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AN EDUCATIONAL METHOD FOR ENHANCING THE ABILITY TO DESIGN INNOVATIVE PRODUCTS

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Abstract

In the modern era, what we produce is important, and synthetic design thinking is strongly needed to create innovative products that bring qualitative changes to users' lifestyles. This paper proposes an educational method for creative design that can enhance a person's ability to generate a new concept of ground-breaking products that are not merely extensions of existing ones. This approach is unique due to its process, which starts with a person coming up with a concept based on 'intuitive synthesis' in which the metaphor of a 'product like a living thing' is instinctively created; then, details are confirmed by 'analyzing and investigating' the concept's characteristics, followed by a 'representation' of the product and the scene in which it will be employed using a virtual reality device. Based on this educational method, the International Design Engineering School was carried out in 2016. Students enthusiastically joined this program, and their design outcomes were found not to be improvements of existing products, but rather, were pioneering previously non-existent products.

Keywords: Creativity, Design education, Innovation, Intuitive synthesis, Virtual reality

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1 INTRODUCTION

In this paper, we describe an educational method for creative design through group work. This method aims to train persons such that they develop the ability to form ideas for new products that are not merely extensions of existing ones. We will explain the outline and results of the design school that was operated based on this method. The school was held in 2016 with the cooperation of Kobe University and Carnegie Mellon University.

Most conventional product developments seek to solve a problem after determining development targets, based on analyzing existing issues through market research and/or technological forecasting for the near future. This method is based on the thought of improving some specific properties of existing products and/or the technologies that are applied to the products. When higher functions and performance are required, this approach is effective at producing competitive products by improving and revising them, while the created products are limited within the scope that can be expected from existing ones. Meanwhile, in the modern era when goods permeate the market, knowing *what* to produce is essential. There are two approaches to building original products: (1) Pursue an extension of an existing product by thoroughly investigating it and/or using a new technology, or (2) Aim to create a new product and/or new scenes or lifestyles that cannot be realized by expanding upon existing products. Mazda's SKYACTIV Technology (2010) is an example of the former approach, and Apple's iPhone (2016) an example of the latter. This paper will focus on the latter approach.

Based on the above considerations, we discuss a method for generating innovative products from the perspective of design thinking, which is divided roughly into 'analytical design thinking' and 'synthetic design thinking' (for example, Taura, 2016). 'Analytical design thinking' examines the gap between the present circumstances and a goal in terms of problems that are inherent in individuals and society; using this method, one searches for a solution based on the results of analysis. On the other hand, 'synthetic design thinking' creates an ideal concept of a product by synthesizing existing concepts or things. Both types of thinking are necessary to design products. However, synthetic design thinking is strongly needed in the modern era, especially for building pioneering products that bring qualitative changes to users' lifestyles that would not be realized by expanding upon existing products.

We turn our focus to design education. Dym (2005) argues that project-based learning is one of the most effective pedagogical models for teaching design. Practical design education (which is connected to the real world) for generating original products began in the 1990s. IDEO's design thinking (2013) has been deemed an effective method that consists of the following process: (1) Observe the end-user to understand people; (2) Find meaning in the user's behavior and feelings based on the results of observation; (3) Generate lots of ideas by brainstorming based on the observations and experiences from previous phases; (4) Build a prototype of the idea and test it with the end-user; (5) Obtain feedback to refine the idea. The design school at Stanford University (2014) introduced a 5-step design thinking process: (1) Empathize; (2) Define; (3) Ideate; (4) Prototype; and (5) Test. In addition, there are project-based learning (PBL) programs (which mainly focus on human-centered design) at many institutions of higher education such as Aalto University (2015) and the Copenhagen Institute of Interaction Design (2016). All of these programs have a similar composition. First and foremost, they thoroughly analyze users and the usage situation to obtain a deep understanding of and/or empathy with users. Secondly, they set goals that the user truly desires. Thirdly, they come up with a new concept from that angle, and confirm it by prototyping. Matthews (2017) investigated design and design thinking in higher education business programs, and pointed out that education programs based on design thinking are categorized into four approaches. While most of them are focused on the "Human-Centered Design" approach mentioned above, education programs also sometimes focus on the "Integrated Thinking," "Design Management", and "Design as Strategy approaches." In the "Integrated Thinking" approach, design thinking and decision making processes are combined. First, the features of the problem are considered. Secondly, causalities between the features are reviewed. Then, the constructed overall model is considered. The "Design Management" approach is explained as a basis of the model for design as differentiator, integrator, transformer, and good business. Although the "Design as Strategy" approach is also based on human-centered design, this approach mainly focuses on design as a strategic as well as an operational process, with the purpose of creating sustainable competitive advantage (Matthews, 2017). However, in any approach, the processes of first analyzing the current situation and then solving

the found problems are similar. It is not easy to create new products that are not merely extensions of existing products by using these approaches.
We are trying to establish a method to create new products with a different approach. Our proposed educational method aims to train persons to develop an ability to design through synthetic design thinking. In other words, by combining concepts or things that are seemingly unrelated to each other, followed by an analysis, innovative products that are not merely extensions of existing ones will be created. We believe that this method will increase the possibility of designing ground-breaking product concepts that cannot be easily imagined from existing ones.

2 THE BASIC IDEA OF OUR CREATIVE EDUCATIONAL METHOD

Based on synthetic design thinking, we have attempted to construct an educational method for group work to design concepts of innovative products that are not merely extensions of existing ones.
With this approach, we introduced a procedure based on concept generation using metaphors of living things. Since living things have many excellent features, are familiar to people, and are easy to associate with many ideas, learning from the features of living things has been studied as biologically-inspired design or biomimetics (Goel et al., 2014). Most of these studies have aimed to solve problems by using the analogical metaphor of mimicking organisms' features, which can be adapted quite well for similar challenges.
Meanwhile, some arguments insist that the synthetic process originates in intuition. For example, Duggan contended that intuition drives the process of discovering new concepts by pragmatically combining elements (Duggan, 2013). In the domain of design research, intuition has also been drawing attention. For example, one study collected attributes of intuitive processes in design (Badke-Schaub and Eris, 2011). Furthermore, intuition has been discussed in connection to empirically formulated mental models, such as schemata and scripts (Durling, 1999). Referring to these discussions, our educational method proposes the idea of intuitively connecting a product with a living thing as follows: First, intuitively connecting a base product with a living thing to which it is seemingly unrelated, such as the metaphor 'bicycle like a dolphin', then trying to incorporate the living thing's characteristics into the product. A metaphor is used as a method of intuitive synthesis. At this stage, it is expected that persons will acquire the ability of 'intuition and synthesis'.
Then, the idea created in the previous stage is concretized into a detailed design concept. Here, technologies to manifest the characteristics of the relevant living thing and products are investigated; using the results, the product idea is examined in detail. Based on the structure and mechanisms of the analysis, principal dimensions are determined. Then, a 3-dimensional CAD model is created. At this stage, it is expected that persons will be trained to develop their ability of 'analysis'.
Innovative products often lead to innovative lifestyles. For example, the portable music player can be explained to have realized a use that is not conventionally possible, such as listening to music while jogging outdoors. In other words, there is the possibility of creating a new way of using a product or new lifestyle by considering a novel combination of a product and the scene in which it will be employed. However, such products do not exist yet. The new lifestyles they are supposed to enable do not exist and can only be imagined, especially if the new lifestyle is not an extension of a conventional one. This means that it would be deeply effective if designers or users could virtually employ the new products and observe how they change their daily lives. Therefore, in this educational method, the 3-dimensional CAD model of the product designed in the previous stage, and the scene in which it might be used, are projected simultaneously onto a virtual reality (VR) device so that they can be experienced virtually. In our design school, we used the VR device pi-CAVE [6], which is a variant of the Cave Automatic Virtual Environment (CAVE), installed in the Integrated Research Center at Kobe University. The pi-CAVE is composed of four upright screens (two in the front and one on each side) and two screens on the floor; it has a rectangular parallelepiped configuration with dimensions of 3 m × 3m × 7.8 m. Users can view stereoscopic visual images with 3-dimensional glasses equipped with a tracking device, which provides the experience of walking through virtual space. A maximum of 20 people can experience virtual space through the device at the same time. At this stage, it is expected that persons will be trained to develop their ability of 'representation'.
To summarize the above, the design procedure in this educational method is as follows: (1) Intuitively generate an idea of a product; (2) Conduct a survey and analyze the idea; (3) Materialize the product using 3-D CAD, and create a situation in which the product will be used with a VR device.

Our proposed educational method is characterized by a procedure that starts with a person coming up with an idea, followed by analysis; this differs completely from the conventional procedure, which starts with a person analyzing the problem, then coming up with an idea.

3 METHODS

Based on the abovementioned policy, the 'International Design Engineering School' program was carried out. The school program is based on a training camp; that is, all participants stayed in the same hotel and had meals together.
To prepare the participants for the program, we requested that they read Chapter 4 of 'Creative Engineering Design' (Taura, 2016) by themselves before the program began. Moreover, we requested that they learn a CAD tool (Inventor, Autodesk 2016) to generate a computer model of their designed product.
We divided the participants into four teams. The task was for each team to work as a group and come up with a creative idea based on the concept of 'a <product> like a <living thing>'. During the program, we gave the participants the following instructions (Table 1). As illustrated, the participants were given no goal, and they were not informed about the purpose of the products. They were asked merely to follow the process of design.

Table 1. Procedure

Number of steps	Contents
Step 1 (5 mins)	Each member lists 10 distinctive living things and 10 distinctive products.
Step 2 (2 mins)	Each team member chooses three living things and three products that he or she finds interesting from the lists made in Step 1, writes them down separately on adhesive slips, and affixes them to his or her team's sheet.
Step 3 (3 mins)	Each team member *intuitively* thinks of an interesting pair (a living thing and a product) combined in the form of 'a <product> like a <living thing>' by choosing them from his or her team's lists that were made in Step 2.
Step 4 (2 mins)	Each team *intuitively* chooses one pair that its members find most interesting from among the pairs (four pairs per team) that were made in Step 3.
Step 5 (5 mins)	Each team member lists characteristics of the living things of the team's pair chosen in Step 4, writes them down separately on adhesive slips, and affixes them to the team's sheet.
Step 6 (3.5 hrs)	Each team discusses the configuration, mechanism, service system (etc.) that 'a <product> like a <living thing>' would have to represent in order to convey the characteristics listed in Step 5. The team puts together its members' ideas and draws a sketch of the product. Each team imagines the scenes in which the product is used and collects visual images.
Step 7 (Interim presentation)	Each team gives a 20-minute presentation (including questions and answers) about their idea and their work so far.
Step 8 (1 hr)	After receiving instructions on using the VR device, each team experiences pi-CAVE with the projection of 360-degree panoramic images of scenes in which the product is used. Each team examines how the product is employed in the projected scenes, as well as its size, structure (etc.).
Step 9 (7 hrs)	Each team finalizes concrete details about its product such as structure and size, and creates a CAD model, making calculations if necessary. Each team collects more visual images of scenes in which the product will be used.
Step 10 (Mid-review)	The staff members carry out an interim review. Each team summarizes the design plan that was formulated during group work, explains what has been achieved thus far, and in what direction their work will proceed. Then, the team receives advice.
Step 11 (10 hrs)	Each team continues to design concrete details. If necessary, each team uses the VR device to examine how the product will be used, as well as its size, structure, (etc.).
Step 12 (Final presentation)	Each team gives a 15-minute presentation and, using the VR device, demonstrates how the product can be used and in which scenes.

During Steps 1 to 6, steering staff members give instructions step by step. After Step 9, each team progresses in the task on its own.

When all the steps were completed, we asked the participants to answer a questionnaire. The questionnaire contained eight items on a five-point-scale (1: Strongly disagree to 5: Strongly agree). Furthermore, we asked them to write comments and opinions in a free format for the program.

Q1. Did you enjoy this design school experience?
Q2. Did you and your team members perform well together?
Q3. Were the design instructions easy to understand?
Q4. Were the tools (pi-CAVE, Inventor etc.) of interest? Were they effective?
Q5. Do you think that considering the field/situation is effective in developing new products?
Q6. Compared with no procedure, was a metaphor ("○○like △△") a good way to come up with ideas?
Q7. Compared with no procedure, are bio-inspired designs (something that mimics living things) a good way to come up with ideas?
Q8. Was this workshop (group work) a helpful experience for your future, directly and/or indirectly?

4 RESULTS

The school was held over a period of four days from Thursday, 19 May to Sunday, 24 May 2016 at the Integrated Research Center of Kobe University in Kobe, Japan.

4.1 Participants

The participants consisted of eight engineering students each (for a total of 16) from Kobe University (Japan) and Carnegie Melon University (USA). They were 19 to 33 years old and comprised 12 males and 4 females. For instruction and school management, nine staff members (academic or administrative faculty members) also took part. The students were divided into four teams each comprising four members, such that a balance of technical skills and knowledge could be ensured. The teams were named Team R (Red), Team G (Green), Team B (Blue), and Team Y (Yellow).

4.2 Group work

Figure 1 shows pictures in Steps 1 through 6. For each team, members sat at a table. They shared their ideas about <products>, <living things>, and a living thing's characteristics by using a sheet of paper, which was put on the table or hung on the wall near it. Each team gave a presentation lasting about 10 to 20 minutes; the first presentation took place in Step 7. Seven staff members attended the presentations and asked questions.

Figure 1. Pictures of group work (Steps 1 to 6)

Figure 2 shows pictures of Steps 8 and 9. In Step 8, each team received guidance for operating the pi-CAVE and experienced a VR. Each team presumed some situations where the designed product would be used and collected panoramic pictures of the situations. While projecting the pictures onto pi-CAVE, some team members had heated discussions about the product, leading them to go over the scheduled time limit. In Step 9, a team went to a furniture shop to conduct fieldwork and take pictures to make a conjecture about the situation in which the designed product would be used. In Step 10, six staff members provided each team with a review that lasted between 10 and 20 minutes.

Figure 2. Discussions on VR and fieldwork in a furniture store (Steps 8 and 9)

In Step 11, to experience a VR onto which both the CAD model and the situation in which the product would be used were projected, all the teams used the VR device at least once, with each use lasting nearly 30 minutes. When using the VR device, at least two members entered it and talked about the products and the situation through sharing the VR space (Figure 3).

Figure 3. Having discussions in the VR (Step 11)

Figure 4 shows one of the final presentations and demonstrations (Step 12). For the final presentation, each team spoke for about 20 minutes and made use of the VR device for about 10 minutes to show how the designed product would be used in the presumed situations. Ten staff members attended the presentations and took part in the question-and-answer sessions afterward.

Figure 4. Final presentations and demonstrations

4.3 Design outcomes

Tables 2 and 3 display the outcomes of each team in Steps 2 and 3. Table 4 lists the combinations of products and living things that are the basis for creating design concepts and presumed situations. Figure 5 illustrates the sketches and CAD models of the designed products. As shown in the picture, the design outcomes are not improvements on existing products but were pioneering, previously non-existent products.

Team R devised the notion of ‘a <camera> like an <ant>’. The designed product is an ant-like camera that can crawl into places hard to access for humans (such as disaster sites), and forms a ‘swarm’ with other cameras, with each camera taking photos. Team G thought of ‘a <watch> like a <bee>’. The designed product is a watch that transmits information (such as time, location, and warnings of danger) by bone conduction, just as a bee communicates its location or other information by buzzing. They estimated the cost and the price of the product and its parts. Team B came up with the idea of ‘a <lamp> like a <monkey>’. Team B’s designed product is a lamp that can be fixed in various positions, just like a monkey attaches itself to things using its hands, legs, or tail, flexibly adjusting to the situation. Team B went to the furniture store for fieldwork in Step 9. They considered that the product might be sold in the assembled style. Team Y came up with the concept of ‘a <fish net> like a <baleen whale>’. The designed product is a submarine that functions like a whale (blowing a bubble ring to trap fish in it, and emitting noise to confuse the fish) and coordinates with other units to drive fish into a net.

Table 2. Design outcomes in Step 2

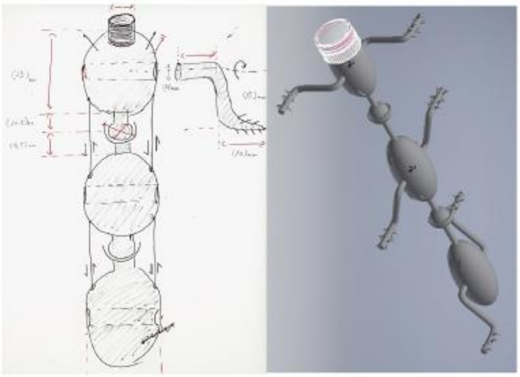
	Product	Living Thing
Team R	Computer, Jet engine, Glasses, Watch, Purse, Robot, Car, Chair, Clock, Camera, Segway, Helicopter	Cockroach, Cactus, Lily, Kangaroo, Crane, Butterfly, Ant, Green caterpillar, Lion, Bacteriophage, Water strider, Elephant
Team G	Wheelchair, Vending machine, Motorcycle, Bicycle, Suitcase, Mobile phone, Glasses, Scissors, Watch, Scuba diving, Robotic pipeline inspector, UAV surveillance	Snake, Fly, Jellyfish, Bee Octopus, Bald eagle, Giraffe, Butterfly, Shell, Rabbit, Squid, Crab
Team B	Desk Organizer, Cup holder, Pen case, Lamp, Clock, Case, Scissors, Sunglass, Chopsticks, Glasses, Traffic light, Scooter	Llama, Turtle, Monkey, Giraffe, Peacock, Elephant, Tuna, Camel, Jelly fish, Shark, Monkey, Turtle
Team Y	Plane, Train, Hotel, Boat, Hot-air balloon, Sport car, Backpack, Luggage, Bike, Bag, Fish net, Shoes	Starfish, Bird, Giraffe, Butterfly, Ginkgo, Water dog, Baleen whale, Armadillo, Octopus/Squid, Hummingbird, Gorilla, Mantis shrimp

Table 3. Design outcomes in Step 3

	Product—Living Thing
Team R	Camera—Ant, Chair—Cactus, Chair—Crane, Robot—Butterfly
Team G	Wheel chair—Squid, Suit case—Shell, Watch—Bee, Vending machine—Octopus
Team B	Desk organizer—Camel, Lamp—Monkey, Scissors—Shark, Traffic light—Turtle
Team Y	Sport car—Bird, Shoes—Bird, Plane—Humming bird, Fish net—Baleen whale

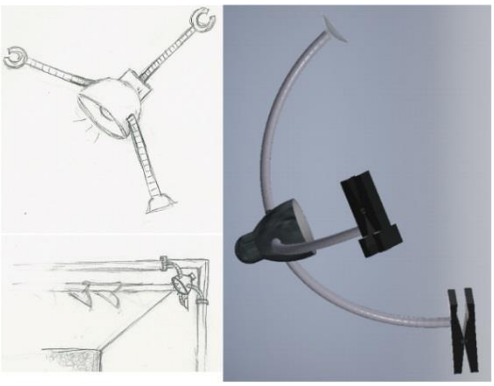
Table 4. Design outcomes

	Product—Living Thing	Concept	Field/Situation
Team R	Camera—Ant	Ant Camera	Disaster-stricken area
Team G	Watch—Bee	The Bee Watch	Crowd of people, inside of a car
Team B	Lamp—Monkey	Aggrappa Lamp	Inside and outside a house
Team Y	Fish net—Baleen whale	Fish Seeking Missile	Deep-sea

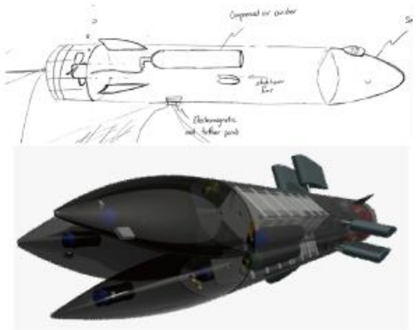


(a) Team R

(b) Team G



(c) Team B



(d) Team Y

Figure 5. Outcomes – Drawing and CAD model

5 QUESTIONNAIRE SURVEY RESULTS

Figure 6 shows the results of the questionnaire survey given to the students who participated in the design school. The bar graph indicates the mean value of the students, the error bar, and standard deviation.

The findings indicate that the participants generally viewed the design school program favorably. Some of them provided the following feedback: ‘The design process was interesting and I learned some things I probably would not have without this inter-university collaboration’, ‘The design process to integrate two unrelated objects is stimulating’, and ‘The design process to integrate two unrelated objects is stimulating.’

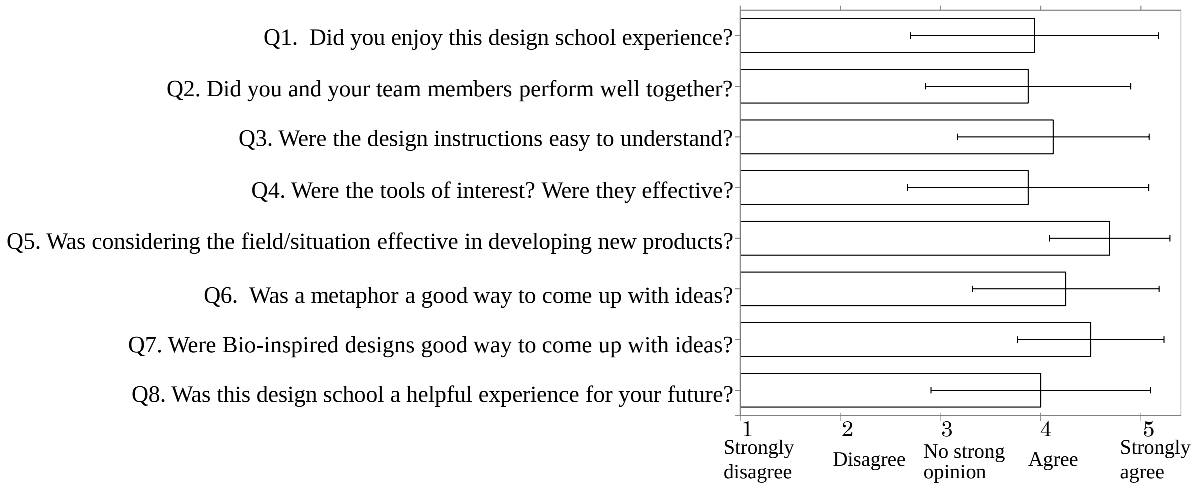


Figure 6. Results of the questionnaire

6 CONCLUSION

This paper introduced an educational method based on synthetic design thinking in the modern era. This approach is unique due to its process, which starts by a person forming a concept based on ‘intuitive synthesis’; then, details are confirmed by ‘analyzing and investigating’ the concept’s characteristics, followed by ‘representing’ the designed product and the scene in which it will be employed using VR. The design outcomes and participants’ comments suggest that using metaphors related to living things is effective for coming up with ideas. Further, all teams gave a final presentation, demonstration, and discussion, going over the scheduled time limit. This suggests that the students enthusiastically joined the design school.

The participants had some requests, such as: (1) Improve the operability of the VR device; and (2) Provide objective feedback on the design outcomes. Due to time restrictions in this program, discussions from the viewpoint of utility in the real world and business were not sufficient. However, using the VR space to project the designed product onto situations where it would be used enabled participants to sense the user’s impression more realistically.

By using a VR space, we will incorporate the following into the next school program: market research on the designed product, and an evaluation of the design outcomes by some industrial experts.

Further, the method proposed could be extended to adoption of more in-depth characteristics by trying this out in a bio-engineering curriculum.

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