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Engineering Education Evolution: Integrating 3D Printing into Packaging Courses

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Abstract: To nurture engineering talents of exceptional innovation and creativity, a sophisticated talent development framework is pivotal, necessitating profound interdisciplinary collaboration and posing novel challenges to university curriculum design. Courses in packaging engineering, such as Packaging Engineering and Packaging Technology, confront hurdles like dwindling student engagement, the challenge of bridging theoretical knowledge with practical applications seamlessly, and a disconnect between educational content and real-world experiences. These obstacles impede the effective nurturing of new-age engineering talents. In response, integrating 3D printing technology into packaging engineering curricula, initiating reforms, and transitioning from a predominantly theoretical to a balanced theory-practice teaching methodology can reignite students' learning enthusiasm, elevate teaching standards, and cultivate comprehensive, innovative talents who are well-suited to the demands of the contemporary engineering landscape.

Packaging engineering is an essential and indispensable component of science and engineering education. Its multidisciplinary nature, crucial role in the production and distribution of goods, significant impact on the packaging industry, and contribution to environmental sustainability make it a field that cannot be overlooked [1-3]. Firstly, packaging engineering is a multidisciplinary field that integrates knowledge from areas like materials science, mechanical engineering, chemistry, and industrial design. This interdisciplinary nature makes it a unique and valuable component of science and engineering education, fostering students' ability to integrate knowledge from different fields and solve complex problems. Secondly, packaging plays a crucial role in the production and distribution of goods. It protects products from damage, extends shelf life, and enhances the overall consumer experience. Packaging engineering, therefore, plays a vital role in ensuring the quality, safety, and efficiency of the products we consume. Thirdly, with the rapid development of technology and the increasing demand for sustainable packaging solutions, the packaging industry is undergoing significant transformations. Packaging engineers are needed to develop innovative packaging materials, designs, and technologies that are environmentally friendly, cost-effective, and consumer-friendly. This demand creates ample opportunities for students pursuing a packaging engineering education. Lastly, packaging engineering also has a significant impact on the environment. By developing sustainable packaging solutions, packaging engineers can contribute to reducing waste, conserving resources, and promoting environmental sustainability. This aspect of packaging engineering aligns with the growing emphasis on environmental responsibility and sustainability in science and engineering education [4].

However, the current educational model often emphasizes the infusion of theoretical knowledge while neglecting the cultivation of students' practical abilities and innovative thinking, underscoring the necessity of curriculum reform in packaging engineering [5, 6]. Traditional courses in packaging engineering and packaging technology often suffer from issues such as the disconnect between theory and practice and low student engagement, limiting students' ability to translate theoretical knowledge into practical applications and making it difficult to meet the urgent demand for high-quality packaging engineering talents in modern industries. Therefore, curriculum reform in packaging engineering is imperative. Through reform, we can strengthen practical teaching components and introduce more real-world cases and projects, allowing students to deepen their understanding of theoretical knowledge through hands-on experience and enhance their ability to solve practical problems. Additionally, curriculum reform can inspire students' innovative thinking and cultivate their sense of innovation and capabilities, injecting new vitality into the development of the packaging engineering field. Emphasizing the importance of packaging engineering in science and engineering education is not only because it serves as a crucial link between products and the market, ensuring product safety and aesthetics, but also because it plays an indispensable role in promoting innovation and development in science and engineering education. Through curriculum reform, we can improve the quality of packaging engineering education, cultivate more high-quality talents with innovative spirits and practical abilities, and contribute to the sustainable development of society [7].

3D printing is a new rapid prototyping technology that relies on digital models. It can use materials such as paper, plastic, ceramic, and metal to construct objects layer by layer. Its speed and convenience, driven by curiosity, can easily engage students in teaching activities, stimulating their interest in learning and clarifying and guiding their motivation to participate in learning activities actively [8, 9]. As a technology that integrates multiple disciplines such as machinery, materials, and computer science, 3D printing technology can seamlessly integrate the cultivation of innovative abilities in emerging engineering fields with the OBE teaching model [10-12], making it a teaching hotspot in intelligent manufacturing-related majors in universities in the context of emerging engineering. There have been some studies and practices in integrating 3D printing technology into engineering courses, such as teaching mechanical principles [13, 14], plastic product design courses [15], mechanics courses [16], and aviation instrumentation courses [17]. However, currently, there is no exploration of the application of 3D printing in packaging engineering course teaching, making this article somewhat innovative.

1. Establishing a Course System

The professional course of Packaging Engineering is generally offered in the fourth or fifth semester of university education. Its prerequisite courses include inorganic and analytical chemistry, organic chemistry, fundamental polymer science, advanced mathematics, university physics, engineering mechanics, and mechanical design fundamentals, among other introductory courses in science and engineering. By this time, students have already developed specific spatial imaginative abilities and basic CAD design and CAM processing skills. Therefore, incorporating the concepts, equipment processes, and practical applications of 3D printing technology into the teaching of Packaging Engineering can significantly stimulate students' interest in learning and achieve excellent teaching effects (Figure 1).

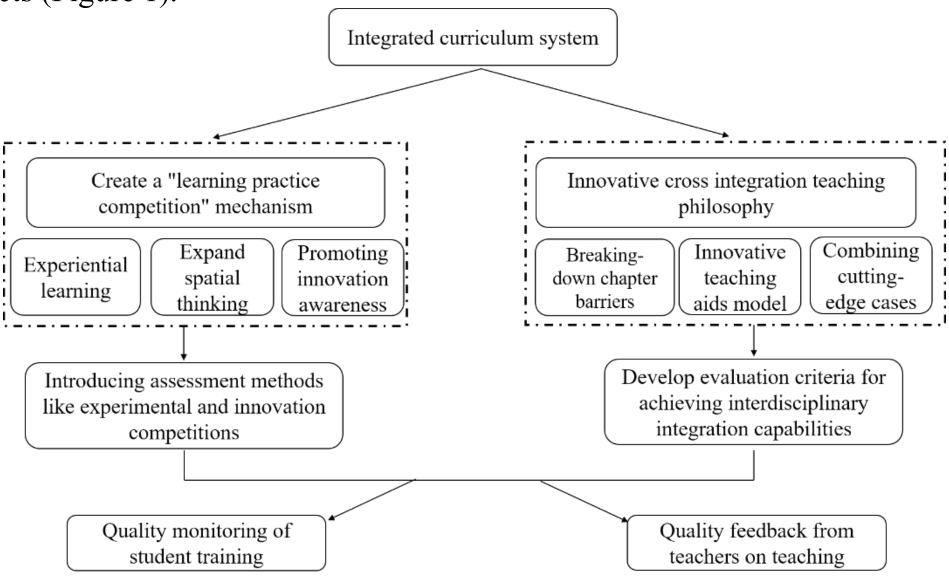


Figure 1: Schematic diagram of integrated curriculum system.

1.1 Enhancing Students' Learning Confidence and Motivating Their Active Learning

The Packaging Engineering course consists of numerous chapters, and many material properties discussed are related to processing techniques. These process flows and conditions are often abstract and complex to grasp from textbook concepts. When teaching, instructors can incorporate the current development status of 3D printing technology and assign pre-class knowledge preview tasks, enabling students to gain a preliminary understanding and recognition of the technology before class, shifting away from a passive learning mode. As the course progresses, students' independent thinking and innovative abilities are enhanced and fostered. While following the theoretical teaching, students can promptly grasp and digest the corresponding knowledge. They can further engage in independent thinking and innovation, integrating their expertise under the guidance of instructors and carrying out project-based learning and design. In this process, students will not find theoretical knowledge uninteresting; instead, they will actively engage in learning with enthusiasm.

The most significant feature of 3D printing technology is its ability to facilitate "experiential learning" for students, organically combining creative design with physical verification. With the help of a 3D printer, students can visually present their innovatively designed graphics or ideas as tangible objects, allowing them to observe the effects of their designs directly and gain a strong, authentic cognitive experience conducive to entering a state of deep learning. Traditional teaching methods do not quickly provide students with opportunities to explore the authenticity of things, which can suppress the development of their design and creative abilities. Integrating 3D printing technology into the teaching process of Packaging Engineering can transform students' virtual design concepts and models into tangible physical representations. The physical exhibition of 3D-printed objects can present a realistic on-site scenario, allowing students to receive their designed works promptly. This approach increases student engagement and motivation, broadens their design thinking, expands spatial thinking, and inspires personalized creativity [8]. Teachers can conduct thematic exploration designs during the teaching process, provide students with several design references, and guide them to understand and grasp the cases to carry out creative designs.

1.2 Innovating Teachers' Instructional Philosophy and Enhancing Teaching Effectiveness

Taking the Packaging Engineering course taught by Wang Jianqing at Tianjin University of Science & Technology as an example, this course is comprised of nine chapters. Materials such as paper, plastic, metal, and glass each form an independent knowledge structure, have their content mutually independent, and their knowledge points relatively scattered. With traditional teaching methods, teachers tend to adhere strictly to the textbook, which can result in a lack of interest among students and easy forgetfulness of course content. However, the integration of 3D printing technology breaks down these chapter barriers and allows for the integration of chapters. By comparing various materials' physical and chemical properties and processing performance, teachers can guide students to consider the 3D printing processes required for different materials and the design application scenarios. This approach activates students' desire to explore and curiosity, enhancing their abilities to think, question, and seek answers actively. In addition, it also addresses the issue of a disconnect between theoretical and practical teaching. In many universities, experimental or practical training courses are often conducted after completing theoretical courses, resulting in a significant time lag and a significant amount of forgotten theoretical knowledge. Moreover, limited practical classroom time makes it difficult for students to integrate theoretical knowledge with practical operations quickly. Therefore, teachers can consider incorporating 3D printing into practical training courses and changing the traditional practical training course arrangements. By dividing the practical training courses into timed segments, teachers can create a closer connection between practical training and theoretical teaching.

During classroom teaching, teachers can present teaching aids printed by 3D printers that are tailored to the course content. This approach can enhance students' direct senses and perceptual experiences, making implicit knowledge and cognitive structures explicit. It also makes the teaching materials more specific, vivid, and visually simpler to understand. This addresses the shortage in teaching equipment and materials and compensates for the teachers' lack of experience in traditional classroom teaching.

With the rapid development of materials science, combining case studies and expanding on the latest developments and research frontiers related to the theories covered in this course can effectively increase students' interest in learning Packaging Engineering and lead to better teaching results [18, 19]. Table 1 summarizes the latest reports on 3D printing technology in various material-related fields gathered by students and the applications of 3D printing technology in packaging materials learned through multiple sources. It can be observed that although 3D printing technology has made significant progress in numerous research areas of materials science, its application in packaging materials is still in its infancy and has excellent potential for further development. Students' timely understanding of technological advancements enhances their interest in learning and lays a solid foundation for further exploration and future research work.

Table 1: Corresponding Table of 3D Printing Frontier Technology Cases and each chapter of Packaging Engineering

No.	Main knowledge points of the course	Course content	Frontier Cases of 3D Printing Technology	Available raw materials	Reports on the application of packaging materials
1	The meaning and classification of paper, The manufacturing	Paper packaging materials	In December 2022, a research team from the Hamburg University of Technology	paper/pulp	none

	process of paper, The Properties of Paper and Paper Plate		embarked on a project titled "Green 3D Printing," with a focus on attempting to convert widely discarded paper waste, such as egg cartons or egg trays, into raw materials for 3D printing		
2	Introduction to plastics and polymer materials; The structure and properties of plastics; Selection and processing of commonly used plastic packaging materials	Plastic packaging materials	In May 2023, researchers from Washington State University reported in the journal "Green Chemistry" that they had developed a method to convert plastic waste into resin suitable for 3D printing	ABS plastics, PLA plastics, acrylic plastics, etc	none
3	The properties and classification of glass, Manufacturing, and Forming Technology of Glass	Glass packaging materials	In April 2023, an Austrian company launched "LithaGlass powered by Glassomer," a 3D-printable quartz glass designed for high-performance applications	Phosphate glass, fiberglass	none
4	Composition, Application, and Forming of Ceramic Packaging Materials	Ceramic packaging materials	In April 2023, the scientific journal "Nature Communications" reported that Chinese scientists had developed a novel technology for 3D printing ceramics in the air without the need for support structures	Aluminum oxide, zirconia, tricalcium phosphate, etc	none
5	Introduction to Metal Materials, Common metal packaging materials	Metal packaging materials	The torch for the Winter Olympic Games, which began its relay on February 2, 2022, features a ribbon designed using metal 3D printing technology. The "Flying" torch boasts a high level of technological sophistication, achieving innovations in materials, energy, and manufacturing processes	Steel, titanium, aluminum alloys, cobalt-chromium alloys, etc	none
6	Structural characteristics of composite packaging materials; Composite process and application	Composite packaging materials	In May 2023, Impossible Objects, a US-based 3D printing company, announced the release of a new composite material 3D printer that boasts a printing speed purportedly 15 times faster than existing technologies	Nylon 3200 glass filled (glass filled nylon)	none

1.3 Prompting Changes in Course Assessment Methods and Teaching Quality Evaluation Standards

Although the theoretical knowledge of Packaging Engineering can be somewhat complex, it possesses strong practicality and provides significant inspiration for packaging design. Therefore, 3D printing technology can be integrated to explore corresponding college student innovation and entrepreneurship projects based on the content taught in different chapters. By incorporating course design tasks into innovation and entrepreneurship training, students can actively think, explore with a sense of ownership, and maintain lasting interest and curiosity. Encouraging students to expand their course knowledge through various projects exercises their scientific research and practical operation abilities and cultivates their innovative skills and scientific literacy. In addition to innovation and entrepreneurship competitions, other competitions can consider utilizing 3D printing technology to create packaging-related competition entries. When evaluating students' comprehensive abilities, it is appropriate to incorporate 3D printing design and manufacturing skills into the assessment, reasonably setting their proportion and establishing a new comprehensive evaluation method. Compared to traditional assessment methods, the latest assessment method focuses on the learning process, can more comprehensively assess students' knowledge mastery and comprehensive problem-solving abilities, and is more aligned with the talent cultivation goals and requirements of "new engineering."

Promoting the deep cross-integration of disciplines is an essential approach to cultivating compound high-level talents that meet the needs of national economic and social development. 3D printing lacks a comprehensive disciplinary framework and is a typical interdisciplinary field that integrates multiple disciplines, such as mechanical engineering, materials science, computer science, and art design. The research areas of interdisciplinary integration pose higher and more diverse requirements for teachers, necessitating their continuous learning and absorption of new knowledge to cultivate cross-disciplinary capabilities. Integrating Packaging Engineering courses with 3D printing technology in educational reform projects, combining the monitoring and effectiveness evaluation of interdisciplinary integration construction with teaching performance appraisals such as subject assessments in higher education institutions, a new evaluation and assessment system can be explored. This is conducive to promoting the better development of interdisciplinary integration.

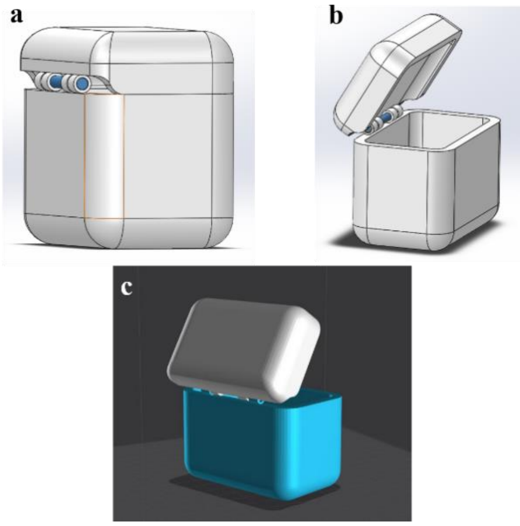
2. Course Example

(1) 3D Model Design

Taking a round packaging box as an example, Figure 2 shows the 3D model designed by a group using 3D software (SOLIDWORKS). This packaging device consists of a box body and a box lid. While independently learning 3D modeling, students became familiar with the basic knowledge of engineering drawing and commonly used commands in 3D software.

(2) Software Data Processing

The product model is initially designed using SOLIDWORKS, an advanced CAD (Computer-Aided Design) software. To ensure compatibility and portability of the model data, it is saved in STP format after completion. STP is a widely supported 3D CAD data exchange format that guarantees data integrity and accuracy. The designed product model is then converted into a file suitable for 3D printing using specialized slicing software. This software slices the 3D model into a series of two-dimensional layers for layer-by-layer printing. The STP format file is imported into the slicing software and undergoes necessary settings and adjustments to optimize the process. The processed file is then sent to the 3D printer for production, resulting in the physical product model. Figure 2c exhibits 3D shapes and the sliced model of the printed product.



(a) and (b); (c) the slicing software processing diagram of 3D printing.

Figure 2: Three-dimension Shapes of packing box

(3) 3D Output of the Product

The 3D printing process begins with the import of processed data from the slicing software into the printing device. This ensures seamless integration between the device and the data, readying it for printing. Before commencing, the device undergoes an initialization procedure to check its functions and ensure it's in the best condition. Material extrusion occurs, with the device precisely controlling the extrusion of resin (ABS) or plastic (nylon) filament based on the printing needs. Before starting the print, we can preview the effect and adjust parameters like speed, temperature, and layer height to achieve optimal results. Finally, the device prints the model layer by layer based on the imported data and settings, resulting in a 3D model that matches the original design (Figure 3).

The steps are as follows: initialize the equipment → extrude the resin (ABS) filament or plastic (nylon) filament → preview the print and set relevant parameters → start printing.

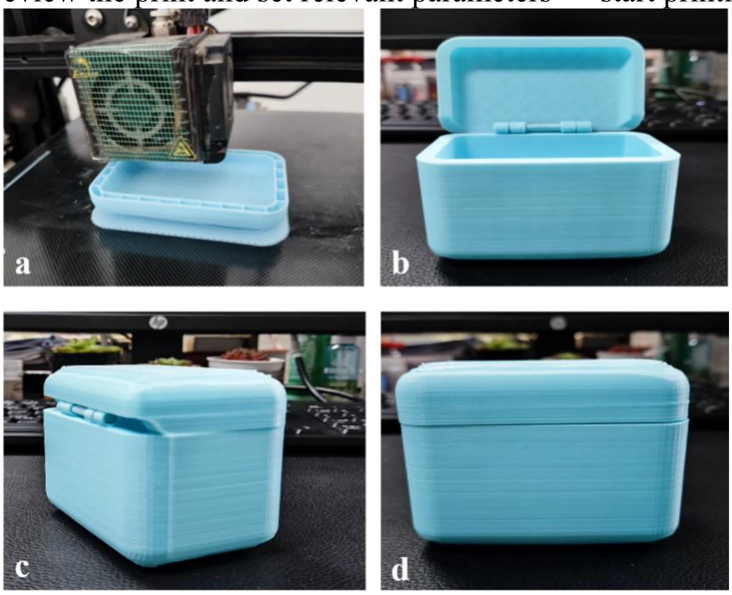


Figure 3: The physical map of 3D printing Molding.

3. Teaching Suggestions

This experiment can be conducted for students from various disciplines, such as packaging engineering, materials science, and mechanical design, among others, at the undergraduate level. The course can be offered in the second or third year of university when students have already acquired basic engineering drawing skills and their interest in scientific research is gradually increasing [20]. The project's duration can be 8 to 10 hours, with group sizes of 3 to 4 students per group.

Firstly, I would assign tasks for data collection and literature retrieval, asking students to choose a packaging material from a specific chapter and conduct information retrieval and literature review on its research and the progress of 3D printing technology. Secondly, we would engage in a discussion about packaging material design projects, mainly focusing on the design ideas and concepts proposed by each group. The teacher should provide feedback on each group's experimental activities after guiding students in software operation, data processing, and physical printing. Students can then correct their innovative designs and improve their operational procedures based on the printed physical objects. Finally, a project summary should be conducted with personalized finished products, which can also be used as entries for various innovation and creation competitions.

4. Conclusion

Packaging Engineering is a course that is conceptually abstract and highly theoretical. The traditional teaching mode fails to mobilize students' initiative and enthusiasm for learning effectively, and it also cannot meet the requirements for cultivating outstanding engineers in the "New Engineering" education system. By leveraging the cross-integration of 3D printing technology with Packaging Engineering and adopting a project-based group approach, we have organically combined theoretical learning with practical operations. This not only enhances the learning enthusiasm of students from non-materials science majors and exposes them to the latest cutting-edge technologies in the field of materials but also allows students to promptly showcase their designs, effectively cultivating and improving their innovative thinking. This teaching reform of Packaging Engineering courses in the context of New Engineering promotes the cross-integration of disciplines. It significantly enhances the teaching capabilities of professional teachers, thus providing a guarantee for cultivating high-quality, composite new engineering talents.

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Author contributions

Fenfen Liang conceived the idea of the study and wrote the paper. Yali Wang and Wei Jiang performed the experiments. Linna Yin analyzed the data and wrote the paper.

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