Training Methods for Young Designers in Mechanism Design and Development of Training Materials

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Abstract. A common source of concern for designers at the beginning of their careers is the factors that need to be determined on the basis of experience and a sense of balance as designers. Such factors are no obstacle to experienced designers. However, no matter how much young designers think about those factors, they cannot arrive at the solution. As a result, they can pose only very simple questions about such factors. To create new machines, knowledge of kinematics becomes necessary. Furthermore, to create better machines, a crucial aspect is the development of design sensibility. Design sensibility in this context refers to the ability to incorporate balanced motion and force without unnecessary complexities on the basis of a combination of extensive knowledge and experience with mechanisms. In this paper, we reaffirmed mechanism design as one of the fundamentals of mechanical design principles. We examined the content that young designers can effectively apply, for example, basic approaches that enable the rapid ideation of various mechanisms, when engaged in mechanism design, especially in advancing new product designs. In addition, we developed training materials that present practical examples for learning.

Keywords: Mechanism design, Theory of Mechanism, Creative Process Training Method and Materials, 2D and 3D Drawing.

1 Introduction

When considering the design of a mechanism to fulfill a certain function, the ideation of mechanisms involves the process of searching for mechanisms, within the realm of knowledge, that can achieve the desired motion and their combinations. This process is often intuitive because solutions are not limited to a single mechanism, and formalizing the mechanism into equations can be difficult. To intuitively find solutions, a broad knowledge of various cases is essential. By associating and examining mechanisms with similar motions, new ideas for mechanisms can emerge.

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In this paper, we reaffirmed mechanism design as one of the fundamentals of mechanical design principles. We examined the content that young designers can effectively apply, for example, basic approaches that enable the rapid ideation of various mechanisms, when engaged in mechanism design, especially in advancing new product designs. In addition, we developed training materials that present practical examples for learning.

This study covers the following aspects: (1) kinematics and dynamic mechanisms, (2) design as a creative process of combining mechanisms, (3) improvement of technical skills for mechanism designers, and (4) development of training materials to clarify the relationship between 2D and 3D drawings, along with the outcomes of using these training materials.

2 Kinematics and dynamic mechanisms [1]

In categorizing the content and methods of mechanical design, structural design involves designing stationary elements such as a car body or frame (designing the product's exterior is referred to as enclosure design). On the other hand, mechanism design involves designing moving components such as the drive components of a car or the arms of a robot.

The strength of the product and fluid flow are considered in the design of a car body (structural design). Calculations of motor gear ratios and the load applied to shafts become necessary in the design of drive components (mechanism design).

The skills required for mechanical design include knowledge of material mechanics, thermodynamics, fluid dynamics, and mechanical dynamics for structural design. In addition, the design and operability (ease of holding and user-friendliness) of the product should be considered. In the mechanism design of moving components, knowledge of electrical design and programming, as well as mechanics, is essential. Therefore, merely understanding the structure of individual components is insufficient; a thorough understanding of when and how such components operate under different conditions is necessary.

Kinematics is the study of the mechanisms that constitute machine devices. It involves the systematic analysis of the motion (relative motion) derived from a combination of elements, irrespective of the actual shape, material, or transmitted force of mechanical components. Kinematics is a subfield of mechanical engineering.

The history of mechanisms dates back to BC and has been in practical use since then. Many ideas from predecessors have been inherited over the years. This is because without understanding mechanisms, both the design and operation of machine devices become nearly impossible. In other words, the mechanism is the foundation of machines. [2]
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To provide a specific explanation, when a design objective is determined, the required movement for each component is initially estimated. The key then becomes how to realize the movement by a suitable mechanism. This is where kinematics comes into play. Multiple mechanisms are considered as the candidate. The optimal one is selected among these multiple options by considering the simplicity of elements that realize the movement, the mechanism that satisfies the required forces, the mechanism with the least energy consumption, precision, the number of power sources, and other factors.

3 Design as the creative combination of mechanisms

Manufacturing is an area in which Japan excels, and it is an act that brings joy to people. However, in the modern era, merely engaging in traditional craftsmanship is not enough to survive; it requires the creation of new products through creativity and technological improvement.

In our daily lives, we often face difficulties or unexpected problems, and we navigate through them by various methods. At these times, we unconsciously engage in small acts of creativity. The fact that we are alive today is evidence of the success of such creative acts. Let us take a somewhat systematic look at these unconscious creative processes.

In newspapers and magazines, the term "innovation" is frequently encountered. Innovations are born from creativity. While riding the wave of the times is crucial, one might feel that being creative is challenging and that they are not naturally inclined toward creativity.

Creativity is often associated with generating groundbreaking ideas that nobody else has thought of. According to dictionaries, it is defined as the ability to overcome existing ideas, rules, patterns, and relationships, and the capacity to create meaningful new ideas, forms, methods, and interpretations. To foster creativity, one must consistently maintain a positive outlook, along with possessing a flexible and imaginative mindset.

3.1 Creativity is not a flash of inspiration

First, creativity in fields such as business, science, engineering, and art refers to combining two or more existing elements in a new way. Creativity involves a process that

everyone has likely encountered in everyday life. The need for creativity arises when we face problems that require new solutions.
Second, the common notion of “inspiration” occurs not spontaneously but rather, after earnestly contemplating a problem and then engaging in entirely different activities. It does not emerge from anything but is a result of dedicated thought and exploration in search of breakthroughs.

3.2 Creativity

When we talk about creating new products through creativity, it does not mean designing and producing entirely new products from nothing. It is essential to clarify the definition of creativity.

Despite the widespread acknowledgement of the importance of creativity and innovation by many experts, there has been no detailed discussion on how to approach creativity and innovation specifically. This is because there is a lack of a clear understanding of the definition of creativity.

First, it is necessary to dispel the common notion that “new products are created from nothing”. The reality is that new products are created by “combining two or more existing products”. In other words, it involves “integration”.

In practice, very few entirely new products are invented from nothing. Just looking at the products in our homes can show this point. Even items such as mobile phones are combinations of preexisting components. Discovering entirely new products is difficult.

Creativity is the integration of two or more existing elements. It does not emerge suddenly from nothing. Instead, it involves integrating known facts and elements.

3.3 The fascination of creativity lies in the “wonders” of combinations

Designing is frequently based on the perspectives and ways of thinking of designers. For example, fixed ideas arise from successful facts in companies, leading to a lack of awareness of changing times and customer demands. Companies that are unaware of these changes may fall behind, lose competitiveness, and eventually disappear. Breaking free from established fixed ideas is not an easy task.

By breaking down old, established sets of facts and establishing new combinations, one can transform seemingly outrageous combinations into remarkable combinations. There are various possible combinations, and the key lies in the effort to try different combinations.

The only way for resource-scarce Japan to survive is to remain competitive by creatively combining existing products, including software, through its intellectual capabilities.

To lead the world in the fields of science and engineering and to nurture young talent, it is crucial to create an environment that can foster independent creativity free from fixed ideas, not simply following trends. In essence, carefully observing various issues and integrating facts systematically help us understand what is happening in the world.

3.4 Significance of conceptual design in manufacturing

The ability of manufacturing companies to develop innovative products that lead to their success often relies on the capacity to nurture, conceptualize, and develop new ideas and concepts that eventually give rise to new products. Companies that allow designers the time to create and consider multiple alternative design ideas tend to stay one step ahead of those that do not.

The conceptualization phase is positioned upstream of the entire design process, and the success or failure of the conceptual design significantly affects the quality, cost, and delivery schedule of the product in subsequent processes. What should be considered in conceptual design?

For instance, the keys of conceptual design include the following: (1) how to unfold the overall concept, (2) what layout to adopt, (3) how to design the overall product, (4) what mechanisms to use, (5) what drive system to use, (6) what control system to use, and (7) how to satisfy cost target. By considering various aspects, an image of the design is gradually solidified. The key challenge during conceptual design is how to generate ideas effectively while contemplating these diverse elements.

3.5 Freehand drawing with paper and pencil

I recommend using paper and a pencil in the conceptual design stage. The process involves drawing on paper until a solid outline image is firmly established in your mind. Despite the convenience of 3D computer-aided design (CAD) systems, the time required to sketch rough ideas on paper with a pencil is faster than that using 3D CAD systems.

If each component is analyzed and sketched in a picturesque fashion, you can consolidate the image using the outline without the need to memorize every detail in the drawing.

By naturally controlling the pencil's angle and repeatedly drawing and erasing lines that do not meet your expectations, elements that contradict each other, such as existence and nonexistence, and fullness and emptiness, are constantly blended until they eventually merge. An environment is constructed, where vivid lines show infinite expanses, unintentional lines evoke new ones, and conventional ideas lead to more innovative ideas. By evaluating the drawn drawing and making further corrections, you ultimately reach the ideal image.

Hand drawing and 3D CAD, while sharing the same ideas for design and drafting, overlap in some roles but also diverge in other roles. Analog, as well as digital, has advantages.
Freehand drawings do not require the precision of 3D CAD systems. Fine chamfering and processing can be implemented on 3D CAD systems during detailed design. Freehand drawings used in function verification or structural validation serve as excellent conceptual design documents (drawings) and can be valuable resources for the conceptual design of next-generation models.

4 Improvement of skills of mechanism designers [3]

The following was revealed through technical education for young designers and new employees.
(1) They have a broad range of engineering knowledge but lack true fundamental knowledge.
(2) They have not received experience-based education that leads to practical design.
(3) They lack knowledge of mechanical materials and machining methods.
(4) They are unable to construct mechanisms.

Regardless of the product, the structure becomes complex as the number of functions increases. Technologies from different areas are combined in many aspects of the product. Overall, the complexity of the entire product increases. The difficulty in design increases exponentially as the complexity of the product increases, which results in a low probability of success.

Under such circumstances, the skill to comprehend the design contents is required.
(1) Is the integrity of components ensured?
(2) Is the overall composition appropriate?
(3) Are safety and recovery features properly incorporated into the product?

Designers should be able to comprehend the design contents from various perspectives. Otherwise, high-quality design cannot be maintained. To this end, it is necessary to improve creativity and design skills. The following are the details of the required improvements in skills.

1) Broad view of design process.
The term “design” may make us think of actual tasks such as calculating and drawing or testing and measuring prototypes. In a narrow sense, it is true that the design process is centered around such tasks. However, designers should assume a broader view of the design process when designing a product with a certain level of complexity or

when they are trying to improve the quality of design.

2) Following design procedures.
In actual designing, the first thing to do is to define the requirements that the object to be designed (design object) must satisfy. Evaluation during the design process is helpful for preventing inappropriate design. Evaluation after using the product will contribute to the improvement of design quality in the long term.

3) Exercising autonomy as designers.
The nature of the design process is inconsistent with control. While giving designers a certain level of freedom, it is necessary to provide them with a framework or direction of design by defining goals and requirements. Encouraging each designer to exercise his/her autonomy and to show his/her ability to the fullest within that framework is the best and realistic strategy.

5 Development of training materials to clarify the relationship between two-dimensional (2D) and 3D drawings and their outcomes [3],[4]

5.1 Training material to provide experience of workflow

It requires some ingenuity to turn a knowledge-oriented mindset into a hands-on mindset. To this end, we developed training materials through which young designers and new employees experience an ordinary workflow of observing, thinking, deciding, and yielding output on their own responsibility.

One of the training materials is a practical exercise used for mechanical education, called the "disassembly" of a calligraphy machine named Fude-R. The structure of this machine has three axes, X, Y, and Z. The X- and Y-axes are equipped with a stepping motor and a ball screw driving device, while the Z-axis is equipped with a push-pull solenoid. The task for young designers and new employees is to create freehand drawings of parts from the assembly drawings of the calligraphy machine and the machine itself. This is a common task in mechanical courses, and "comprehending and creating drawings" is one of the fundamental skills. Namely, young designers or new employees must recognize the shape from the drawings and convert the information received through the eyes into freehand drawings.

1) To create drawings.
To create drawings, it is necessary to fully understand the mechanism. A vague understanding is not sufficient. If one knows mechanical drawing techniques but is not able to comprehend and create drawings, it is like knowing the structure of a bicycle but not being able to ride it. The knowledge obtained through memory-based learning alone is not enough to find solutions.

2) Sense of accomplishment, fulfillment.

Young designers or new employees gain a feeling of accomplishment when they find a reasonable solution to a problem on their own, which gives them some confidence and a sense of fulfillment. It serves as a stepping stone to the next step. This is what we aim to achieve.

3) Ingenuity in lectures.
The lecture method is also well considered. Corrections are marked in red. Only the type and number of errors are given to young designers or new employees. We encourage them to solve the issues, giving them hints but not telling them the answers. This requires persistence on the part of both the instructors and the young designers and new employees.

4) Evaluation of drawings.
The evaluation of drawings is based on whether a product that meets the requirements can be manufactured from the drawings. Drawings are considered to be acceptable if young designers or new employees have defined the tolerance, surface texture, and surface treatment on the basis of their own reasoning. The key is whether their intention is conveyed in the drawings. When they give an answer but are unable to explain the reasoning behind their answer, their understanding is insufficient.

5.2 Outcomes of using training materials

A common source of concern for designers at the beginning of their careers is the factors that need to be determined on the basis of experience and a sense of balance as designers. Such factors are no obstacle to experienced designers. However, no matter how much young designers think about those factors, they cannot arrive at the solution. As a result, they can pose only very simple questions about such factors.

In design, young designers often encounter factors that cannot be determined from the standards or logical calculation. We are trying to give simple answers to their simple questions by using analogies. If we can draw out “I get it” from them, then they have acquired and assimilated a piece of knowledge.

We have developed training materials that help young designers understand how mechanisms work. The training materials are based on a book entitled “*Mechanism no Jiten* (Encyclopedia of Mechanisms)” with the original 2D drawings in the book having been replaced with 3D drawings.

The example of the mechanism used in this research is “Encyclopedia of Mechanism” by Shigeru Ito (published in 1983, Ohmsha). The original text is a book by Gonpachi Asakawa, professor emeritus of the Tokyo Institute of Technology, and is part of his masterpiece “Machinery Elements”, first published in 1912 (Meiji 45). “Machinery Basics”, which can be called the bible for engineering engineers, is a beloved classic from the Meiji era to the Reiwa era. [2]

The outcomes of using the training materials are as follows.
1) Young designers understand design procedures (total flowchart).
2) They experience the problem resolution process (concept design and rough sketches) keeping in mind that their design directly affects the manufacturing process (design = manufacturing).
3) They understand mechanisms on their own (solids and projection drawings).
4) They become able to choose appropriate materials (examples of application of new materials).
5) They become able to devise machining methods (how to manufacture products).
6) They become able to design existing instruments.
We are still at the trial stage and have achieved no noteworthy outcomes. However, the questionnaire survey conducted after the training indicates positive changes in how young designers approach a design process and a design object.

6 Conclusions

If one's unlimited wisdom can be brought forth through thinking and struggling, creating an idea and visualizing it in rough sketches are the essence of the design process. There cannot be improvement in machine design procedures without taking these steps.

When concrete ideas about component configuration are provided, it becomes easy to choose the optimum mechanism from among several candidates because the advantages and disadvantages of each mechanism are made clear.

When there is a certain mechanism that significantly affects the quality of products, designers may prefer to first design that mechanism and then the peripheral components, so that the peripheral components fit with the mechanism.

It has been noted recently that young designers are unable to comprehend drawings.
We hope these proposals will be helpful for young designers.

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