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Practical Research Based on Goldberg Simple Machinery Project on the Cultivation of Engineering Thinking of High School General Technology

WANG Bo
Ziwei Senior High School in Haining City, Haining, China

With the rapid development of STEAM education, engineering education has become particularly important. The "General Technology Curriculum Standard for Ordinary High Schools", which was published in 2017 in China, proposes five core competences in the subject, with engineering thinking being one of them. This shows that cultivating students' engineering thinking ability in high school is of great significance. The author creatively took the design and production of Goldberg Simple Machinery Project as the course carrier, driven by tasks, and aimed at solving problems. In teaching design, the theory and practice were organically integrated and the complementary advantages of the theory and practice were achieved in teaching practice activities. Moreover, the effectiveness of project-based teaching in cultivating students' engineering thinking has been verified through this practice. Meanwhile, some experience and a few shortcomings have been summarized. And these shortcomings need to be further improved to better serve teaching.

Keywords: Goldberg Simple Machinery, General Technology of High School, engineering thinking, core competence

Introduction

With the rapid development of STEAM education, engineering education has become particularly important. The "General Technology Curriculum Standard for Ordinary High Schools", which was published in 2017 in China, proposes five core competences in the subject (Ministry of Education of the People's Republic of China, 2020), with engineering thinking being one of them. This shows that cultivating students' engineering thinking ability in high school is of great significance.

So, what is engineering thinking? Engineering thinking is a planning thinking centered on system analysis and comparative trade-off. It requires students to understand the diversity and complexity of system and engineering; be able to use the method of system analysis to analyze elements, conceive the scheme, and compare the trade-off in a specific technical field; understand the practical application of basic concepts and methods of structure, process, system, and control, and be able to use them for simple decision analysis and performance evaluation (Ministry of Education of the People's Republic of China, 2020).

In fact, how to cultivate students' engineering thinking depends on the teacher's cognition. At first, the teacher lacked a thorough understanding of engineering thinking and ignored its importance, so she did not

WANG Bo, Ziwei Senior High School in Haining City, Haining, China.

consciously cultivate students' engineering thinking through practical activities. Although the curriculum standard establishes five levels of engineering thinking and corresponding content, the teacher evaluated students' engineering thinking just only based on their mastery of the knowledge and skills covered in the textbook. The knowledge and skills involved in engineering thinking are detailed in Table 1.

Table 1

The Knowledge and Skills Content Involved in Engineering Thinking

Knowledge Theme	Details of knowledge content
Fundamentals of Technology and Design	The relationship between design and technology; General principles of design
The general process of design	Identify and clarify issues;Design Analysis;concept design;Compare and weigh design options;design evaluation;Optimize design scheme;Material selection and planning;Tool selection and planning
Structure and Design	analysis of the structure;Relationship between structure and function;Simple structural design and optimization
Process and Design	Process expression;Basic factors considered;process analysis;Simple Process Design and Optimization
System and Design	System analysis process;systemic analysis method;System Design and Optimization
Control and Design	Elements of Control;Control measures and methods;Control System Design and Optimization

Literature Review

However, with the in-depth study of curriculum standard, the teacher has realized that cultivating students' engineering thinking must rely on systematic practical activities. At present, the teachers lack practical teaching carriers for the cultivation of general technology engineering thinking for students, while cultivating engineering thinking of students requires experiencing a complete engineering project (Wang & Zhang, 2023).

The teacher takes "DIY Creative Design" project as the carrier, and based on real-life problems, let students propose, analyse, and solve problems on their own. Through the entire project practice process, they learn and experience the "general process of design", pay attention to the coherence and completeness of the project, and ultimately achieve the goal of cultivating students' engineering thinking (Xu, 2019). Research has shown that "robot teaching" projects also have advantages in cultivating students' engineering thinking development (Ruan, 2024). Using Goldberg Simple Machinery Project as a carrier to conduct practical research on general technology teaching can guide students to solve problems in real situations and cultivate their engineering thinking (Wang & Zhang, 2023). The research also chooses the design and production of the Goldberg Simple Machinery Project as the course carrier. In addition to cultivating students' engineering thinking, it can also review the "general process of design", achieving complementary advantages between theory and practice, and making the general technology course full of fun (Pan, 2021).

Methodology

This research, which was conducted under the guidance of constructivism theory and the "General Technology Curriculum Standard for Ordinary High Schools", mainly adopted the action research method. At that time, the teacher selected four classes' students in the second year of high school as the research subjects.

Because the curriculum standard proposed to cultivate students' engineering thinking, the teacher initially taught based on the five levels of engineering thinking levels determined by the curriculum standard and the corresponding content of the textbook, but the effect is not significant. With the in-depth study of curriculum standard, the teacher realized that cultivating students' engineering thinking must rely on systematic practical activities. So, the teacher introduced Goldberg Simple Machinery Project into the classroom.

Based on this activity, the teacher determined the teaching path:

Firstly, teaching analysis. Taking scientific decision-making as the goal, analyze teaching content, objects, and objectives to form the basis for teaching design. To ensure the smooth progress of this research, the teacher should have the ability to integrate subject knowledge and teaching knowledge into curriculum teaching. That is to say, the teacher needs to process, transform, express, and impart knowledge to students in a way that is easy for students to understand, which is the PCK theory, and the concept of it was introduced by Shulman (1986).

Secondly, preparation for teaching. Develop the learning process and prepared the necessary conditions for teaching.

Thirdly, teaching implementation. Based on constructivism, the teaching setting included creating situation, knowledge guidance, project analysis, design and production, knowledge internalization, and sharing and evaluation, guiding students to experience embodied learning through "embodied experience, knowledge internalization, reflection and improvement", realizing the entire process of project implementation, and cultivating students' risk assessment and decision-making abilities through iterative practice.

Fourth, expand teaching. Around the three dimensions of "knowledge strengthening", "project upgrading", and "ability enhancement", the teacher aimed to promote students' mastery of the concepts, methods, and skills of general technology, and enriched their engineering thinking system (Ma & Tang, 2024).

Implementation of Goldberg Simple Machinery

Theory and Practice Each Have Their Own Strengths

General technology is a relatively broad technology except for information technology, which reflects foundational and universal characteristics and is distinct from professional technology. It is a widely used technology in daily life and has broad migration value for the development of students. In essence, general technology course is a course based on practice, emphasizing creativity, highly comprehensive, and integrating science and humanities. Its learning process is a process in which students actively construct knowledge, constantly expand their abilities, and form good emotional attitudes and values. It is an activity process full of vitality, full of exploration and diversified ways. However, the traditional teaching model is teacher-centered to impart theoretical knowledge, and students can only passively accept it, which goes against the original intention of the curriculum design.

Rube Goldberg Machinery is a precision and complex device designed to accomplish very simple tasks in a convoluted manner (Yang, 2019), like pouring a cup of tea, beating an egg, turning on a switch, or raising a flag, etc. In order for this device to accurately complete a task, it requires the designer to make comprehensive use of the knowledge they have learned during the design process. Of course, when the teacher uses Goldberg Simple Machinery as a medium for teaching, she does not ask students to design a simple machinery device by themselves, but rather to have students repeatedly study and use materials and tools at hand to imitate and make this device. The production process of Goldberg Simple Machinery is aimed at specific tasks, formulate specific design scheme, make specific structures, and test and optimize to form a stable mechanical system. In fact, it is a process of comprehensively applying knowledge of general technology.

The Organic Combination of Theory and Practice

After studying the 2017 edition of the new curriculum standard, we can see that the guiding ideology of education is to focus on human development and put forward the concept of "Core competence". Core competence of general technology mainly includes: technology awareness, engineering thinking, innovative design, technical drawing, and materialization ability. Core competence is the concentrated embodiment of the educational value of a subject, which is the correct values, essential qualities, and key abilities gradually formed by students through subject learning.

In quality-oriented classroom teaching, the teacher has introduced the design and production activities of Goldberg's Simple Machinery, with the aim of providing students with a practical platform to apply theory to practice and promote the digestion and absorption of knowledge. This practical activity not only helps students review the general process of design and master the processing techniques of metal or woodworking, but also makes up for the shortcomings of theoretical teaching only based on paper and without hands-on practical operations, which increases the interest of learning and cultivates students' engineering thinking and hands-on abilities.

How are the five core competences reflected through Goldberg Simple Machinery, and in what stages are they reflected? How to apply the knowledge from textbooks to achieve the design goals of Goldberg Simple Machinery? Table 2 provides a detailed explanation of the above issues.

Table 2

Implementation Points of Technology Core Competences

Core competence	Teaching aims	Application of textbook knowledge
Technology awareness	In the process of imitation design and production, students should respect originality, pay attention to environmental protection, and have a sense of safety and responsibility	Technology and Design 1(Gu Jianjun,2020) 1. General principles of design 2. General process of design
Engineering thinking	Students can use the method of system analysis to compare and weigh design solutions. Be able to comprehend basic thinking methods such as structure, process, system, and control, and apply them effectively	Technology and Design 1: 1.The conception method of the scheme; 2.Comparison and weigh of scheme Technology and Design 2(Gu Jianjun,2020): Comprehensive knowledge application
Innovative design	In the process of imitation, students comprehensively use the knowledge of various disciplines to innovate and design, including technical innovation on the basis of others' schemes	The nature of technology: 1. Comprehensive; 2. Innovation
Technical drawing	Students are required to watch the video repeatedly and then submit a complete design proposal in groups. At the same time, each group should write out the general process of the design and draw technical drawings	1. General process of design: 2. (1) Drawing of technical drawings (2) Mechanical processing diagram
Materialization ability	Finally, students convert the scheme into items.	1. Metal processing technique 2. Wood processing technique 3. Test evaluation and optimization

Complementary Advantages of Theory and Practice

Goldberg Simple Machinery may seem easy, but designing and producing a precise and complex system is not an easy task. In view of the students' practical ability, the practical class is mainly imitation.

Students were required to watch the video repeatedly and then submitted a complete design proposal in groups. At the same time, each group should write out the general process of the design and draw technical drawings. Finally, they should try to use the materials in their hands to make the devices in the video and achieve specific functions. Of course, innovation was encouraged in the actual operation process.

Take the production of "raising flags" as an example to realize the complementary advantages of concept and practice. The teaching process is divided into four lessons.

Lesson 1: Clarify requirements and formulate schemes.

Table 3

Bonus and Deduct Points

Bonus points（no limit）	Deduct points
10 points are added to complete each part of the mechanical structure	Not submitting the design proposal, each group will lose 10 points
Can successfully raise the flag, add 50 points	The finished product does not match the design scheme ，reducing 50 points
Later beautification, add 10 points	20 points will be deducted each time for influencing others to display, making loud noises, and damaging the environment
Designed your own team flag, adding 10 points	
Identify the structural type and force situation, and add 2 points each time	

Table 4

Scheme Table

Name________Class _______ Group ______	remarks
Design sketch (drawing, dimensions, notes) Materials used	

In Lesson 1, firstly, let students watch the video-carefully. and then they began to formulate design schemes. Emphasis was placed on cultivating students' abilities in "technology awareness", "engineering thinking", "innovative design", and "technical drawing".

Lesson 2: Distribute materials, hands-on practice.

Materials provided by teachers: Each group had a hard paper shell of the same size, a ruler, a small knife, a hot melt glue gun, an unlimited supply of glue sticks, a magnet, a marble, a nut, and a balloon.

Materials prepared by students themselves: Two bamboo sticks (or chopsticks), two straws, a plastic bottle, a hollow hard paper tube in the middle of toilet paper (as it was difficult to find, you could make your own paper tube or use other materials instead, as long as it did not affect the effect). Individual groups had prepared colored cardboard or pigments to beautify the final works.

In this class, the students began to actively create according to the plan, which could be said to be the Eight Immortals crossing the sea and showcasing their respective abilities. During this period, the teacher was mainly responsible for answering questions, providing assistance, managing discipline, and reminding students to pay attention to safety.

Lesson 3: Install, debug, and improve works.

After the active efforts of the first two classes, most groups were able to submit their works by the end of this class; some groups wanted to strive for excellence and used their noon time to improve their works. This practical course has truly stimulated students' enthusiasm and interest in learning technology.

Lesson 4: Communicate and evaluate, summarize and reflect.

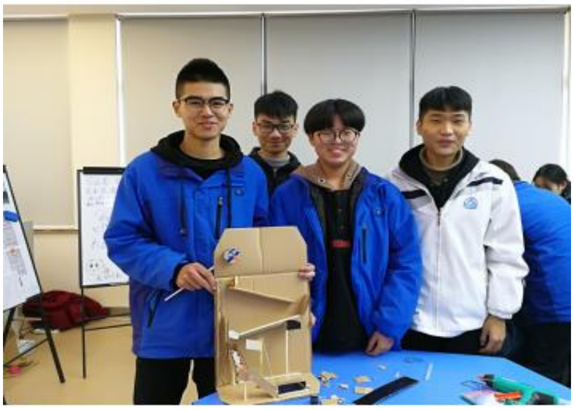

Figure 1. Show their works.

Figure 2. Show their works.

Four classes in total participated in this practical activity, each class was divided into six groups and the works of above are from one class.

Figure 1 is the work of Group 1. This group is all boys; they are very thoughtful and have strong hands-on abilities. At the very beginning, the team leader clearly defined the division of labor, so they were able to achieve unity and cooperation throughout the entire production process. Although there were also differences during the production process, it was the spark of wisdom generated by the collision of such ideas that they completed the task efficiently, with high quality and quickly. Unfortunately, their Goldberg Simple Machinery device was not very smooth when raising the flag, and further improvement and optimization were needed.

Figures 2, this group is all girls. Although practical classes are a form of exercise for them, it is not a small challenge. Fortunately, they could try to overcome difficulties and complete tasks on time.

With the deepening of teaching and continuous reflection on this practical activity, the teacher found it unreasonable to evaluate students' engineering thinking solely based on their knowledge acquisition from the textbook or evaluate students' engineering thinking from the level hierarchy of curriculum standard. Instead, it is more reasonable to evaluate engineering thinking from the perspective of students' ability development laws. So the teacher divided engineering thinking into a three-level structure of cognition, behavior, and thought. The corresponding indicators from low to high are analytical comprehension, innovative design, and scientific decision-making, and provide specific descriptions based on the level and content of engineering thinking (see Table 5) (Ma & Tang, 2024). After students handed in their finished products, the teacher would score, select, and reward them according to Table 5.

Besides engineering thinking, the materialization ability of core competences has also been fully reflected in this practical activity. It has been proven that as long as you provide a platform for students, they will surprise you with their abilities. While completing the practical project and achieving learning objectives, the students also consolidated the knowledge of processing techniques for different materials in the textbook *Technology and Design 2*. They collectively expressed that practical activities made textbook knowledge more concrete, deepened their understanding and memory of knowledge, and changed their learning methods. Therefore, they hope to have more such practical activities in the future.

Table 5

The Three-Level Structure and Level Hierarchy of Engineering Thinking [3-5]

	First level structure: Analytical comprehension	Second level structure: Innovative design	Third level structure: Scientific decision-making
Level 1	Through experiencing the general process of technical design, preliminary multi-factor analysis of the design scheme, understand the system analysis methods of comparison, trade-off and optimization; through typical case analysis, perception, system and engineering phenomena, understand the basic characteristics of the system	——	Explore and explain how the input, process, output and various factors affect the system, form a preliminary engineering awareness and thinking
Level 2	Be able to analyze design cases in conjunction with the system, summarize and generalize methods for system design	Be able to use system, structure, process, control and other principles and analysis methods to conduct simple technical activities,and attempt to solve technical problems;Be able to determine a simple object of life and production, analyze the factors that affect the system,try to optimize the system by changing the input, process, output, feedback, and interference	——
Level 3	Be able to use the method of system analysis on a clear technical problem in some specific technical field	Identify the characteristics and details of technical problems, clear constraints and various influencing factors, and propose possible solutions	Try to use simulation experiments or mathematical models to consider various influencing factors, and to conduct decision analysis and performance evaluation
Level 4	——	Be able to apply systematic analysis to complex problem scenarios in a certain technical field , make it specific ,form possible solutions and continuously optimize and improve design	Be able to initially use a simple, simulation experiment or mathematical model for performance and risk assessment, improve the decision-making ability and develop engineering thinking
Level 5		Ability to integrate and apply knowledge from science, technology, mathematics, engineering, and other fields and colligate multiple technical fields for system analysis and options design	Use simulation experiment or mathematical model to evaluate the design scheme, and optimize and improve it through trend analysis and risk assessment

Specific Unity of Theory and Practice

The design and production activity of Goldberg Simple Machinery Project, which lasted for four lessons, has come to an end. This type of teaching activity, which takes a perfect practical project as a course carrier and helps students review knowledge and master basic skills step by step, is worth promoting. First, it makes up for the shortcomings of traditional teaching models. Secondly, it achieves a concrete unity between theory and practice.

Results and Discussion

The activity theme of Goldberg Simple Machinery Project is clear, interesting, and challenging, whose design philosophy is to complicate simple problems. It requires participants to design and complete a complex system within a limited time and make all parts to work together to achieve functionality, which may take students too much time to complete or even exceed their ability. So the premise of this kind of practical activities is that the teacher lets students watch, imitate, and make a Goldberg Simple Machinery device according to the video, rather than designing a device themselves, because the difficulty of the two is completely different. Students are willing to actively participate, which makes the activity easy to promote. Meanwhile, the materials used in the activity are familiar to students, easily accessible and cost-effective and the tools in our practical classroom can meet the needs of students' production.

Goldberg Simple Machinery Project is a great teaching practice carrier. As for its effectiveness of teaching, teachers should take into account the overall applicability of the students. Because different regions, student levels, and hardware conditions of different schools will definitely have different implementation effects, practical activities should also be tailored to local conditions.

Taking Goldberg Simple Machinery Project as a teaching carrier has the following benefits besides cultivating students' engineering thinking:

(i) It can not only exercise students' hands-on abilities, but also help them develop good qualities and communication skills such as cooperation, sharing, and proactive progress;

(ii) It is beneficial for cultivating students' ability to collect and process information;

(iii) It is conducive to cultivating students' ability to discover and solve problems, enabling them to gain rich experience in hands-on practice, and stimulating their innovative potential;

(iv) It contributes to promoting a fundamental transformation in students' learning methods.

Conclusion

The problems faced by human beings in the future will certainly be complex and challenging. Simple knowledge and skills can only stay at the level of manufacturing, and it is difficult to rise to the level of intelligent innovation. In order to cope with the uncertain challenges of the future, the education oriented to cultivate people-oriented and engineering thinking is imperative. Students can really have the engineering thinking ability only through the real field under the real problem solutions, from analytical comprehension, innovative design, scientific decision-making three angles, repeatedly to find and solve the reality training, in the process of design, testing, iteration constantly summary reflection improvement.

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