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Interdisciplinary Innovative Talent Training Method and Practice on Modeling and Simulation for Intelligent Manufacturing

Yuanjun Laili[1], Lin Zhang[1,*], Lei Ren[1], Lei Wang[1] and Yang Li[1]

[1]School of Automation Science and Electrical Engineering, Beihang University

[*]Corresponding author. Email address: zhanglin@buaa.edu.cn

Abstract

Modeling and simulation are the key to implement digital and intelligent manufacturing. It is of great necessity to train high-level innovative talents on the interdisciplinary area of modeling and simulation and intelligent manufacturing. This paper proposes a talent training method by bridging three gaps, i.e., the gap between multiple disciplines, the gap between countries, and the gap between students of different grades, and connecting national major requirements and international state-of-the-art technologies. According to tens of years of exploration and trying, an advanced interdisciplinary training system is established. It includes a training chain with multiple angles, an open study and research platform with international organizations, and a collaborative mode with important national projects. It attempts to lead young talents to solve complex industrial problem innovatively, independently, and collaboratively. Practice examples have shown that the proposed method is able to provide full resources for young talents to train their innovation ability, international communication ability, and teamwork ability, and thus raised many talents on the area of modeling and simulation for intelligent manufacturing.

Keywords: Interdisciplinary training system, Interdisciplinary courses, International communication, Industrial practice.

1. Introduction

Intelligent manufacturing means using the combined intelligence of resources, human, and machines, to implement efficient and custom manufacturing. It is both a big system including heterogenous manufacturing capacity that keeps constantly evolving and an advanced manufacturing technology. Intelligent manufacturing is an important direction of the national strategy of several countries [1-5]. Meanwhile, the Defense Advanced Research Projects Agency (DARPA) of the United State has pointed out that modeling and simulation (M&S) is one of the most important technology for intelligent manufacturing.

Currently, high-quality interdisciplinary talent requirement on the area of M&S for intelligent manufacturing is strong in market [6-8]. However, most of the talents focus on a single discipline, such as computer science, or mechanical engineering, or electrical engineering, etc., without enough knowledge in other disciplines. Few engineers have enough ability and knowledge on both M&S and intelligent manufacturing, which limit the development and implementation of intelligent manufacturing systems. Therefore, it is of great importance to train interdisciplinary innovative talents who have sufficient skill on both M&S and intelligent manufacturing. These talents are expected to establish more efficient intelligent manufacturing system and make precise system analysis and control using simulation models [9][10].

On account of the above drawbacks, this paper proposed a training method by bridging three gaps and connecting national major requirement and international state-of-the-art. It is the training experience from tens of years of exploration and involves three main actions. First, a training chain is re-established through three dimensions, i.e., introducing international quality courses, introducing international teams of experts, and applying multi-level flipped classroom. This action aims at cultivating student's innovation ability during the training process. Second, an open study and research platform is initiated depending on international society, international conference, and international student forum. The platform targets to connect students to international state-of-the-art and the related organizations. Third, a collaborative mode is promoted to encourage senior students and low-grade students together to solve engineering problems from important national projects and national requirements. This mode is presented to help the students to improve the ability of team collaboration and the ability of applying new theory to practice. Some training results have shown that the proposed method is able to provide full resources for young talents to train their ability from different angles, and thus raised many talents on the area of modeling and simulation for intelligent manufacturing.

This paper is organized as follows. Section 2 provides the mainframe of the proposed interdisciplinary innovative talent training. Sections 3 to 5 give the details of the method from three level, i.e., the training chain, the international platform, and the collaborative mode. The practical achievements and outstanding cases are summarized in Section 6. Conclusions are drawn in Section 7.

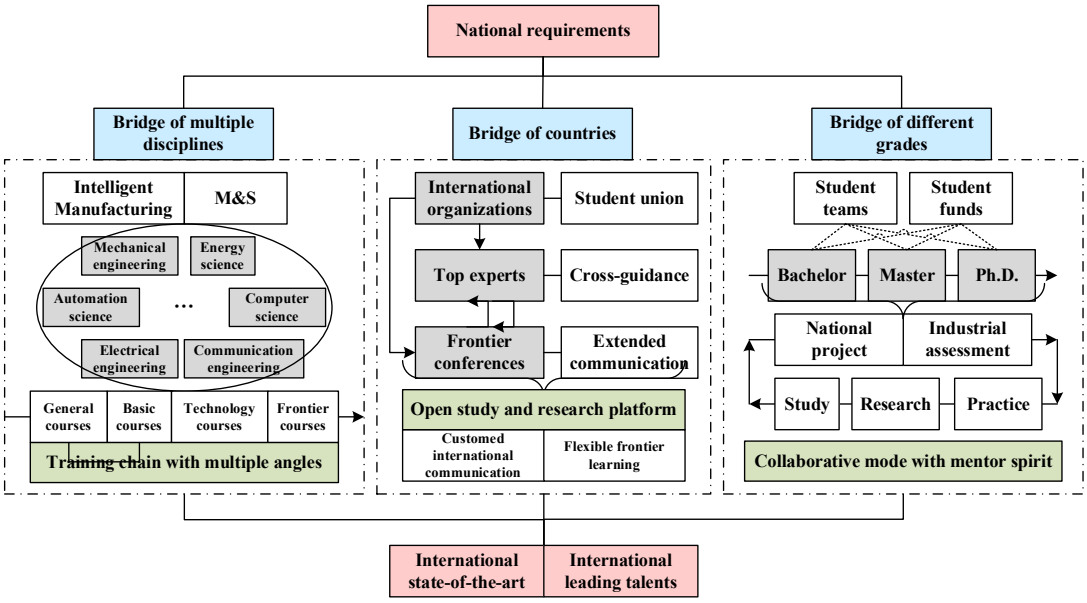

Figure 1. The mainframe of the interdisciplinary innovative talent training

2. The mainframe of the interdisciplinary innovative talent training

A The mainframe of the interdisciplinary innovative talent training method is demonstrated in Fig. 1. It connects important national requirement, and establish the training system by bridging three gaps:

1. Bridging the gap between multiple disciplines: Based on the basic course of automation science, mechanical engineering, computer science, electrical engineering, and so on, ten featured courses of M&S for intelligent manufacturing are created, including two general courses, one interdisciplinary theory courses, two interdisciplinary technology courses, two interdisciplinary frontier courses, and two international quality courses. These ten courses are lectured by local professors and international experts, who give a broad and advanced view on "the general concepts, the theories, and the practices" of M&S for intelligent manufacturing. They are open for both undergraduate students and graduate students.
2. Bridging the gap between countries: First, an international academic exchange mechanism is constructed by introducing international first-class experts in the area of M&S and intelligent manufacturing. Then, a student union is established as a branch of the international academic organization. In addition, students are encouraged to initiate their own forum on international conferences to do keynote speech and topic discussion. These three aspects together form a wide road for international exchange, and thus provide a more flexible way of studying the state-of-the-art.
3. Bridging the gap between students of different

grades: This method encourages students to find key problems from important national requirements and form their own teams to apply student projects and funds. From the important national projects and the student projects, students can learn the rule of project management and the way of problem solving. It is the best way of training students to connect the theories to practices and make more innovations. It is also the best way of cultivating the team collaborative spirit and the team leading ability for both undergraduate students and graduate students of different grades.

3. A training chain with quality courses

The training chain includes eight quality courses, two international courses, and an international seminar, as shown in Fig. 2.

3.1. Local quality courses

The eight local quality courses on the M&S for intelligent manufacturing are shown in Fig. 2. There are three undergraduate courses, cloud manufacturing and industrial 4.0, information system integration, and virtual modeling and 3D printing. These three courses focus on the general concepts of advanced manufacturing system, the general knowledge on integrated information system modeling, and the technology of establishing virtual simulation model for product and manufacturing equipment, respectively. They can lead undergraduate students to the world of advanced manufacturing system, the requirement of M&S in manufacturing system, and the simple modeling technologies to establish virtual prototype of the key elements in manufacturing system.

For master students who require more advanced skills, three graduate courses are established, including two general courses, i.e., intelligent manufacturing system, advanced simulation technology, and one interdisciplinary technology course, i.e., industrial internet-of-things. The first two general courses provide the newest concepts, technologies and practices of intelligent manufacturing system and M&S to master students, while the last one introduces the key technologies of connecting M&S and intelligent manufacturing system to support industrial internet-of-things. The structure of an intelligent manufacturing system, the interconnection of industrial equipment, industrial big data [11-14], cloud computing for manufacturing, the optimization of manufacturing system [15-17], and the theory and practice of M&S for complex product, manufacturing equipment, manufacturing workshop, and the whole manufacturing system are demonstrated step by step.

The primary way of carrying out the above six courses are flipped classroom. To be specific, the concepts and basic theories are introduced firstly. Then, typical problems are presented in the classroom to guide undergraduate students and master students to brainstorm new possible approaches to solve the problems. The students are encouraged to provide new scheme with the introduced interdisciplinary theories and technologies to implement new function, and thus enhance their professional knowledge and innovation ability on the interdisciplinary area.

In addition, two interdisciplinary frontier courses are constructed mainly for Ph.D. students who are expected to have wider knowledge on frontier theories and technologies of M&S for intelligent manufacturing. The two interdisciplinary frontier courses are intelligent manufacturing and simulation frontier and advances in industrial internet-of-things. The newest platform frameworks, the advanced AI technologies, useful optimization methods, popular products on M&S for intelligent manufacturing, and typical practices and platform solutions are discussed with the Ph.D. students.

The teaching method of the two Ph.D. courses are inspiring students go through the process of "challenge – theory & technology research - practice". Challenges come from national projects and enterprise requirements. Ph.D. students in the classroom are inspired to find and improve the newest methods in automation science, computer science, mechanical engineering, and electrical engineering, and so forth, to overcome these challenges.

The above courses are open for all students from different grades and encourage students of different grades to solve the problem proposed in the classroom collaboratively.

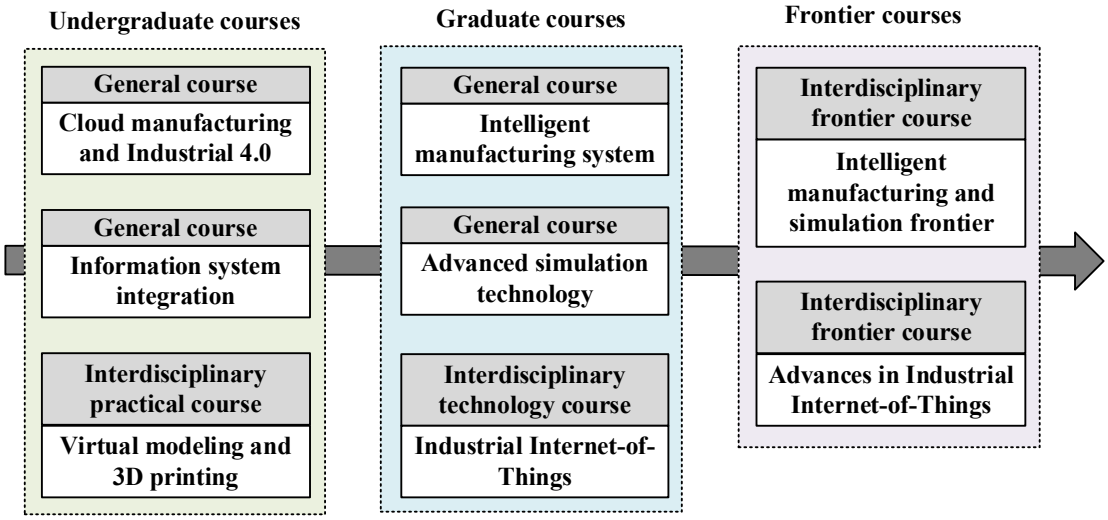

Figure 2. The training chain with eight interdisciplinary courses

3.2. International quality courses

To further improve the international level of interdisciplinary training and provide an English teaching environment, two international quality courses are introduced. They are discrete system simulation and applications and basics of computer-based modelling and simulation: methodologies, technologies and applications, which are taught by renowned professors including the former chairman of The Society For Modeling and Simulation International (SCS) and the Fellow of SCS.

The two courses have 24 class hours and are worth 1.5 credits. The first one primarily faces to undergraduate students, which focuses on one kind of typical simulation application, i.e., discrete system simulation, and provides classroom teaching and experiment teaching. It starts from queuing theory and introduces the basic method of discrete simulation for queuing system. It also introduces the use of typical discrete system simulation software. The second course, facing to both undergraduate students and graduate students, is the extension of the first one and introduces more general concepts and methods for discrete system simulation.

Students can discuss with the renowned professors about not only the teaching content, but also the application of simulation technology in industries and the business opportunities and employment of the interdisciplinary talents in different countries. The renowned professors bring different ways of teaching, such like topic debate, oral presentation, and practical programming, to improve the theoretical level of the interdisciplinary talents and their English proficiency.

3.3. International seminar

To broaden the horizon of interdisciplinary students, tens of leading experts from both academy and industry are invited to the university to initiate international seminars. These experts include foreign scientist of Chinese Academy of Sciences (CAS), Fellow of the Royal Canadian Academy of Sciences (RCAS), Fellow of the Royal Academy of Engineering, IEEE (Institute of Electrical and Electronics Engineers) Fellow, SCS Fellow, SME (Society of Mechanical Engineers) Fellow, and ASME (American Society of Mechanical Engineers) Fellow, etc. Students are encouraged to volunteer the events they are interested, present their research topic, and research progress, and have active face-to-face discussion with these experts.

4. An international open study and research platform

The international open study and research platform includes an international student union and a student channel for international conferences.

4.1. International student union

Students tend to have the inertial thinking of working alone behind closed doors, making it difficult to truly achieve personalized training, and leading to insufficient comprehensive ability and collaboration. To solve the above problems, in 2011, a student branch was established depending on SCS, which is also the only student branch of the SCS in China. All graduate students are encouraged to join this union. They have a steady chance to interact with students from other student unions in more than a dozen countries. As the administrators of the branch, students have frequently hosted and participated in their own academic seminars and various academic activities. In doing so, students became more energetic and motivated, bringing problems that have encountered in the process of theoretical research and projects to the seminars, where they can collaborate and discuss freely. The SCS student union has also received many

visits from the SCS student union of other countries.

4.2. Student channel for international conferences

Interdisciplinary student forums are held annually depending on the series of Simulation Conferences of SCS, the Asian Simulation Conference, the European Modeling and Simulation Conference, the series of conferences of CIRP (The International Academy for Production Engineering), the series of industrial informatics conferences of IEEE, and other high-end international conferences in the field of manufacturing and simulation. In these forums, students act as chairmen, give keynote speeches, and invite experts to comment.

Based on this, students are sent to participate in various international academic conferences every year. graduate student will go abroad to participate in international academic conferences and give academic reports at least once during their academic years.

5. A collaborative mode with important engineering problems

The collaborative mode is established through leading students to participate national project, guiding students by diversified assessment, and constructing mentoring spirit between different grades of students. The three aspects are carried out with important engineering problems to be solved by strong interdisciplinary skills.

5.1. Participation of national projects

Focusing on major national needs, students are encouraged to participated into national projects, such as national 863 projects "Research on Key Technologies of Cloud Manufacturing Service Platforms" and "Key Technologies and Applications of Cloud Manufacturing Service Platforms", national key R&D (Research and Development) project "Complex Product Modeling and Simulation System", national industrial Internet innovation and development project "Industrial Internet Edge Computing and Intelligent Modules", and some NSFC (National Natural Science Foundation of China) projects. Based on these national projects, national core enterprises in the aerospace, aviation, and shipbuilding fields open up long-term major project cooperation channels for students.

In such environment, students are encouraged to actively participate in projects in the form of teams. They are inspired to post new questions from major national projects and engineering practices, and eventually address thematic seminars to discuss methods and ideas for solving problems together.

The seminars are held weekly, with "problem focused guide - brainstorming - project argument" as the main process, allowing students to regroup based on the research content, and on the basis of the technical route designed by the instructor, propose new designs and solutions, apply their theoretical knowledge to practice, and organizing multi-stage study and practical program demonstrations to advance the scientific research and promote the completion of the project through forms like formula derivation, experimental data analysis and etc.

5.2. Diversified assessment

A diversified assessment mechanism and formulated detailed incentives are also established to encourage students to develop in a characterized way based on their own strengths. Students who have made achievements in publishing academic articles, applying for patents, developing software and hardware systems, participating in engineering projects, scientific research management, and public welfare services will be rewarded.

In order to encourage continuous innovation, we have established evaluation indicators for scientific research practice for the students who take in-depth participation in major projects. For subdivided research and industrial application scenarios, students are encouraged to carry out iterative updates based on the hardware and software module resources established by the predecessors, and set the reachable requirements of module performance, accuracy, stability and timeliness. The instructors also align the research process with the requirements of students' graduation thesis, record the update methods and update processes of different modules, implement periodic assessments, allowing students to achieve cross-innovation based on previous research, and cultivate students to pursue the truth and overcome difficulties in science spirit, and the craftsmanship of striving for perfection and pursuing excellence.

5.3. Mentoring spirit construction

Extract scientific questions from major projects and break down them, from the three steps of "proposing problems - program design and demonstration - solving problems", we advocate the mentoring spirit, guiding the upper grades to lead the lower grades, and allowing undergraduates and graduate students to collaborate together, and actively apply for the school's postgraduate student innovation practice fund, doctoral student innovation fund and the academic excellence fund for PhD students, etc.,

Students are also encouraged to set up their own project teams to achieve mutual assistance in project application, technical design, project implementation, research report, and project closing report. In this way, interdisciplinary talents are cultivated with both the abilities to raise questions and the overall quality of problem solving. At the same time, a management system is built to record the research results of previous postgraduate students so that latter students can easily check and learn what previous graduate students did in the laboratory.

Figure 3. The classroom of the international quality courses

6. Main achievement and outstanding cases of the proposed method

6.1. Featured training chain are applauded

The eight local quality courses of the M&S for intelligent manufacturing have been developed for about ten years and are updating continuously. The number of students of each course has been increased from 60 to more than 120. Many students have found their own research direction for Master thesis or Ph.D. thesis from the courses.

The two international quality courses have been introduced for night years. Now, they have been developed as a mixed-teaching mode with both online and offline classrooms and been involved into international summer course that open to all local students and international students in Beihang University. Fig. 3 shows the classroom of the international quality courses.

The international seminar has been carried out for more than 40 times with different renowned scientists. With these discussions, students can collaborate with their mentors/instructors and the renowned scientists. They have published over eight books/monographs and over 20 high-level academic papers with these scientists.

This training chain with quality courses has been promoted to other universities, such as Xidian University (as a quality course "intelligent manufacturing") and Beijing Information Science and Technology University (as two experimental courses, i.e., "Industrial robot assembly and experiment" and "Product design, modeling and 3D printing").

The author Lin Zhang has also been employed as an international instructor of the graduate students of "Industrial Enterprise Engineering and Technology" in University of Genoa. In addition, he has introduced this method to the new Master's degree program for "Industrial Technology for International Strategy and Security" in University of Genoa, as shown in Fig. 4. As a former chairman of SCS, the author Lin Zhang is devoting to promote this training chain and teaching system to the international standard course system of M&S. He has introduced the development of M&S and the related training system, as shown in Fig. 5, in the chapter "M&S as a Profession and Discipline in China (Lin Zhang, Yingnian Wu, Gengjiao Yang)" of the book "The Profession of Modeling and Simulation (Editors: Andreas Tolk, Tuncer Ören)".

Figure 4. the Master's degree program for "Industrial Technology for International Strategy and Security" in University of Genoa

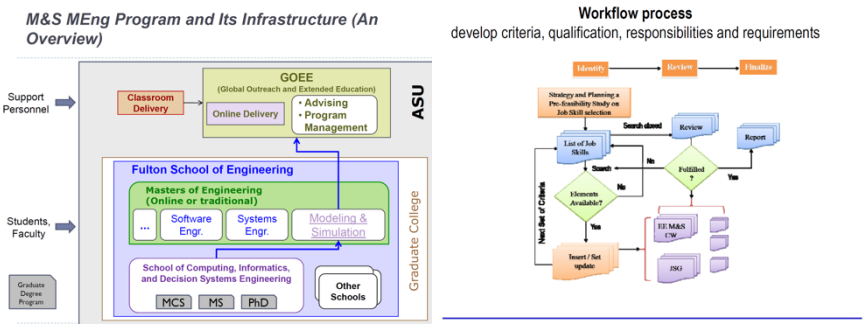

Figure 5. The construction plan of the international M&S training system

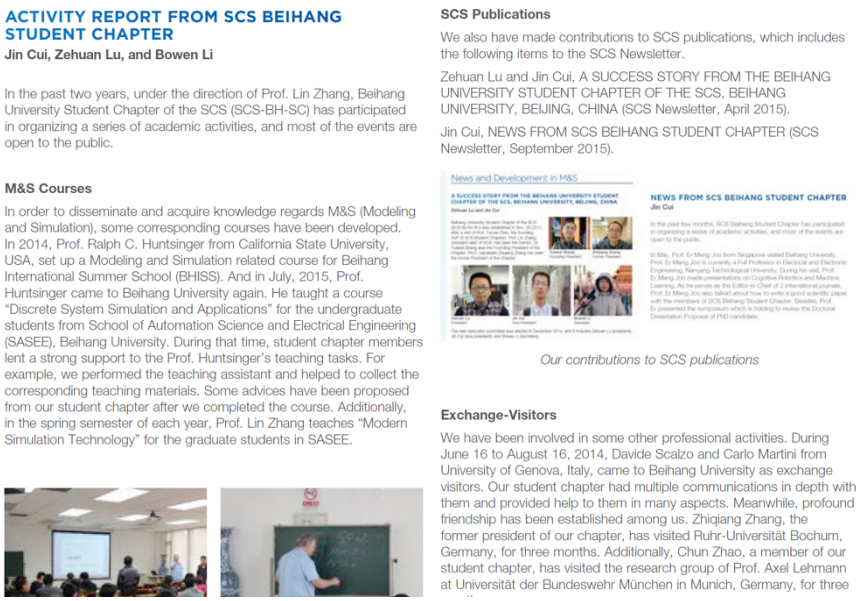

Figure 6. SCS report on the SCS Student Union of Beihang University

6.2. International open study and research platform are promoted

The activities held and participated by the SCS Student Union of Beihang University have been reported by SCS Newsletter many times, which has burnished the international image of BUAA students. December 2013 issue of SCS M&S Newsletter reported on the front page of the activities and achievements of the SCS Student Union of Beihang University, as shown in Fig. 6

According to the student channel for international conferences, eight students have either won or nominated for the Best (Excellent) Thesis Award nine times in the European Modeling and Simulation Conference, the Asian Simulation Conference, the International Conference on Enterprise Systems, and the China Simulation Society, etc. In this process, students not only toughened the ability of international academic exchanges, but also promoted innovative research, to achieve further improvement in the exchanges on international platforms.

Figure 7. An example of students' seminar

Figure 8. Mentoring spirit construction through students of different grades

6.3. Collaborative mode inspires more achievements

With the participation of national projects, students are responsible for writing seminar notes, projects news, research, and lab reports, as shown in Fig. 7 for example. According to these summaries, they applied for 49 invention patents (23 of which are authorized) in interdisciplinary directions. Furthermore, many graduate students have published top journal papers during their master's or Doctoral period.

Encouraged by the diversified assessment, students have created a number of first completed achievements in the research of cloud manufacturing and simulation system: the first cloud manufacturing invention patent (ZL201010132146.3) was approved, the first cloud manufacturing platform prototype system (2015SR047401) was developed. They participated in the formulation of the national standard for the implementation of cloud manufacturing service platform applications (GB/T 37960-2019).

In response to our country's shortcomings in the modeling language of complex systems, we carried forward the spirit of teamwork, dared to fight coronavirus battles, and overcame all the difficulties caused by the epidemic. The students and mentors hold video conferences once a week, which lasted nearly a year, and designed the first intelligent integrated modeling language for complex system simulation and formed a draft of national standard.

Moreover, through mentoring spirit construction, students under this collaborative mode and guidance have successively approved six innovation practice from funds for postgraduates (two were rated as excellent), three from innovation funds for doctoral candidates and one from academic excellence fund for postgraduate.

6.4. The talents and awards

In summary, according to the proposed method, the team supervised 29 doctoral students, 60 master students, and 86 undergraduates. Among them, two doctoral students won the Excellent Doctoral Dissertation Award of the China Simulation Federation, and one doctoral student nominated the Excellent Doctoral Dissertation Award of the Institute, 2two master student won the school-level excellent master thesis award, one master student won the excellent master thesis award of the institute, six postgraduate students won the national scholarship, one doctoral student won the Kwang-Hua scholarship, two students won the Yuyuan scholarship, and six students Received SMC scholarship. The team also trained two outstanding graduates of Beijing city, two outstanding graduates of Beihang University, three merit students of the school, and four outstanding student leader of Beihang University. Undergraduates have won the FengRu Cup second prize three times and the third prize three times, one Honorable Mention Award in the American International College Student Mathematical Modeling Competition, four projects were selected as the National College Student Innovation and Entrepreneurship Training Program and two projects were selected as the Final Thesis of Cross Training (entrepreneurship) of Beijing High Level Universities Talents.

7. Conclusions

This paper introduced an advanced interdisciplinary training system for the development of M&S for intelligent manufacturing. A training chain with eight local quality courses, two international quality courses, and an international seminar series was established. An international open study and research platform with international student union and student channel for international conference was constructed. A collaborative mode was also promoted based on national project, diversified assessment, and mentoring spirit construction. This method has been proved to be able to provide various resources for students to train their comprehensive abilities and thus raises many leading talents on the area of modeling and simulation for intelligent manufacturing.

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