



# Fundamentals of Missile Propulsion and Flight Mechanics Based on CDIO Curriculum system construction and practice

Kai Qu\*, Jiachen Feng, Jinfei Li, Xu Guan, Jingru Huang

Navy Aviation University, Yantai, 264001, China

\*Corresponding author: qu\_kai\_1980@sina.com

**Abstract.** With the continuous renewal of modern education and teaching ideas, teaching objectives are increasingly focused on how to improve students' comprehensive ability and quality. However, as a basic course for aerospace majors, "Fundamentals of Missile Propulsion and Flight Mechanics" has many prominent problems, such as too many basic knowledge points, abstract concepts and formulas, and not close connection between course content and equipment. Students in the learning process are not high enthusiasm, poor learning effect, ability and quality cannot effectively improve. Aiming at the problems existing in the course teaching, combining with CDIO (Conception, Design, Implementation, Operation) engineering education training mode, the course teaching is redesigned and planned. The teaching practice of the course has proved that the introduction of CDIO teaching concept into the course teaching has stimulated students' learning motivation, and students' abilities and qualities in basic theory, hands-on practice and teamwork have been comprehensively exercised and improved.

**Keywords:** course teaching, teaching mode, teaching reform, CDIO.

## 1 Introduction

In recent years, with the rapid development of aerospace technology and the continuous updating of weapons and equipment, the construction of aerospace courses has been paid more and more attention by military academies. Fundamentals of Missile Propulsion and Flight Mechanics, as a professional basic course in this field, plays a vital role in improving students' professional quality, learning follow-up professional courses and adapting to the development of sophisticated weapons in the future. This course system integrates the main knowledge points of traditional mechanics basic courses such as engineering thermodynamics, aerodynamics and flight mechanics. However, it is difficult for students to learn the relevant content, and the traditional teaching mode and teaching conditions can no longer meet the learning needs of students and fail to reach the expected teaching objectives. The course has the following outstanding problems:

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I. A. Khan et al. (eds.), *Proceedings of the 2024 3rd International Conference on Humanities, Wisdom Education and Service Management (HWESM 2024)*, Advances in Social Science, Education and Humanities Research 849, [https://doi.org/10.2991/978-2-38476-253-8\\_15](https://doi.org/10.2991/978-2-38476-253-8_15)

1. Curriculum teaching is not closely combined with active weapons and equipment, and the generation of combat effectiveness of directly serving troops is insufficient.

2. The experimental teaching of the course is monotonous, and some experimental phenomena are abstract, which is difficult for students to understand and master.

3. Course teaching cannot effectively improve students' comprehensive knowledge application ability, practical exploration ability and teamwork ability.

4. Students lack enthusiasm and poor learning effect in the learning process.

Therefore, it is of great significance to reform the existing course teaching mode reasonably. At the same time, CDIO teaching mode has been successfully applied in the curriculum reform of different majors in dozens of famous universities around the world, and a new wave of reform has started in China. Shantou University and other pilot universities have made joint efforts. CDIO education reform has achieved significant results [1-6]. This new educational concept of CDIO also has important guiding significance for the teaching reform of "Fundamentals of Missile Propulsion and Flight Mechanics".

Therefore, the project team through constructing for missile engineering background, office needed to advance and flight mechanics knowledge for the course system of traction, introducing the CDIO teaching mode, to promote the teaching reform of students professional foundation courses, increase practice teaching link, strengthen the contact forces and equipment, enhance the capacity of students comprehensive quality, and military positions.

## 2 CDIO talent cultivation mode

As an advanced engineering education concept and innovative talent training mode, CDIO was first proposed and advocated by MIT, Linkping University, Royal Swedish Institute of Technology, Chalmers Institute of Technology and other four universities in Sweden. The main theoretical basis of CDIO comes from the "learning by doing" of John Dewey, a famous American pragmatist philosopher, educator and psychologist. "Learning by doing" is Dewey's educational thought on the basis of criticizing traditional school education and building on pragmatism, which emphasizes students' instinct and interest. "Learning by doing" means learning from practice, learning from experience, linking the knowledge acquired in school to the activities in life. Dewey believed that "learning by doing is a better way to learn than by listening", which conforms to the law of human cognition of objective things [7-11].

After continuous practice and improvement, CDIO has put forward the corresponding teaching syllabus. For the first time, the outline expresses the basic engineering knowledge, personal ability, team work ability and CDIO whole-process ability that engineers must possess in a step-by-step manner, so that the engineering education reform is more clearly oriented and systematic, as shown in Figure 1 [11]. Generally speaking, CDIO mode is a talent cultivation mode with "ability cultivation" as the main line. This teaching mode can well solve the problems in the current talent training in colleges and universities, such as paying more attention to theory teaching than

practice, students' high expectations and low skills, and the weak ability of combining theory with practice.

The curriculum teaching concept of CDIO<sup>[12]</sup> was introduced into classroom teaching, that is, concept-design-implementation-operation based on project or product research and development process. This teaching philosophy emphasizes "learning by doing". "Learning by doing" is Dewey's educational thought on the basis of criticizing traditional school education and building on pragmatism, which emphasizes students' instinct and interest. "Learning by doing" means learning from practice and experience, connecting the knowledge acquired in school with the activities in life. Dewey believed that "learning from doing is a better way to learn than listening", which conforms to the law of human cognition of objective things<sup>[13]</sup>.

In the concrete implementation process of course teaching, we pay attention to the whole process from theory to practice. After adopting this teaching mode, the enthusiasm of students has been greatly improved. Driven by project tasks, we really realize the transformation from "I want to learn" to "I want to learn". In the practice link of the curriculum knowledge system, the practice of "three levels" of theoretical research, structural principle and design, processing and manufacturing is established to enable students to "see and learn", "do and learn" and "use". The full combination of information technology and CDIO teaching concept inspires students' learning desire and achieves a good learning effect.

### 3 Cdio-based curriculum reform practice

#### 3.1 Refer to the CDIO outline to clarify course knowledge, ability training objectives and corresponding training links

Draw lessons from shantou university curriculum archives system and take the "Fundamentals of Missile Propulsion and Flight Mechanics" as the foundation, according to the index system of three-level refinement of this course, students need to master professional knowledge and degree, need to develop the ability and degree, and master the knowledge and ability requirements of the teaching, classroom teaching, experiment, discussion, comprehensive practice project, etc.). The professional knowledge and degree required for this course are shown in Table 1, in which Bloom's definition of cognitive level is adopted. From low to high, there are six levels of cognitive, understanding, application, analysis, synthesis and evaluation, which are represented by numbers 1-6 respectively.

**Table 1.** Course professional knowledge, master degree and training link

Level 1	Level 1	Level 3	Degree
The base theory of course	Fundamental law of thermodynamics	An expression for the fundamental law	2
		The conditions under which the fundamental law holds	2
		Application of the fundamental law	3
	Fundamental equations of gas dynamics	The expression for the fundamental equation	2
		The conditions for the fundamental equation	2

Level 1	Level 1	Level 3	Degree
		Application of fundamental equations	3
		Basic assumptions and thermodynamic relationships	2
	Nozzle theory	Calculation of one-dimensional isentropic flow in nozzle	3
		Nozzle configuration and nozzle flow loss	2
		Transformation of coordinate systems	2
	Flight performance	The relation between force and fundamental motion	2
		Missile trajectory programming simulation	3
	Thermodynamic calculation of rocket engine	Basic equations for thermodynamic calculation	2
		Thermodynamic calculation method for rocket engines	3
		Analysis of thermodynamic calculation results	3

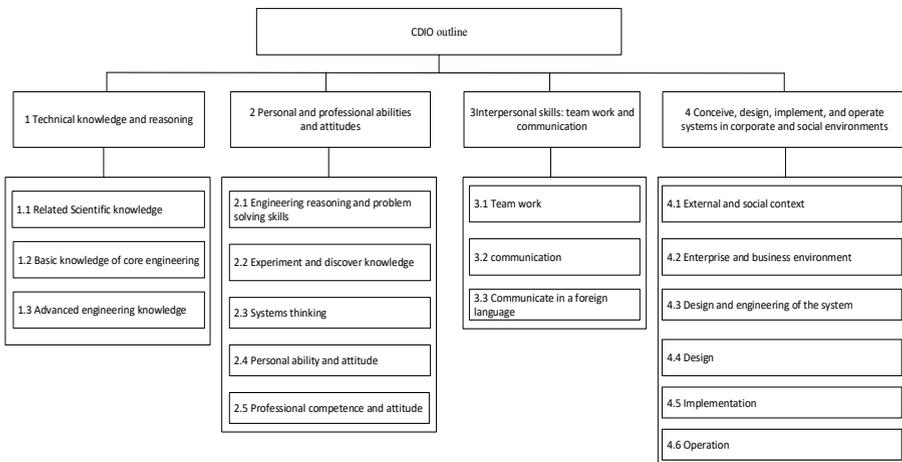


Fig. 1. CDIO mode outline

In terms of training students' abilities (team ability, communication ability, practice and problem solving ability), we refer to the training program of aerospace Engineering major of MIT and The United States Naval Academy, and adopt the ability training target system stipulated in the CDIO teaching syllabus in combination with the characteristics and requirements of this course. Under the three first-level indicators of personal skills and vocational skills, interpersonal skills and CDIO system ability, the second-level and third-level indicators that can be closely combined with the teaching content of this course are selected for training, and the training links are defined.

Compared with the traditional curriculum standards, the CDIO engineering education mode has more specific knowledge and ability training objectives, and the related links that reflect core knowledge and ability training objectives are also synchronized and clear. Not only have a goal, but also know how to get there. As far as this course is concerned, in addition to the practice and problem solving abilities that are emphasized together with the curriculum standards, the pilot project adds the training requirements and links of team ability and communication ability (written communica-

tion, electronic and multimedia communication, graphic communication, oral expression and interpersonal communication), which are shown in Table 2.

**Table 2.** CDIO-related abilities and training links

Level 1	Level 2	Level 3	The main part
2. Personal skills and professional skills	2.1 Engineering reasoning and problem solving	2.1.1 Discovering and expressing problems	Teaching; Practice project; Group experiment; Group discussion 1,2
		2.1.2 modeling	
		2.1.5 Solutions and Suggestions	
	2.2 Experiment and discovery knowledge	2.2.2 Querying paper and electronic literature	Practice project; Group discussion 1, 2; Assignment 1
		2.2.3 Experimental exploration	Practice project; Group experiment; Group Discussion 2
	2.4 Personal Skills and attitude	2.4.1 Initiative and willingness to take risks	Teaching; Practice project; Group Discussion 2
		2.4.4 Critical thinking	
		2.4.6 Thirst for knowledge and lifelong learning ability	
	2.5 Occupational Skills and ethics	2.5.1 Professional ethics, integrity, responsibility and responsibility	Practice project; Group discussion 1, 2; block
	3. Inter-personal skills	3.1 Teamwork	3.1.1 Build an effective team
3.1.2 Team operation			
3.2 communication		3.2.3 Written communication	
		3.2.4 Electronic and multimedia communication	
		3.2.5 Chart communication	
		3.2.6 Oral expression and interpersonal communication	
4.CDIO system ability	4.3 System design and engineering	4.3.1 Oral presentation	
	4.4 design	4.3.2 PPT report	Practical project (Laval nozzle design)
	4.5 implementation	4.3.3 Processing and production	
	4.6 operation	4.3.4 Experimental verification	

**3.2 According to the requirements of ability training, relevant teaching contents are integrated and practical teaching links are designed**

Integrate relevant teaching content, design discussion topics and comprehensive practice projects, teach students how to solve problems through practical teaching links, and exercise students' abilities. Especially in the comprehensive practice program, students experience a complete process of conception, design, implementation and operation, and improve their practical ability and application knowledge to solve problems.

1) Discussion topic design: The main purposes of setting up the seminar are :(1) let students experience the research process and master the analytical research methods

preliminarily; (2) Exercise students' ability to use theoretical knowledge to analyze practical problems; (3) Cultivate students' ability of teamwork, independent exploration, literature inquiry, communication, technical report writing and other abilities.

Two research topics were designed for this pilot. The first is the calculation and analysis of the nozzle parameters of navy missile engine. The second seminar is the relationship between ballistic flight and flight course.

2) Comprehensive practice project design: Using project-based teaching, students can "learn by doing", so that students from passive learning to active learning, overcome the disadvantages of "cramming and forgetting after the exam", so that students have a deeper understanding of the knowledge learned, truly achieve "learning to practice". The design of the project must be comprehensive, feasible and open, that is, the comprehensive use of the knowledge of this course (including the prerequisite course), the difficulty of the project is appropriate to be completed by students through efforts, in the case of the design goal is determined by students to choose reasonable parameters, personalized design results are given.

This pilot comprehensive practice program mainly allows students to experience the process of project conception, design, implementation and operation, and cultivate their CDIO system ability. Therefore, under the content and requirements of the curriculum standards, combined with the construction of 2110 laboratory, the comprehensive practice project "Laval Nozzle Design" was designed for 8 class hours. Considering that the practical links such as seminars and comprehensive practice projects will occupy more extracurricular time of students, and some knowledge and application have been reflected in these links, in order to reduce the extracurricular burden of students, the extracurricular homework will be reduced from 30 times and 49 questions to 10 times and 18 questions.

### **3.3 Part of classroom teaching adopts inquiry teaching method to promote students to master knowledge and its application**

In order to improve students' active learning enthusiasm and ability and make students become the "initiative" in class, the teaching of the course mainly draws lessons from the inquiry-based learning method of Shantou University and adopts the "inquiry question" design at the level of knowledge units and knowledge points. The "inquiry question" at the level of knowledge unit is put forward in the guide of each lesson, which is aimed at the design of teaching unit and can summarize the core teaching content of the unit. Generally, students are not required to answer it accurately immediately, but it should stimulate their interest in inquiry and guide students' thinking of inquiry. In the classroom teaching, select some knowledge points that can be combined with the practical application of naval missile engine or difficult for students to understand, design "inquiry questions" to explore and discuss, so that students can master knowledge and application.

For example, in the thrust knowledge of rocket engine, the thrust discussion section is designed to explore and discuss the relationship between nozzle outlet pressure and engine thrust, the height characteristics of rocket engine thrust, how to take nozzle outlet pressure of tactical missile and strategic missile rocket engine, how to get large

thrust and other issues. Guide students to think critically about the relationship between thrust and nozzle outlet pressure, and master the characteristics of actual rocket engine nozzle.

In addition, in each classroom teaching design, knowledge points and requirements, CDIO ability that can be cultivated in combination with the teaching content or involved in the teaching content should be listed in addition to the teaching content.

### **3.4 The course assessment is mainly based on the results of practice, focusing on the students' personal skills, team ability and CDIO system ability**

The original comprehensive evaluation method: 70% final exam, 10% usual score, 20% experiment. Because this pilot a lot of knowledge, application and ability training are reflected in the practice link, students will spend more time in the practice link, so we must improve the proportion of the practice link score. The proportion of the test scores is: homework 10%, experiment 10%, group discussion 15%, group discussion 15%, practical project 20%, final examination 40%.

The practice will be carried out in groups, and the teachers will evaluate the group scores according to the grading standards. Students' individual scores are evaluated by team members first, and then determined according to the rank of mutual evaluation and group scores. It is required that the difference between the highest score and the lowest score is no less than 5 points, and the average score is equal to the group score evaluated by the teacher. The group leader will sign and hand it in to the teacher.

## **4 Teaching effect evaluation based on CDIO course**

After three years of teaching reform practice, a questionnaire survey was conducted among missile engineering students who participated in the CDIO teaching mode. The majority of students generally hold a positive attitude towards the teaching reform under the CDIO mode. About 90% of the students believe that the CDIO concept can be applied to the teaching of "Fundamentals of Missile Propulsion and Flight Mechanics", and that the CDIO curriculum reform model is worth promoting. It can be seen that the students' recognition of the teaching reform of the course "Fundamentals of Missile Propulsion and Flight Mechanics" is extraordinary. With the constant change of technology and ideas, the teachers of military academies should actively change their ideas and teaching methods to meet the learning needs of the new generation of students. The traditional teacher-led teaching mode of "one word" cannot be accepted by students, while the student-centered teaching mode with ability cultivation as the goal is favored by students.

Through reform and practice, about 93% of students believe that CDIO "Fundamentals of Missile Propulsion and Flight Mechanics" has improved their comprehensive knowledge application ability and communication ability, and about 97% of students believe that CDIO "Fundamentals of Missile Propulsion and Flight Mechanics" is conducive to the cultivation of team cooperation ability. Communication ability and teamwork ability are the most important competency indicators in CDIO teaching

mode, so it can be seen that this teaching mode is feasible and effective. The teaching of Missile Propulsion and Flight Mechanics foundation should be completely freed from the teaching mode of "coping with examinations", and the teaching of Missile Propulsion and Flight Mechanics Foundation should focus on the quality education of cultivating students' communication ability, communication ability and cooperation ability.

Through reform and practice, it can be seen from the comparison of theoretical assessment scores of students under traditional teaching methods and CDIO teaching mode that the average assessment scores of students after using CDIO teaching mode are significantly higher than the former. Especially in the theoretical analysis and comprehensive calculation questions, students' scores have significantly improved by about 20%. It can be seen that the students' comprehensive application ability of theoretical knowledge has been significantly improved. They not only master the knowledge itself, but combine the theoretical knowledge with specific equipment, especially the related knowledge system of the preceding courses, and enhance their ability to solve practical problems.

Through the reform practice, teachers of subsequent courses, especially the instructors of undergraduate graduation projects, generally reflect that compared with other students, students who have participated in the reform of CDIO teaching mode have stronger ability to solve practical problems, better hands-on ability, better language expression ability and teamwork ability. These abilities are particularly prominent in the students' graduation projects, many of which were rated as excellent graduation papers of the school. The teaching reform improves students' participation in class, effectively exercises their learning ability, cultivates their thinking habits and comprehensive quality, and lays a solid foundation for them to adapt to the army.

## 5 Thinking after the practice of teaching reform

In view of the problems and deficiencies existing in the pilot, the improvement measures are as follows:

(1) To increase the teaching of knowledge units and seminars, so that students can learn complete research ideas and methods in classroom teaching. In the third chapter of nozzle theory and thermodynamic relations, the teaching of knowledge unit seminar is planned. Firstly, the actual working state of the nozzle of the missile engine is shown by video, so that the students can determine the nozzle parameters and nozzle flow research objectives that they are interested in. According to the research objectives and their accuracy requirements, the corresponding simplified hypothesis of the actual nozzle is made, and the error caused by the simplified hypothesis is discussed. Based on the simplified hypothesis, the nozzle flow calculation model was established by using mechanics, thermodynamics, gas dynamics and other knowledge, and the transformation method was used to derive the nozzle flow calculation formula. The nozzle of a typical missile engine was solved and calculated to study the flow characteristics, parameter variation and influencing factors, and analyze and understand the design considerations of nozzle area ratio of the actual missile engine. The effect of

simplified assumption error on the accuracy of nozzle flow calculation results was studied by comparing the theoretical calculation results with the measured results of nozzle test, and the correction method was discussed.

(2) Improve the course assessment model. It is planned to increase the proportion of practical results, improve the evaluation method of students' individual results in practical results, and adopt open-book written examination for the final exam, which mainly focuses on basic knowledge and theoretical application.

(3) Strengthen the practice of process guidance and assessment management. In the early stage of the project, we will focus on plan formulation, data inquiry and guidance of research methods, so that students can adapt to the CDIO teaching mode as soon as possible. In the later stage of the project, I mainly guided students to write research reports and strengthen the standardization of documents. Supervise students to complete the practice project as planned, and carry out the practice assessment and comment in time.

## 6 Conclusion

Through the reform of CDIO teaching mode, it not only conforms to the innovative psychology of young students seeking new innovation, but also meets the desire of students to master practical skills, and inspires students' learning consciousness. By comparing students' learning effects, it is found that students' abilities and qualities in all aspects have been comprehensively exercised and improved.

Although the teaching reform has achieved some stage achievements, but it is also a complex system engineering, need to constantly explore, pioneering and innovative, constantly communicate with peers, draw lessons from the advanced education and teaching experience at home and abroad, in order to effectively consolidate and promote the curriculum teaching reform work.

## References

1. Gu P.H., Shen M.F., Li S.P. et al. (2008) From CDIO to EIP-CDIO: a probe into the mode of talent cultivation in Shantou university. *Research in Higher Education of Engineering*, 28: 12-20. <http://www.cnki.net/>.
2. Gu P.H., Lu X.H., Xiong G.J. et al. (2006) Development of design directed engineering curriculum based on CDIO framework. *World Transaction on Engineering and Technology Education*, 5:30-34. <http://www.cnki.net/>.
3. Song D.D. (2018) Comparison of CDIO and Chinese Engineering Education Accreditation for Animation Specialty of TUST. 8<sup>th</sup> International Congress of Information and Communication Technology. *Procedia Computer Science* 131:765-770. <https://creativecommons.org/licenses/by-nc-nd/4.0/>.S election and peer-review under responsibility of the scientific committee of the 8th International Congress of Information and Communication Technology. 10.1016/j.procs.2018.04.322.
4. Sushma K., Sachin P., Rajendra P. (2020)Adoption of the Conceive-Design-Implement-Operate approach to the Third Year Project in a team-based design-build environment. 9th World Engineering Education Forum, 172:559–567. <http://creativecommons.org/licenses/>

- es/by-nc-nd/4.0/Peer-review under responsibility of the scientific committee of the 9th World Engineering Education Forum 2019. 10.1016/j.procs.2020.05.068.
5. Gennady B., Igor Y., Aleksandr B., et al.(2021) Application of the CDIO standards for cyber-physical education in mechatronics and robotics in a research university on the example of development of digital electronic skills. 2020 Annual International Conference on Brain-Inspired Cognitive Architectures for Artificial Intelligence: Eleventh Annual Meeting of the BICA Society, 190:45–50. <https://creativecommons.org/licenses/by-nc-nd/4.0/>. Peer-review under responsibility of the scientific committee of the 2020 Annual International Conference on Brain-Inspired Cognitive Architectures for Artificial Intelligence: Eleventh Annual Meeting of the BICA Society.10.1016/j.procs.2021.06.006.
  6. Liang. Z.W., Deng H.G., Tao J. H.(2011) Teaching Examples and Pedagogy of Mechanical Manufacture based on the CDIO-Based Teaching Method. *Procedia Engineering*, 15:4084-4088. <http://creativecommons.org/licenses/by-nc-nd/3.0/doi:10.1016/j.proeng.2011.08.766>.
  7. Thomas H., Nina T., Kristian M.(2018) CDIO Design Education Collaboration Using 3D-desktop Printers. *Procedia CIRP*, 70:325–330. <http://creativecommons.org/licenses/by-nc-nd/3.0/Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.10.1016/j.procir.2018.03.277>.
  8. Jason P., David T., Alan R. et al. (2021) Developing CDIO Practitioners: A Systematic Approach to Standard 10. *Procedia Manufacturing* 38: 680–685. <http://creativecommons.org/licenses/by-nc-nd/4.0/Peer-review under responsibility of the scientific committee of the Flexible Automation and Intelligent Manufacturing 2019. 10. 1016/ j. promfg. 2020. 01.087>.
  9. Ahmed S., Monther A.(2022) The impact of CDIO's dimensions and values on IT Learner's attitude and behavior: A regression model using Partial Least Squares. *Heliyon* 8: e11433. <https://doi.org/10.1016/j.heliyon.2022.e11433>.
  10. Svante G.(2017) Automatic Control Education in a CDIO Perspective. *IFAC Papers On Line* 50-1: 12161–12166. Peer review under responsibility of International Federation of Automatic Control.10.1016/j.ifacol.2017.08.2145.
  11. Zhang L., Jie J., Zhu W. (2021) Exploration and practice of automatic control principle teaching reform based on OBE-CDIO concept. *Journal of higher education*, 36:128-131. <http://www.cnki.net/>.
  12. Meng Y.Y., Jia C.H., Liu M.(2021) Research on talent cultivation of applied undergraduate colleges based on CDIO engineering education concept under new engineering background. *Journal of higher education*, 36:152-155. <http://www.cnki.net/>.
  13. He X.K., Yao J., Shen Y., et al, (2021)Discussion and reform of energy and Power Engineering curriculum system under CDIO mode. *China Modern Educational Equipment*, 23:121-123. <http://www.cnki.net/>.

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