book series *Arts, Creativities and Learning Environments in Global Perspective*, Brill/Sense Publisher.

Xinbo Sun, PhD, Professor in Department of Organization Management, Associate Dean in School of Business Administration, Director in Global Enterprise Transformation Research Center, Executive Director in EMBA Education Center, Vice Director in PBL Teaching Innovation and Research Center, member of the Undergraduate Teaching Committee, Northeastern University (NEU), China. Xinbo is also working as the Executive Director of the Professional Committee of Organizational Behavior and Human Resource Management in Association of China Management

Modernization Research, and Vice President of the Professional Committee of Management Philosophy under China Enterprise Management Society. He is a key member of the Academic Committee of the Confucius Institute, a member of the Academic Committee of "China-Practice-Management". Xinbo's background is across areas of Industrial Automation, Marketing Administration, Business Administration, Management Science, and Engineering Education. His research interests mainly include Management Philosophy, Data Governance, Organizational and Strategic Management, Leadership and Motivation, and Innovation and Entrepreneurship, etc. His teaching experience covers many themes in Management Philosophy, Principle of Management, Management Philosophy and Leadership, Project Management, Outward Bound, I Ching (The Book of Change), and Chinese Managerial Art, etc. So far he has supervised more than 190 master and Ph.D. students. He has published more than 190 academic articles and more than 20 books and textbooks. He has rich experience of leading and participation of a number of key projects funded by the highest national level of research foundations in China, such as the National Natural Science Foundation and the National Social Science Foundation. He has taken leadership of over more than 60 regional level and university-industrial research projects. Xinbo has particularly done contributions to training courses and programmes of Management Philosophy and Leadership that has benefited to more than 10,000 managers of hundreds of companies in China.