DEVELOPMENT OF TRAINING METHOD AND MATERIALS FOR YOUNG DESIGNERS IN THREE-DIMENSIONAL MECHANICAL DESIGN

Shigeo HIRANO [1, 2], Susumu KISE [2], Sozo SEKIGUCHI [2], Kazuya OKUSAKA [2] and Tsutomu ARAKI [3]
[1] Professor emeritus, Tokyo City University, Japan
[2] Artner Co. Ltd, Osaka, Japan
[3] Professor emeritus, Tsukuba University of Technology, Japan

ABSTRACT: Three-dimensional (3D) computer-aided design (CAD) is a mechanical design tool and helps designers embody their conceptual plan of a design to examine and realize it. It is possible to save time and avoid confusion and establish a more efficient design method by effectively using a 3D mechanical design tool. It has been noted recently that young designers are unable to comprehend drawings. Also, customers have pointed out that young designers in our company lack the ability to comprehend drawings. To solve this problem, the total period of technical training was reduced by 5% and training in hand drawing was introduced in our company. During this training in hand drawing, the young designers are required to model the shape of products three dimensionally in their mind. This training in hand drawing includes tasks at which young designers are inept, and they learn to understand ambiguous portions of blueprints, pictures, and drawings. In general, young designers rely on their intuition gained from 3D models. In the absence of 3D models, their spatial imaginative power tends to decrease. In addition, their basic skills related to mechanical subjects decline because of the reduction in the contents of mechanical courses given at educational institutions, leading to the decline in the ability to understand drawings and in the amount of knowledge on materials, basic engineering, and kinematics. We have revised the educational contents to be compatible with both virtual and real spaces by analyzing the characteristics of 3D shapes. We also aim to improve the quality of engineering education, including 3D printer prototyping as well as designing and evaluation of prototypes. We first developed standard forms of training. By thinking outside of the stereotypical concept based on drawings, we need to carry out a zero-based review of new ideal methods of information transmission. To this end, we must clarify the information required for manufacturing and examine the method of conveying such information by using the merit of 3D data. In this paper, we describe the ideal method of 3D mechanical design and the development of the training method and materials for beginners in mechanical design. (1) Fundamental knowledge of mechanical engineering is generally examined as a basis of 3D mechanical designing. (2) The expected improvement in the skills of machine designers upon mastering the shape modeling technique using 3D CAD (design = shape determination = ambiguity reduction and shape formation) is examined. (3) We developed training materials to clarify the relationship between 2D and 3D drawings. (4) We developed a method for creating 2D drawings using model data generated by 3D CAD to facilitate understanding of both data for functional design and those for production design.

Keywords： Ability to Comprehend Drawings, Human skills, Technical skills, Design Technique and Know-How, Development of the Training Method

1. INTRODUCTION

3D CAD can realize, at a low cost, an environment in which accurate and complete production technical data is available for use when and where it is required by whoever needs it in thenecessary form. Namely, 3D CAD enables accurate and speedy communication.

However, partial optimization, such as the pursuit of modeling functions alone, often leads to results that are far from the original purpose.

While discussing when and how the qualities for 3D mechanical design and manufacturing evolve, there are various phenomena of interest to be clarified. Here, “interest” is an important keyword.

The cycle of interest, discovery, and enthrallment becomes a soft power that encourages us to explore the reality of things. If you see a bolt, you may want to unscrew it. If you see a machine, you may want to disassemble it. Such a simple impulse is one of the most important qualities for design engineers who are at the beginning of their career. Fundamental knowledge of engineering as well as a flexible mindset and creativity are required to nurture excellent design engineers.

In this paper, we describe the ideal method of 3D mechanical design and the development of the training method and materials for beginners in mechanical design.
(1) Fundamental knowledge of mechanical engineering is generally examined as a basis of 3D mechanical designing.
(2) The expected improvement in the skills of machine designers upon mastering the shape modeling technique using 3D CAD (design = shape determination = ambiguity reduction and shape formation) is examined.
(3) We developed training materials to clarify the relationship between 2D and 3D drawings.
(4) We developed a method for creating 2D drawings using model data generated by 3D CAD to facilitate understanding of both data for functional design and those for production design.

2. EXAMINATION OF FUNDAMENTAL KNOWLEDGE OF MACHANICAL ENGINEERING

Recently, with increasing importance being placed on boundary areas, university students have more to learn compared with students in the past. It is also true that their basic academic skills have declined.

Conventionally, students who major in mechanical engineering have to learn four areas of dynamics, namely, mechanics, material mechanics, fluid dynamics, and thermodynamics. Today, they also have to learn quantum mechanics and biological evolution. In addition, in whatever area, they need to acquire the skills to present their idea using a computer. Moreover, they need to understand the finite element method (FEM) in order to make use of the knowledge of material mechanics.

As a result, the content of textbooks for each subject of mechanical engineering has been reduced. For example, up to now, the industrial processing textbook had been like a handbook containing sections with lists of names of machine tools and materials. Now, topics such as cutting theory are absent from textbooks. Students do not even learn the difference between a vertical milling machine and a horizontal milling machine.

For automation technology, there is not even an academic discipline called “mechanization” or “automation”. It is often thought that all that need to be done for automation is to design the necessary parts and couple them together to create a system. However, what is actually required is to determine how the target of mechanization or automation will act.

Academic subjects such as mechanics, kinematics, dynamics, control engineering, and system engineering are related to the process of analyzing an action that humans are able to perform well, extracting what appears to be the essence of the action, and simulating the action by machine. Also, electronic engineering is needed to develop the control elements and software engineering is needed to show how the machine works. These subjects have been fully generalized.

Therefore, it takes a considerable amount of time and effort to apply academic knowledge to practical design processes. Through academic subjects, students can understand that it is important to make fine, simple, and efficient "mechanisms". However, it makes little sense to provide students with automation techniques for specific mechanisms. If students have fundamental engineering knowledge that can be applied to automation, no special education on automation is required.

On the other hand, an important task for automation engineers is to determine the mechanism that satisfies functional specifications. Until recently, the fun of automation was in understanding how the end of a link mechanism works, seeing the achievements of predecessors, and discovering a new mechanism on one's own. One could learn from the past as the old saying says, "visit old, learn new".

That is a lovely thought. However, when link and cam mechanisms become things of the past, taking good old mechanisms as examples is merely nostalgia. Young engineers will not go into the world of automation if experienced engineers insist that things were better in the past. The kind of fun that attracts young engineers resembles what they feel when they are pursuing their goal in video games.

Automation engineers, therefore, should leave nostalgia behind when talking about automation while retaining mechanisms that stir interest. Also, they should show young designers some prototype mechanisms that are stored in a corner of a prototype plant. When young designers see skillfully built mechanisms that actually move, they will be inspired to create such mechanisms on their own. We hope that young designers will create ingenious mechanisms in a new way.

3. IMPROVEMENT OF SKILLS OF MECHANICAL DESIGNERS

The following was revealed through technical education for young designers and new employees [1].

(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.

When the design object is complex, high-quality design results are not ensured without fundamental engineering knowledge. Also, design procedures need to be adjusted in accordance with the design object. Design procedures that worked well for one design object do not necessarily work well for another design object. Designers are required to assess the characteristics of the object they are going to design.

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.

While providing technical training to new employees, we found that, for example, young machine designers have little experience in reading, writing, drawing, and comprehending drawings. To come up with an answer, they first run a search, then retrieve and copy and paste the information. As a result, their answer is correct but some of them are not able to explain the reason for their answer.

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 mechanical design procedures without taking these steps.

4. DEVELOPMENT OF TRAINING MATERIALS TO CLAREFY THE RELATIONSHIP BETWEEN TWO-DIMENSIONAL (2D) AND 3D DRAWINGS AND THEIR OUTCOMES

4.1 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* (Figure. 1). 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 (Figure. 2) 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].

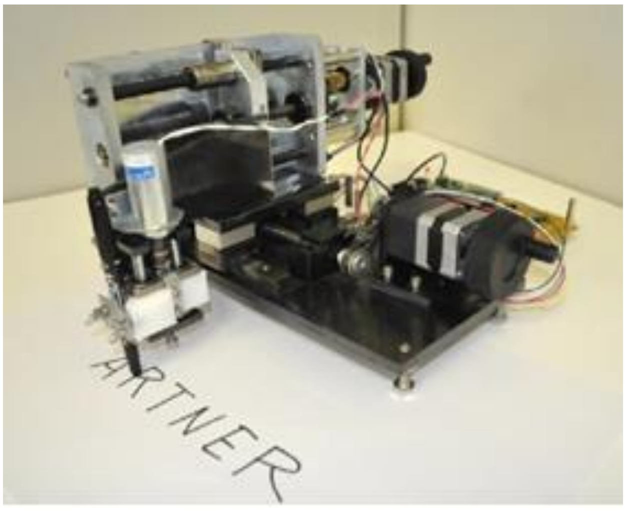


Figure 1: Calligraphy machine named *Fude-R*

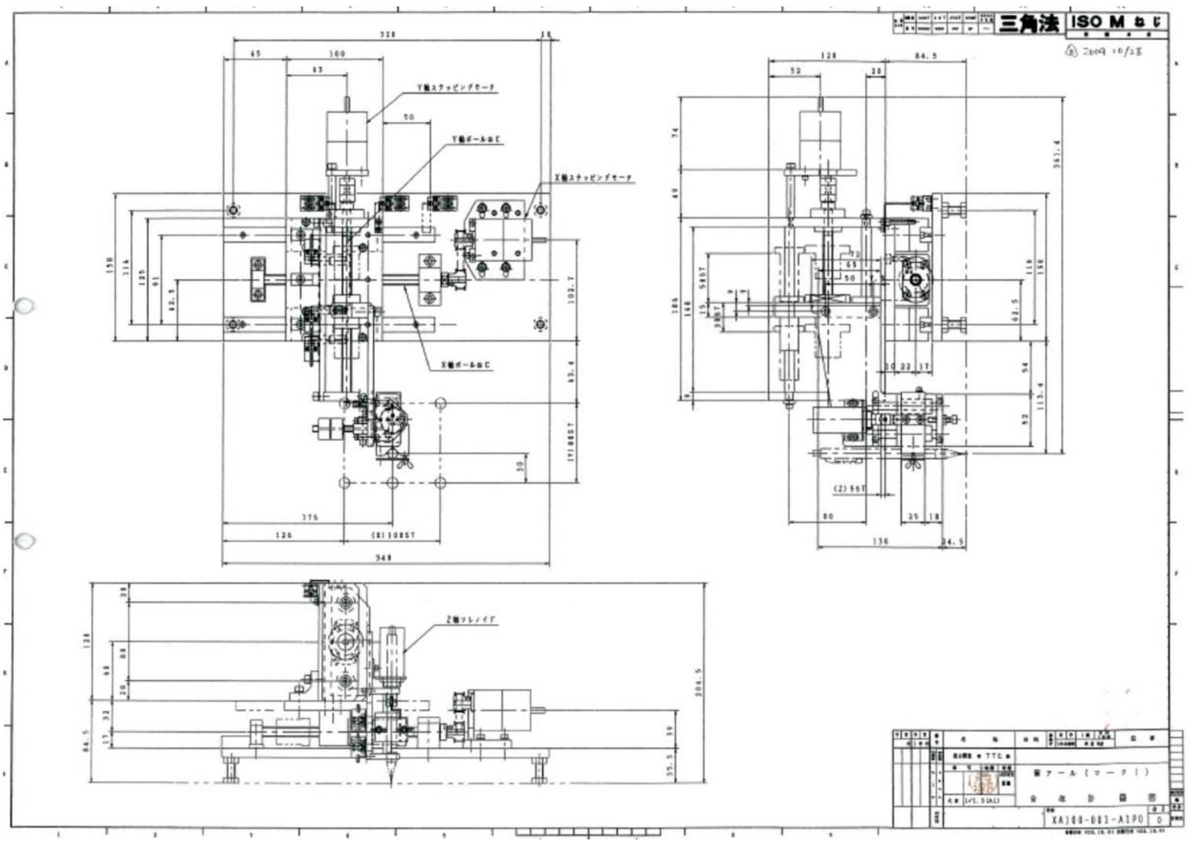


Figure 2: Assembly drawings (*Fude-R*)

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.

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.

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.

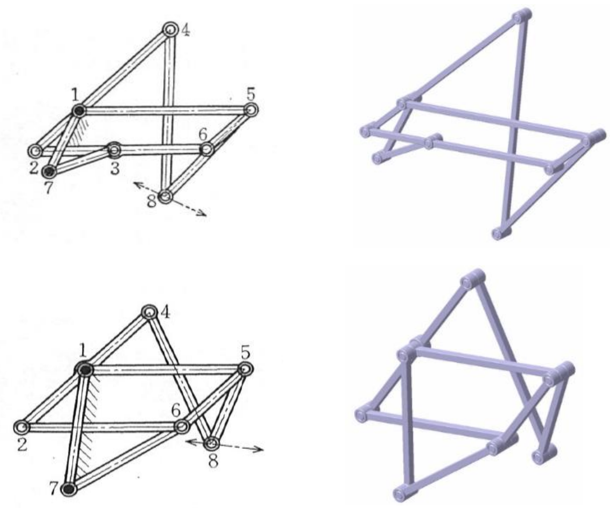
The evaluation of drawings is based on whether a product that meets the requirements can be manufactured from the drawings. Drawings are considered to be acceptable if young designers or new employees have defined the tolerance, surface texture, and surface treatment on the basis of their own reasoning. 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.

4.2 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.

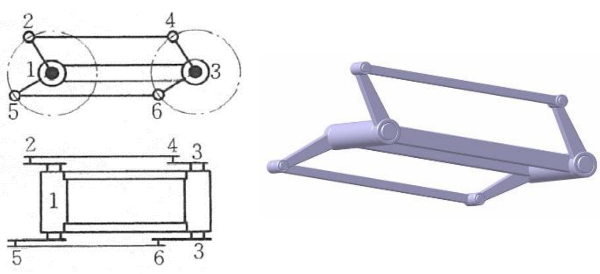
In design, young designers often encounter factors that cannot be determined from the standards or logical calculation. We are trying to give simple answers to their simple questions by using analogies. If we can draw out “I get it” from them, then they have acquired and assimilated a piece of knowledge.

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 all the original 2D drawings in the book having been replaced with 3D drawings. Figures 3–15 show some of them [2].



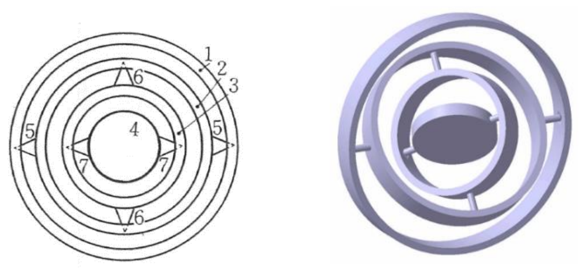
2D Drawing 3D Drawing

Figure 3: Hirakawa parallel motion



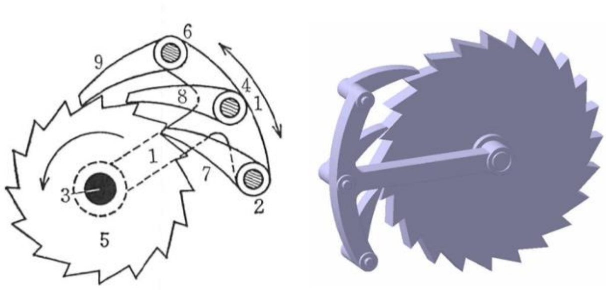
2D Drawing 3D Drawing

Figure 4: Parallel cranks cross compound



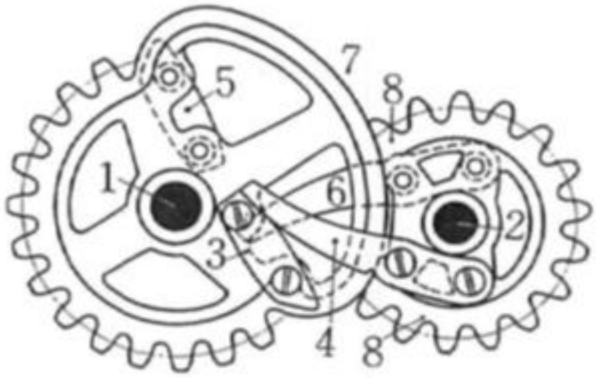
2D Drawing 3D Drawing

Figure 5: Ginbal (Universal joint)

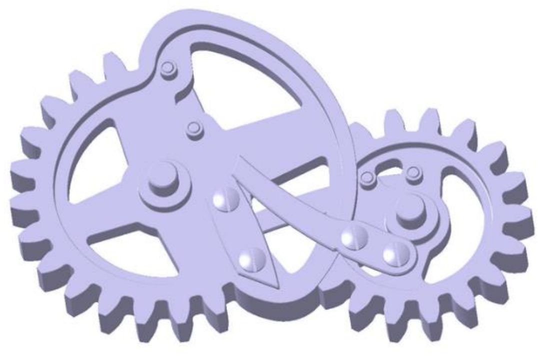


2D Drawing 3D Drawing

Figure 6: 3 Ratchet wheel

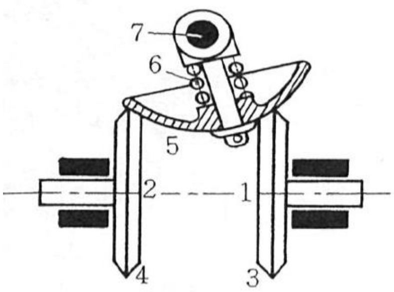


2D Drawing

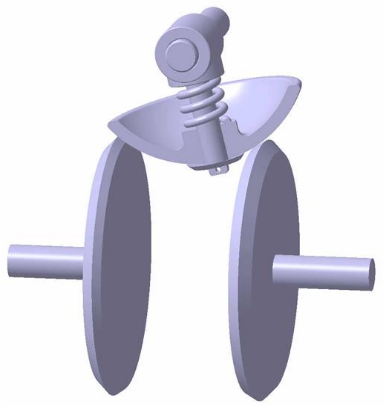


3D Drawing

Figure 7: Irregular formed gear

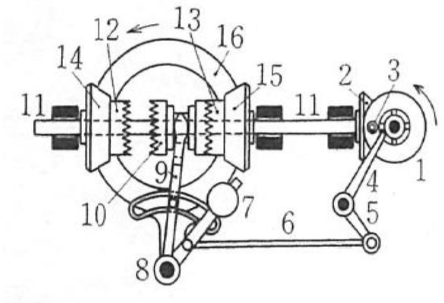


2D Drawing

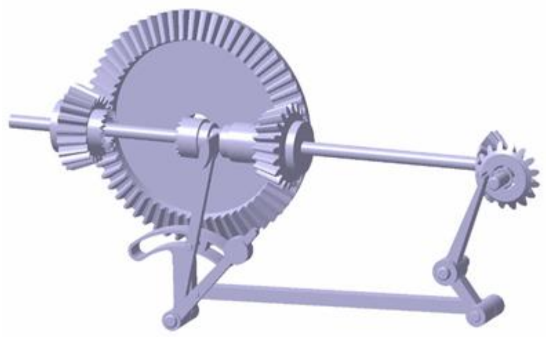


3D Drawing

Figure 8: Friction-using apparatus

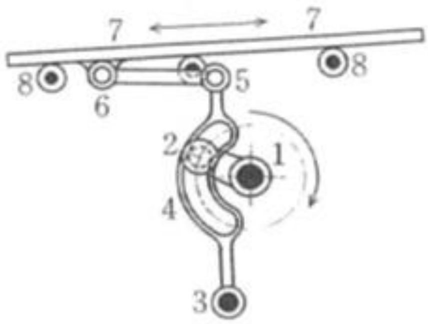


2D Drawing



3D Drawing

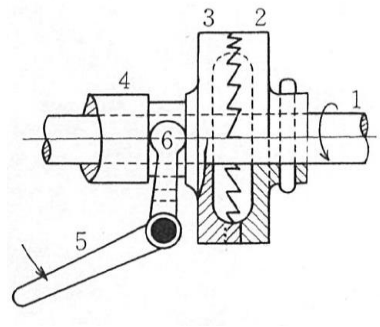
Figure 10: Self-reversing motion



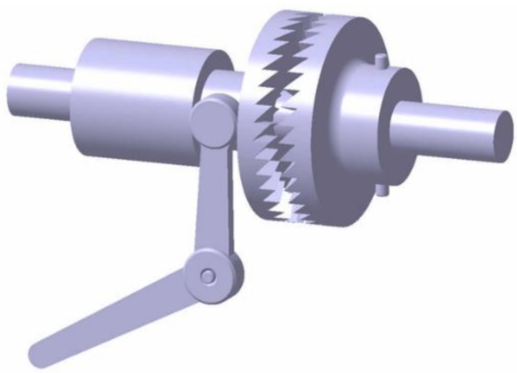
2D Drawing

3D Drawing

Figure 9: Reduced form slider crank

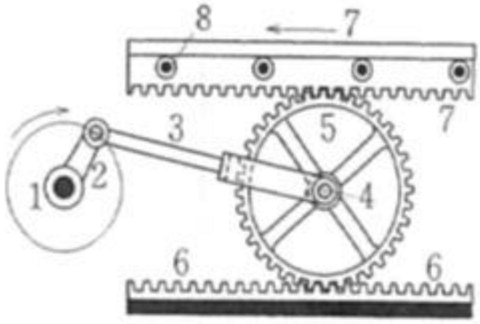


2D Drawing

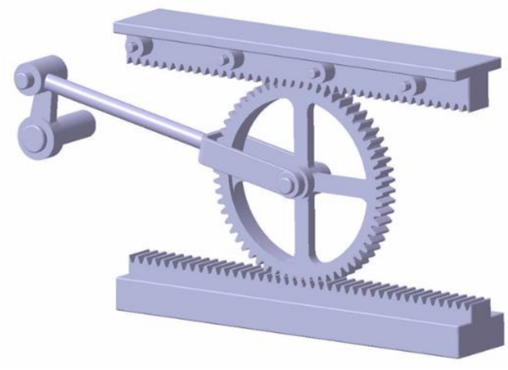


3D Drawing

Figure 11: Running face ratchet

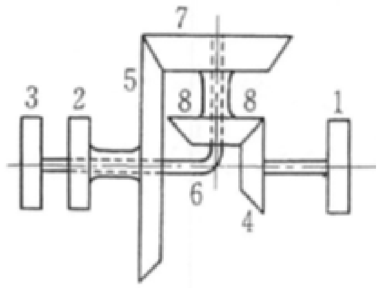


2D Drawing

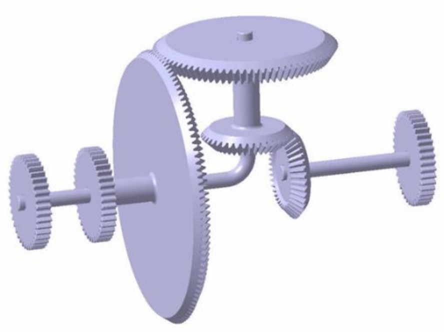


3D Drawing

Figure 12: Compound mechanism

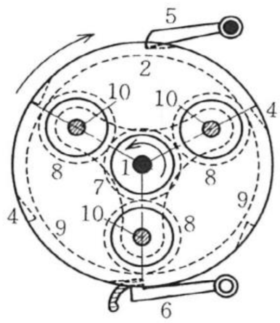


2D Drawing

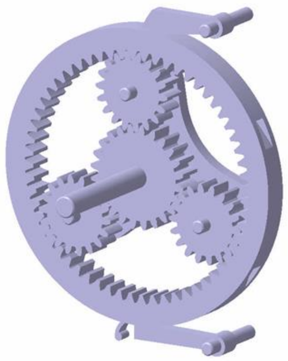


3D Drawing

Figure 14: Differential gears

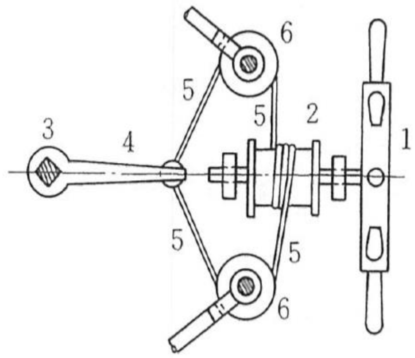


2D Drawing

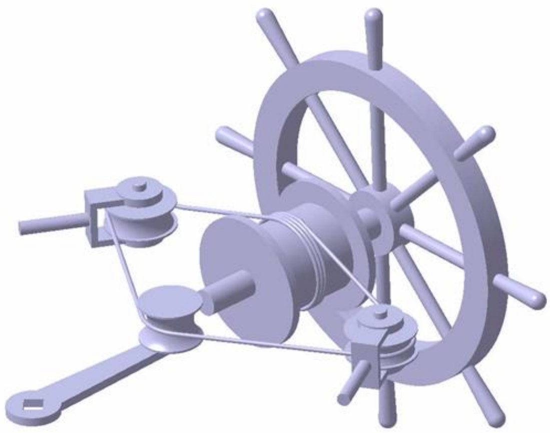


3D Drawing

Figure 13: Capstan gear equipment



2D Drawing



3D Drawing

Figure 15: Steering equipment

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 (conceptual 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 instrments.

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.

For example, the following comment was given in the opinion column on the submitted answer sheet: "All manufacturing processes or some of them, such as the examination of structure, the determination of shape and dimensions, the analysis for functional verification, the realization of a shape by controlling the machine tools, and the evaluation of the deliverable, can be reflected in the model. Now I clearly see the connection between the processes through a 3D environment, although they previously showed little correlation."

5. DEVELOPMENT OF MEASURES TO PROMOTE MUTUAL UNDERSTANDING BETWEEN FUNCTIONAL DESIGN AND PRODUCTION DESIGN

The use of 3D CAD models is a standard technique in designing automobile-related equipment and home-electric appliances. The design process is largely based on 3D CAD data. By making the best use of the originally developed mechanical training sheet, as well as 2D and 3D drawings, and using 3D CAD assembly, we have established environmental facilities to run interference checks and operation checks.

5.1 Measure to improve 3D spatial recognition ability

Even when young designers are able to operate 3D CAD software to some extent, their 3D spatial recognition ability may be insufficient. To address this issue, they are given a hand drawing lesson every morning in the form of an A4 assignment sheet.

5.2 Shape formation

In design, the requirements of products are often satisfied by devising the shapes of the parts. Taking this into consideration, we provide examples of shape formation to young designers and advise them to refer to those examples when they make decisions during a design process.

5.3 Example of reducing ambiguity during design process

In 3D mechanical design, designers have to reduce ambiguity by themselves in order to advance the design process. With the aim of improving the skills of young designers, we provide them with examples of the basis for determining shapes.

5.4 Design skills and know-how

Hands-on education, in which young designers can see, touch, and feel real products, is required. To this end, we provide young designers with training using our originally developed mechanical training sheet and machine element library. Through this training, young designers learn the weight, smoothness, hardness, movement, and mechanism of real products rather than virtual products. Also, through the hands-on education based on know-how accumulated on-site, young designers can be groomed into industry-ready human resources.

The transition from 2D mechanical design to 3D mechanical design is difficult. To facilitate the proper procedures of 3D mechanical design, we propose the following step-by-step approach rather than a single-step approach.

1) Learn the minimum necessary commands required in design.
2) Learn the procedures of modeling in 3D design.
3) Design products in a style similar to that used in 2D CAD.
4) Consider the design style that can make full use of the functions of 3D CAD with a minimum amount of knowledge.
5) Use 3D CAD in actual design and then improve the productivity by utilizing the functions of CAD.

The key is how rapidly young designers can work though steps 1) to 5).

6. CONCLUSIONS

Young designers must develop abilities to invent and design a product that they have never seen before, seek ways to manufacture such a product, and transform their idea into a product. In other words, at the initial stage of design, they create rough sketches that describe the elements and mechanisms of a product based on specifications. Also, they continuously try to find clues about the requests from clients for the product and design, and incorporate such requests into the rough sketches. Such processes are the starting point of mechanical design.

The passing on of intangible techniques from one person to another and the conservation of those techniques as permanent resources are difficult to accomplish through the efforts of one academic group alone. A person supports another person. Experienced designers accept young designers and back them up. Such relationships must underlie the technical support system.

It is important to develop and establish a work process suitable for 3D mechanical design.

REFERENCES

[1] Susumu KISE and Shigeo HIRANO.A Case of New Employee Training in Business (About Technical Skills and Human Skills). *Journal of Japan Society for Design Engineering*, 2019.3:163-169.

[2] Shigeru ITOU. Encyclopedia of Mechanisms. Ohmsha1983.

ABOUT THE AUTHORS

1. Shigeo HIRANO Ph.D. Professor emeritus Tokyo City University, Tokyo, Japan. His research interests are Technology Philosophy, Engineering Ethics, Mechanical Design and Drawing, CAD Design System Education and Development of New Products for Human Support Science.
He can be reached by e-mail: rs4775hirano@ybb.ne.jp
2. Susumu KISE, is a Ability Development Section Supervisor in the Artner Co. Ltd.
e-mail:kise@artner.co.jp
3. Sozo SEKIGUCHI, is a President in the Artner Co. Ltd.
e-mail: sekiguchi @artner.co.jp
4. Kazuya OKUSAKA, is a Ability Development Section General Manager in the Artner Co. Ltd.
e-mail:okusaka@artner.co.jp
5. Tsutomu ARAKI
Professor emeritus Tsukuba University of Technology.
e-mail: tutaraki@yahoo.co.jp