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Project-based teaching of product innovation design based on KJ/FAST/TRIZ

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Abstract

In the new era of "mass innovation," higher requirements are being placed on the cultivation of innovative talents in colleges and universities. In response to this, the project teaching process of product innovation design based on KJ/FAST/TRIZ is proposed. Firstly, the original user needs are obtained through investigation, and the KJ method is used to classify these needs in order to determine the target of product design. Subsequently, guided by these objectives, the FAST function tree is utilized to establish the functional model. Then the Function-Oriented Search in TRIZ theory is employed to address key sub-functions, and the conflicts within the functional model are resolved using the Contradiction Matrix. Ultimately, a product innovation design scheme that meets the needs of users is obtained. Furthermore, a case study of this project-based teaching process was provided using the innovative design of a Household Intelligent Storage Cabinet as an example. This teaching method takes user demand as the orientation takes project implementation as the carrier and utilizes a comprehensive application of various tools to guide students' completion of product innovation design projects in steps, thereby to enhance the cultivation of students' innovative practical abilities.

Keywords: Innovative design, Project-based teaching, TRIZ, User needs

1. Introduction

In the recent international trend of "returning to engineering," project-based teaching, as a student-centered pedagogical approach, has garnered significant attention and promotion in various engineering institutions. This is due to its proven ability to effectively enhance students' engineering practical skills, teamwork capabilities, problem analysis, and problem-solving abilities (Zhang et al., 2023). Project-based teaching revolves around student-centered learning, guided by instructors. It relies on a specific real or virtual project, or competition topics within a professional field. This approach integrates and interconnects the foundational knowledge and fundamental principles that need to be taught in the course with their corresponding practical components. It is presented through the process and methodology of hands-on project work within the teaching context. Students proactively acquire relevant knowledge based on the project, as guided by this instructional method (Zhao et al., 2019).

In June 2016, China became an official contracting member of the "Washington Accord", marking a new historical phase in the country's engineering education reform (Geng et al., 2018). According to the requirements of the "Washington Accord," programs accredited through engineering education should be able to cultivate students with the capability to solve complex engineering problems. The accreditation standards for engineering education in China also explicitly state the need to address complex engineering issues, while defining the "1+X" characteristics associated with these complex problems (Lin, 2016). Therefore, the cultivation of students' ability to solve complex engineering problems has become a significant challenge within engineering education. Project-based teaching is well-aligned with the "1+X" characteristics of complex engineering problems. Throughout the process of project-based learning, students engage in solving open-ended real-world engineering problems, applying theoretical knowledge to practical scenarios, and constantly attempting to find solutions to open-ended problems. This approach is a vital means of fostering innovative thinking and the skills to tackle complex engineering challenges.

In response to the era of "mass innovation" and in close alignment with the new demands placed on engineering and technical professionals by innovation-driven development, our university's mechanical department has introduced a course titled "Innovation Methods." This course teaches the Theory of Inventive Problem Solving (TRIZ), also known as the theory of inventing solutions to problems. TRIZ provides engineers with a systematic approach to innovation, which can lead to the reduction of product development time cycles and an increase in design efficiency (Cano-Moreno et al., 2022). However, TRIZ theory primarily focuses on solving engineering problems and may struggle to capture and assess the diverse requirements of users during the early stages of design, which doesn't cover the entire product design process. As a result, many scholars have proposed combining TRIZ theory with other design methods. This integration can offer better clarity regarding user requirements, the identification of relationships between requirements and product functionalities, and subsequently, the utilization of TRIZ theory to solve and optimize product function models, which forms a complete innovation design process. Murat Mayda et al. proposed integrating TRIZ theory into Pahl and Beitz's conceptual design process to assist problem solving and solution improvement (Mayda &Börklü,2014). Yuanwu Shi et al. combined FAST and TRIZ methods to introduce an innovative approach to designing elderly smart care robots (Shi & Pan,2018). Fiorineschi et al. suggested combining TRIZ with Problem Solution Network (PSN) to enhance conceptual design efficiency (Fiorineschi et al.,2018). Yang et al. proposed merging QFD with TRIZ to achieve Radical innovations (Yang et al.,2021). Fuqin Liu et al. presented a product conceptual design process based on KJ, KANO, and FAST models, exemplified by innovative design of a forest fire truck (Liu & Li, 2022). Anqi Wu et al. integrated AHP, QFD, and TRIZ theories to propose solutions for aspects like cabin, seats, battery life, and guidance in a shared mobility vehicle for scenic areas (Wu et al., 2022).

Existing research has demonstrated the value of integrating TRIZ theory into the product design process. However, in the context of project-based teaching, the characteristics of instructional implementation need to be considered. Process design should align with students' theoretical foundation, time constraints, and other practical aspects. This article addresses the cultivation of complex engineering problem-solving abilities outlined in engineering certification standards, as well as the advanced requirements of First-class courses (Yuan et al., 2022). Combining the development of the "Innovative Methods" First-class course, a project-based teaching approach that integrates KJ method, FAST method, and TRIZ theory is proposed. This approach is guided by the organic fusion of knowledge, skills, and qualities, providing a reference for fostering complex engineering problem-solving abilities and developing First-class courses in relevant disciplines.

2. Project-based Teaching Process Based on KJ/FAST/TRIZ

In courses such as "Innovative Methods" and "Project Design," a project-based teaching approach reform has been implemented. Students are required to engage in the concept design of products through three main steps: requirement analysis, establishment of functional models, and functional problem-solving, as illustrated in Figure 1. The initial phase is the requirement analysis stage. After posing the problem, market research is conducted to understand the market background. User's original requirement descriptions are obtained through surveys, interviews, and other methods. Subsequently, the obtained requirements are classified using the KJ method. Following this, the establishment of functional models phase takes place. The FAST functional tree is employed to transform the product's requirements into functions, identifying primary and secondary functions. Lastly, the functional problem-solving phase occurs. Utilizing TRIZ tools such as function-oriented search and the contradiction matrix, general solutions to common problems are derived. These solutions are then linked to specific issues, resulting in specific solutions for the design process. This process culminates in the formulation of a creative design scheme.

In this project-based teaching approach, teachers assign open, real-world, relatively independent projects to student groups for design and implementation. This encompasses tasks such as data collection, conceptualization of solutions, and project design. Regarding the instructional content, teachers, while delivering instruction on innovative methods, appropriately integrate relevant knowledge and methodologies like requirement analysis and functional decomposition. Student-centeredness during the project implementation process is emphasized and practical applications tailored to the project are carried out. By employing a problem-driven approach, students' curiosity and desire for knowledge are aroused, transitioning their traditional learning methods towards exploratory and challenging learning. Additionally, students are encouraged to transform their design proposals into patentable outcomes or to participate in scientific and technological competitions.

In a longitudinal aspect, this project establishes a connection between professional education and societal development. Through the integration and application of the curriculum's knowledge structure within the project, an interactive pathway is forged between knowledge and the external world. This facilitates the practical implementation of professional teaching, catering to the needs of the service industry and societal development, while also embodying the characteristics of complex engineering problems. Horizontally, adhering to cognitive principles, the course content is progressively structured from basic to advanced, and from simple to complex. This incremental approach aligns with students' habits of adapting to actual engineering applications, gradually nurturing and enhancing their ability to solve complex engineering problems.

3. Innovative Design Case of a Household Intelligent Storage Cabinet

3.1 Project Design Background

In traditional household living, storage is typically reliant on conventional furniture such as shelves, cabinets, and coffee tables. However, these traditional storage methods fail to meet the requirements of special groups within the household context, such as individuals with conditions like Alzheimer's disease or lower limb disabilities. For instance, individuals with Alzheimer's disease often suffer from memory loss, leading them to frequently forget the locations where they have stored items, as well as everyday tasks like taking medication. On the other hand, individuals with lower limb disabilities face challenges due to physical constraints. They encounter difficulties in retrieving items placed at a distance or storing items that are positioned either too high or too low. For users lacking organized storage awareness, there's a possibility of important items getting lost due to haphazard placement, leading to a cluttered living environment and a decrease in quality of life. Therefore, to address the storage requirements of these special groups and enhance their daily lives, the design of an intelligent storage cabinet tailored to their requirements is essential. This case study aims to exemplify the process of project-based teaching by having students design a household intelligent storage cabinet that caters to the requirements of these special groups.

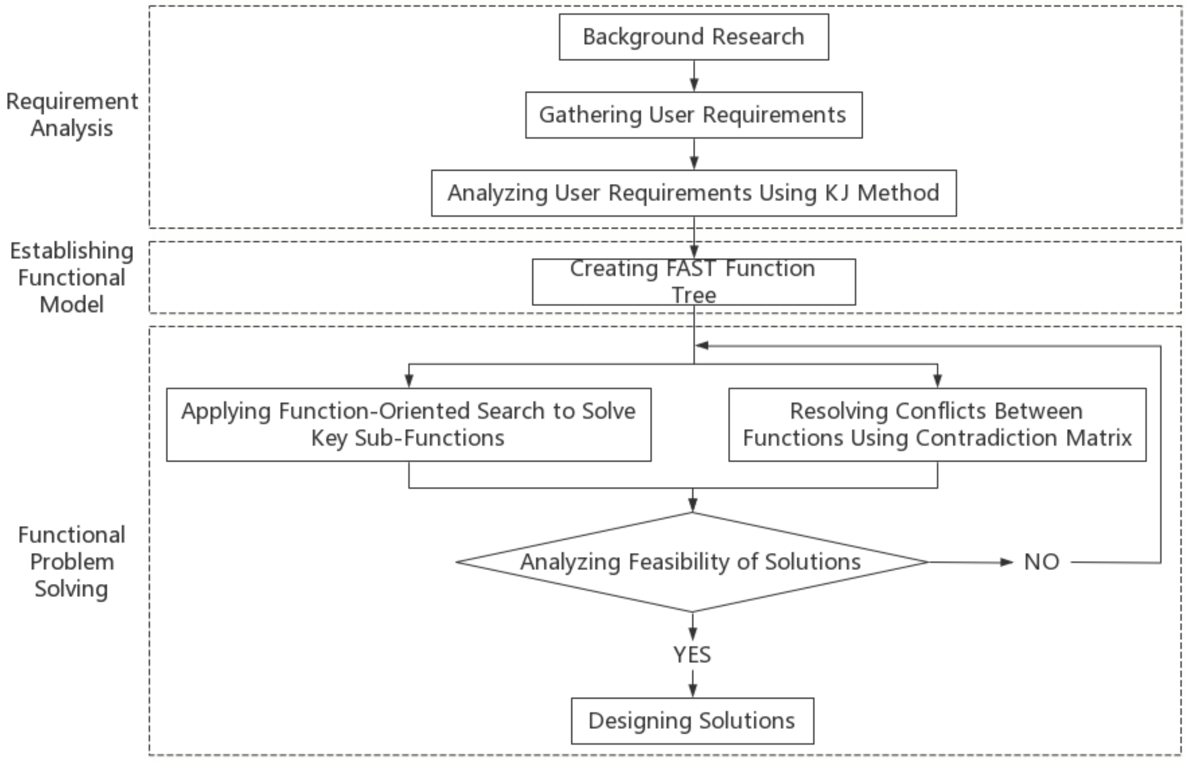


Fig 1. Innovative design process.

Table 1. Original requirement description.

No.	Description of Requirements	No.	Description of Requirements
1	Daily Access to Items	7	Emergency SOS
2	Easy Retrieval	8	User-Adjustable Variability
3	Daily Task Reminders	9	Clear Item Categorization
4	Simple Operation	10	Emergency Medication Box
5	Environmentally Friendly	11	Space Saving
6	Entertainment and Decoration	12	Automatic Tracking

3.2 User Requirements Analysis

User requirements serve as the driving force for product design, permeating the entire design process. Initially, students are tasked with conducting surveys among typical users, Alzheimer's disease patients, and individuals with lower limb disabilities. Subsequently, they are expected to conduct interviews with representative users from each category to gather the original user requirements. Based on the survey results, it is evident that the three groups share a fundamental requirement for convenient storage. However, variations exist in terms of other auxiliary functionalities based on their specific requirements. In summary, for the household intelligent storage cabinet, it is imperative to meet the basic storage requirements of all users. Additionally, it should incorporate human-machine interaction to assist Alzheimer's disease patients in storing items. For individuals with lower limb disabilities, mechanisms for adjusting the cabinet's height and outlet positions should be integrated to facilitate storage. Moreover, efficient classification attributes and user-friendly operations should aid individuals with poor storage habits in accessing and organizing items. Based on the consolidation, a total of 12 original requirements from the special user groups for household storage have been identified, as shown in **Table 1.**

KJ Analysis Method, also known as Affinity Diagram, primarily relies on the interrelation of information to categorize cluttered information into different hierarchies, clarifying the corresponding relationships among the information. When applying the KJ method in the analysis of user requirements for the household intelligent storage cabinet, user needs can be categorized with mutual affinity. This approach is presented through a combination of graphics and text,

using a visual format to reveal the essence of issues within the intricate web of user requirements (He, 2022). As illustrated in **Figure 2**, the three categories of the primary requirement indicator diagram for the household intelligent storage cabinet can be obtained. These categories are considered from the perspectives of storage demands, safety and health, and auxiliary adjustment.

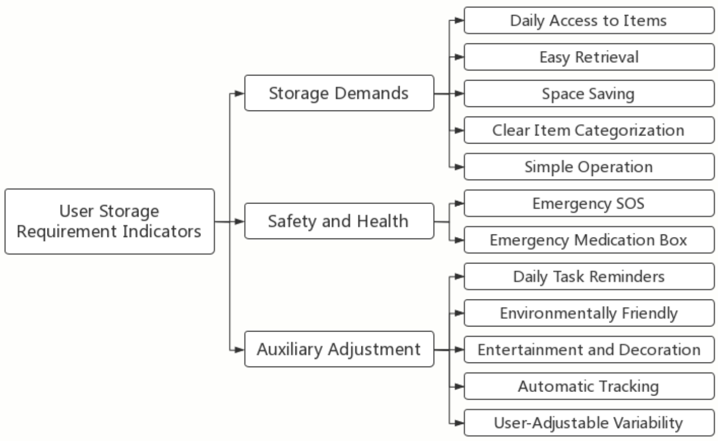


Fig 2. Three-level demand indicator chart.

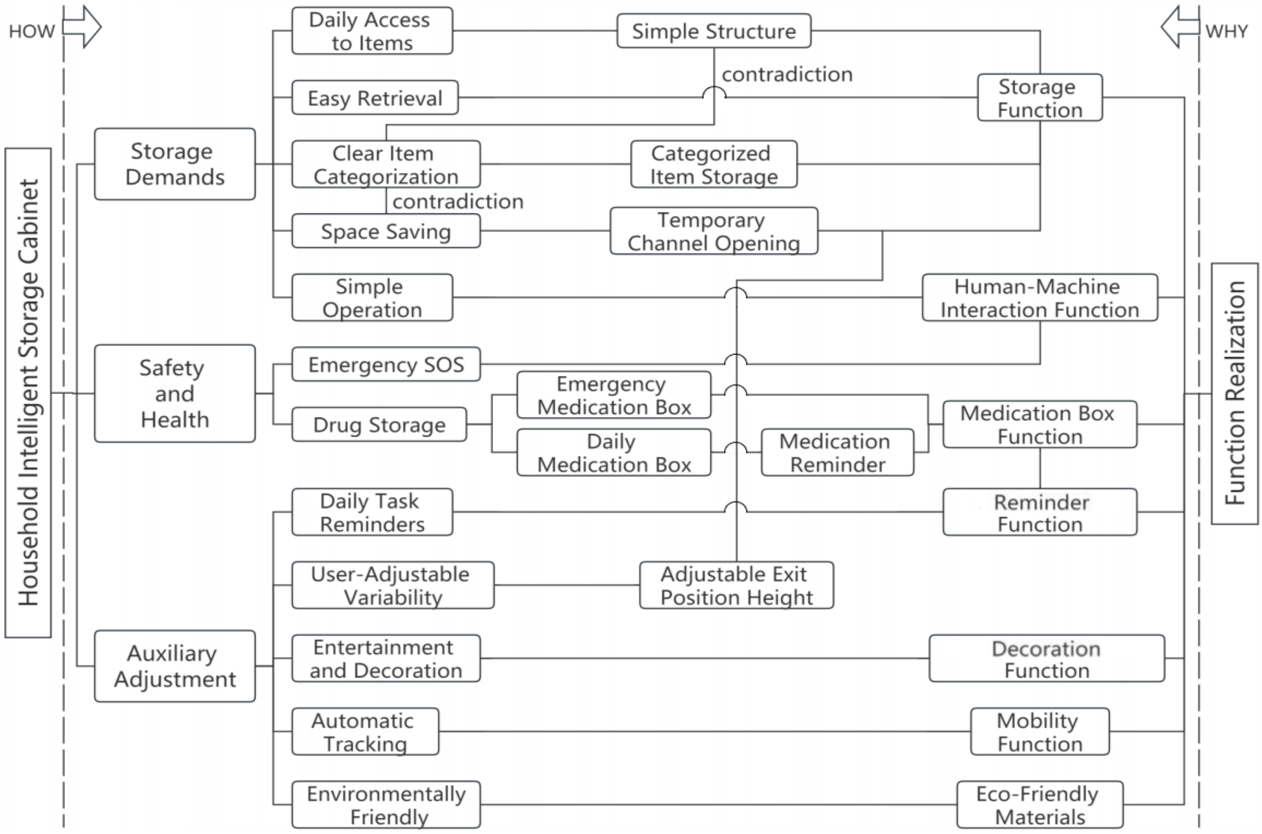


Fig 3. The FAST function tree of household intelligent storage cabinets.

3.3 Constructing a Product Functional Model

FAST method, also known as Function Analysis System Technique, is a top-down approach that analyzes the interrelationships between functions from a systemic perspective. It employs the construction of a FAST function tree to illustrate these relationships (Du et al., 2022). For the user requirements established in this case, a FAST function tree is constructed based on the perspectives of storage demands, safety and health, and auxiliary adjustment. This tree models the functionalities of the household intelligent storage cabinet, progressively analyzing the interrelationships between functions, as shown in Figure 3 below. Ultimately, the primary function of the household intelligent storage cabinet is determined to be storage, catering to users' efficient storage needs. Secondary functions include human-machine interaction, medication box functionality, reminder capability, decoration, and mobility, addressing specific requirements of distinct user groups. Moreover, a conflict is identified between the demand for clear item categorization and the requirements for a simple structure and space-saving design.

3.4 Functional Problem Solving

The general process of solving problems using the TRIZ theory involves simplifying the design-related issues into generic problems. Through the inventive principles, separation principles, scientific effects database, and other tools provided by TRIZ theory, universal

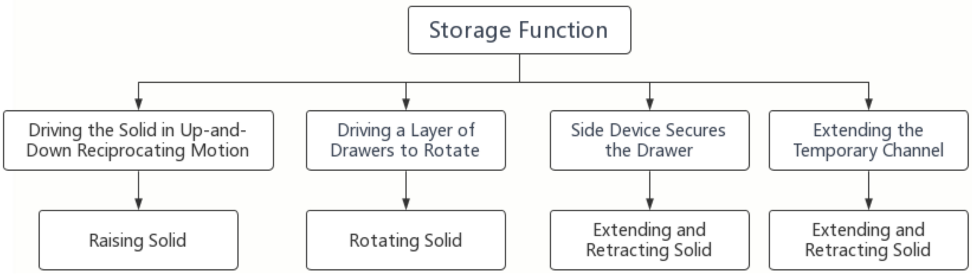


Fig 4. A generalized description of the storage function.

solutions for these general problems can be found (Cheng et al., 2021). Given that the storage function involves a larger number of target users and user requirements, represents a pivotal sub-function within the FAST function tree. The storage function will be taken as an example and TRIZ theory's function-oriented search and contradiction matrix is applied to solve and optimize it.

(1) Functional Problem Solving Based on Function-Oriented Search

Function-oriented search is a problem-solving tool based on the analysis of existing mature technologies worldwide. In the process of functional problem solving, utilizing TRIZ theory's function-oriented search, benchmarking analysis, and feature transfer for design can reduce the randomness in the design process and enhance design efficiency.

a. Generalized Description of Function

Combining the analysis of the usage process, the storage function can be broken down into four secondary sub-functions. Firstly, the up-and-down reciprocating movement of the central rotating device can position it at the same height as the drawers storing the desired items. Secondly, the rotation of the drawer containing the required items is propelled by the rotating device, and rotating the drawer containing the desired items to a reachable position on the side. Thirdly, a side fixation mechanism secures the drawer containing the required items. Finally, by extending a temporary channel, the drawer containing the required items is secured by the side fixation mechanism and then extends alongside the temporary channel simultaneously. It is then moved by the up-and-down reciprocating movement device to the upper exit, enabling users to retrieve the desired items.

As depicted in Figure 4 below, the four-step motion sequence of the storage function can be generalized as follows.

b. Function-Oriented Search

Function-oriented search is a tool that is used to find functional solutions in mature technological domains. It begins with behavior and objects and is used to seek reliable technical solutions in specific knowledge databases through a generalized description of functions. These solutions are then transferred to handle technical issues that arise during the design of new products. Specialized commercial software tools like Invention Tool or Goldfire can be utilized for this purpose, and searches can also be conducted through search engines and patent databases. An example of function-oriented search results for the functions 'Rotating Solid' and 'Extending and Retracting Solid' is presented in Figures 5 and 6 below.

c. Benchmarking Analysis and Feature Transfer

Benchmarking analysis is centered around the primary values within the engineering system, further analyzing and comparing the results selected through function-oriented search. The main principle is to achieve product functionality with low cost and ease of operation. Feature transfer is an analytical tool that extracts relevant characteristics from alternative products, which means transferring solutions or principles from more mature areas in other technological developments that address similar issues to the product being designed, for resolving existing problems (Gui et al.,2016).

Taking the example of driving a specific layer of drawers to rotate, benchmarking analysis revealed that a gearbox is structurally more suitable, relatively cost-effective, and offers higher space utilization. Therefore, the gearbox's structure is applied to drive the rotation of a specific layer of drawers through feature transfer. Through feature transfer, it is discovered that the gearbox primarily relies on the meshing of gears to achieve the rotation of the solid being driven. When applied to drive a specific layer of drawers, gear rotation can also be

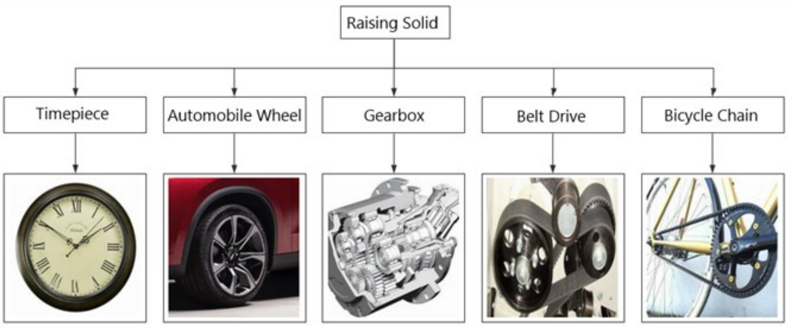


Fig 5. Feature oriented search for ‘rotating solids’

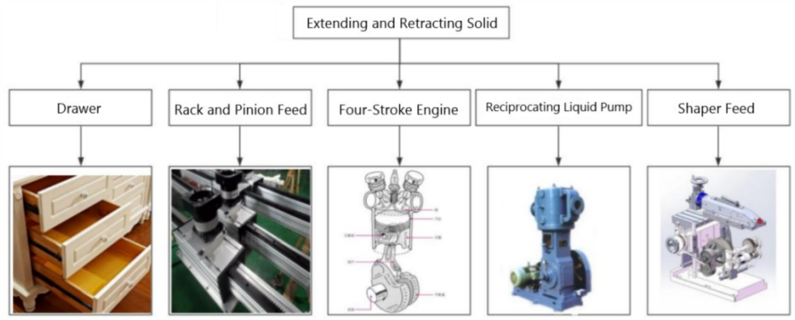


Fig 6. Function - oriented search for 'extend and pull back solids'

achieved through the intermeshing of gears, with a special cam fixed on a large gear to facilitate the rotation of the cam, which in turn rotates a specific layer of drawers.

Applying the same method to analyze other related sub-functions, the results of feature transfer are shown in Table 2 below, thus achieving the four secondary sub-functions of the household intelligent storage cabinet's storage function.

(2). Function Optimization Based on the Contradiction Matrix

The Contradiction Matrix of TRIZ theory establishes a correspondence between 39 engineering parameters and 40 inventive principles. After analyzing practical problems and consulting the Contradiction Matrix, corresponding inventive principles can be found through 'improved parameters' and 'worsened parameters.' These inventive principles provide a direction to help find specific solutions to the problem at hand (Huang et al., 2018).

Identifying contradictions through the utilization of the FAST function tree can sometimes present challenges. To address this issue, it is imperative to ensure that during the establishment of the FAST function tree, all functionalities are distinctly defined, specific, and comprehensible. Categorizing functionalities into primary and secondary categories and conducting an analysis of the relationships and dependencies among them through the depiction of function dependency diagrams is crucial. By discerning direct or indirect dependencies among functionalities, potential conflict points can be pinpointed. Subsequently, through brainstorming sessions and team discussions, potential functional conflicts can be identified.

Analyzing the FAST function tree and user requirements, it is evident that the household intelligent storage cabinet needs to ensure clear classification, which can be achieved by increasing the number of drawers and refining their categorization properties. However, increasing the number of drawers will enlarge the device's volume and complicate its structure, which falls under a technical contradiction. After considering the actual situation, a search in the contradiction matrix pinpointed the engineering parameter to be improved as 'the quantity of substance or transaction,' and the worsened engineering parameters as 'the volume of moving objects' and 'the complexity of the device.' By consulting the TRIZ Contradiction Matrix, corresponding inventive principles can be obtained, as shown in Table 3 below.;

	Original Function Descriptions	Generalized Function Description	Benchmarking Analysis	Feature Transfer
Storage Function	Driving the Solid in Up-and-Down Reciprocating Motion	Raising Solid	Ball Screw Elevator	Ball Screw Transmission Principle
	Driving a Layer of Drawers to Rotate	Rotating Solid	Gearbox	Straight Spur Gear Transmission Principle
	Side Device Secures the Drawer	Extending and Retracting Solid	Gear Rack Feeding	Gear Rack Transmission Principle
	Extending the Temporary Channel	Extending and Retracting Solid	Four-Stroke Engine	Crank and Slider Mechanism Transmission Principle

Table 2. Results of benchmarking analysis and feature transfer.

Table 3. The paradox Matrix of Household Intelligent storage cabinets.

Improved Engineering Parameters	Worsened Engineering Parameters	
	7 Volume of Moving Object	36Complexity of the Apparatus
26Quantity of Material or Events	15，20，29	3，13，27，10

After analyzing the above-mentioned inventive principles, it is found that Inventive Principles 3, 15, and 20 are particularly helpful in optimizing the functionality of the household intelligent storage cabinet. Applying Inventive Principles 3, 15, and 20 to address the conflicts, as shown in Table 4 below.

Table 4. Application of invention principle.

No.	Inventive Principle	Apply
3	Local Quality	It is possible to adjust the shape of the drawers to accommodate various sizes and forms of different household items.
15	Dynamics	Users can create their own designs for drawer shapes, adapting them to suit the storage needs of different items, utilizing rapid assembly and straightforward installation methods.
20	Continuity of Useful Action	Enabling the interlocking of drawers with varying sizes and shapes enhances spatial utilization. Ensuring a more seamless motion flow, reducing gaps between the motion phases of distinct secondary sub-functions, thereby elevating efficiency.

The improved drawer shape, as a result of applying the inventive principles, is illustrated in Figure 7 below.

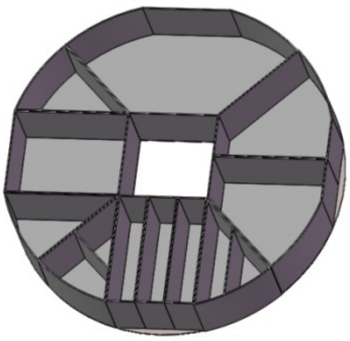
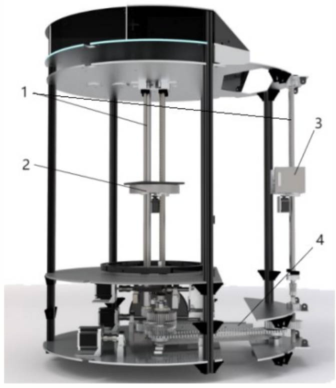


Fig 7. A cross-section of a drawer.

3.5 Integrated Design Solution

For the other sub-functions related to the storage functionality of the household intelligent storage cabinet, we applied a function-oriented search to find suitable methods from mature domains and integrated them into the design of the product. The resulting internal structure of the storage cabinet is depicted in Figure 8. When using the product, users can initially input the items they need through methods such as voice or touch screen. The intelligent storage cabinet will then, based on the user's requirements, perform a series of movements to move the storage space containing the desired item to a convenient location for user access.

The movement of the intelligent storage cabinet is realized through its structural design. First, through user input, the specific location where the user needs to retrieve the item is determined, which is drawer A. Mechanism 2 moves vertically alongside Mechanism 1's rotation to the same height as drawer A. Mechanism 2 rotates to move drawer A to a lateral position. Mechanism 3 locks drawer A in place, and then Mechanism 4 begins to move, creating a temporary passage. Drawer A is fixed by Mechanism 3 and simultaneously moved into the temporary passage. Finally, through the movement of Mechanism 1, drawer A is lifted to the exit position for user access.



1. Ball screw, 2. A middle rotating device, 3. Side-fixed device, 4. Crank-slider mechanism

Fig 8. Internal structure of storage function based on intelligent storage cabinet.

For other important sub-functions in the FAST function tree, a similar process can be applied for design as described above. When combined with conventional design practices, it eventually results in a comprehensive design solution for the household intelligent storage cabinet, as illustrated in Figure 9. The household intelligent storage cabinet designed in this case adds features such as mobility, human-computer interaction, reminder, and medicine box functions compared to traditional storage cabinets. Through intelligent input, intelligent positioning movement, and intelligent daily reminders, the intelligent storage cabinet is characterized by clear classification, convenient storage, simple operation, and a high level of intelligence.

Additionally, the product offers a range of auxiliary functions to meet the daily needs of special user groups. It assists Alzheimer's patients in storing items through human-computer interaction, helps lower limb-disabled individuals store items by adjusting the mobility and height of the outlet, and aids those without good storage habits with effective categorization attributes and convenient operations. Overall, it effectively satisfies user requirements.

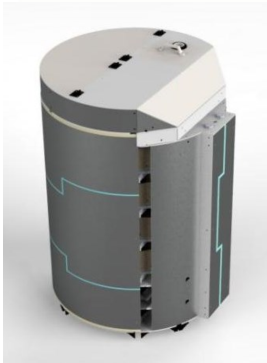


Fig 9. Comprehensive design of household intelligent storage cabinets.

Taking into account that the project topic originates from real-life scenarios, possesses openness and societal relevance, and its implementation process necessitates an in-depth analysis of engineering principles, encompassing multiple interrelated sub-problems, and showcasing creativity, it also strongly emphasizes the development of abilities in addressing complex engineering issues and fostering higher-order thinking.

4. Conclusion

A project-based teaching method for innovative product design based on KJ/FAST/TRIZ methodologies is proposed, to address the requirements for fostering students' abilities to solve complex engineering problems and their higher-order thinking skills. A case study of a household intelligent storage cabinet project completed by students is also presented. The application of integrated project-based teaching using KJ/FAST/TRIZ methodologies can cultivate students' attention to societal needs, implementing a step-by-step progression according to cognitive patterns throughout the entire conceptual design process. This approach enhances the feasibility of innovative design, gradually fostering students' ability to solve complex engineering problems through a gradual deepening of their understanding. Throughout this process, problem-oriented learning encourages students to integrate knowledge from various fields such as engineering, mathematics, and physics to formulate systematic solutions. Simultaneously, project-driven learning through teamwork fosters the development of comprehensive skills including communication, coordination, teamwork, and project management. Establishing regular feedback and reflection mechanisms throughout the learning process aids students in continuously improving their individual thinking and solutions, thereby enhancing self-awareness and self-improvement capabilities.

Compared to existing research, this paper proposes an integrated application of comprehensive innovation methods, presenting a product innovation design process based on KJ/FAST/TRIZ and substantiating its rationality. Oriented toward societal needs, this approach aims to cultivate students' abilities to solve complex engineering problems and meet high-level thinking demands.

This study will provide a certain reference value for promoting engineering certification in related fields and for the construction of First-class courses. In terms of how to better leverage the selection of project themes, the guidance during project implementation, and the assessment of project completion, further practical exploration is still required in the future.

Acknowledgements

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