



Instruction in Divergent Thinking for Conceptual Design: A Case Study Based on a Corkscrew

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Abstract: Abstraction is a powerful tool for designers in the conceptual design stage. Such abstractions take various forms, and little is known as to how a particular method of abstraction would support designers in specific design cases. A method is proposed which includes a deliberate step for divergent thinking. The method presents learners with an abstract representation of an existing artifact, and encourages them to explore potential concepts that are different in style but are based on the same or similar abstraction as that given in the representation. To evaluate how the method would help novice designers, a summer workshop activity of designing stylish corkscrews was conducted with twelve recent graduates from industrial design graduate programs. The students come from a variety of academic backgrounds. The processes for concept generation, making a prototype and a summarized statement are the main inputs used for activity assessment. Students proposed a total of 56 design concepts, with an average of 4.7 concepts per student. Design-related students (six participants) generated between 3 and 12 concepts, while students without a design background generated between 1 to 6 concepts. The concepts were divided into five classes based on appearance: human-like, animal-like, artificial product-like, plant-like, and phenomena-like. Of the 12 students, three produced mechanically functional prototypes. Based on student feedback, the pros of the instructional approach included support for the linking of concepts, encouraged learner engagement, and promoted specific thinking processes. Results suggested this method has potential for supporting positive learning outcomes, particularly in generating a range of stylish concepts based on an existing artifact within a limited time frame. However, prototype development would require additional support.

Keywords: Conceptual design, corkscrew design, design methodology, innovation, mechanical movements, novice designers

Introduction

Conceptual design is a critical design stage in new product development [1], generating outputs that often includes initial concept sketches [2]. This stage should focus on generating a wide range of concepts as designers typically tend to stick to a few select concepts, and thus may miss opportunities to explore some better alternatives [3]. A deliberate step of generating a broad range of concepts is considered to be a better design practice than sticking to a specific concept [4]. However, this is challenging for novice designers or learners as they

would find it difficult to generate multiple concepts [5]. Having generated concepts, it is also important to make a prototype so as to communicate the concept, and to validate the concept at the earliest possible opportunity before a concept is selected for production [1].

Activities involving concept generation and prototype making can be even more challenging for learners with specific backgrounds, who might have limited knowledge in certain solution domains, e.g., mechanical movements for automation. In this paper, we propose a new “thinking” method for novice designers or learners. The method sets a particular path for exploring existing designs in combination with learning,



brainstorming and making activities. It is considered to be “learning while inventing” in that learners grasp related domain knowledge, while brainstorming some innovative ideas and experiencing the embodiment of these ideas in terms of prototypes. In this paper, we investigate the implementation of this method through a workshop activity. The remainder of this paper is organized as follows: the following section describes the method, followed by an empirical evaluation using a specific corkscrew design workshop to see if the method helps novice designers or learners based on a review of the concepts generated and their subjective evaluations of the experience.

The Divergent Method in Concept Generation

We develop the thinking method through a modified process on functional synthesis [6], which was originally used in the domain of function-based design in which conceptual divergence is explored using different physical principles, e.g., levers, friction, etc. However, in this paper, we apply this process to generate concepts that are different in style but similar in terms of physical principle. The idea of transforming an existing artifact into its bond-like spatial representation is modified from Liu [7]. This abstract representation (i.e., bond-like structure) is taken as the stimulus for concept generation with the Input and output areas of the spatial representation identified with their respective motions (e.g., translation or rotational motions).

The method has two steps. The first step involves presenting learners with an abstract representation of an

existing artifact so as to stimulate design concepts. This is meant to allow learners to focus on an understanding of a feasible kinematic behavior and spatial configuration of the artifact regardless of any advanced physical forms, supports, or contacting surface. In the second step, learners are encouraged to come up with new, potential design concepts based on their individual interests, memories, or imagination. The learners are encouraged to follow the mere arrangement of the bond-like structure (see Fig. 1(a)) and its kinematic motion of the artifact at any particular moment. Based on this type of thinking, potential events perceived with the same or similar abstraction could be linked and thus sketched to represent the concept. In Fig. 1, the existing design (Fig. 1(a)) is abstracted. The screw portion of the design is not considered for divergent thinking. A partial snapshot of the design is shown in Fig. 1(b), where the big dot stands for the connectivity (e.g., joint) of any two elements, and the constraints of the elements (e.g., the housing components for the two toothed element) are hidden.

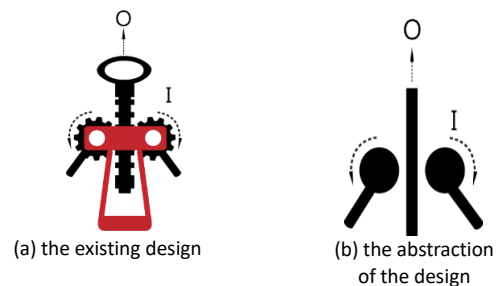


Figure 1. Concept with original and modified representation.

Study Design for Evaluation

Twelve recent graduates from MA industrial design programs participated in the summer course called “design practice”. The students came from different academic backgrounds, including media, visual & communication design (four participants), engineering (three participants), and other majors (three participants). Figure 2 illustrates the activity progression. The activity started with a hand-on team building warm-up. The students were then given sixty minutes generate potential design concepts. Each student was then asked to select and given 90 minutes to prototype their favorite concept.

In this course, a typical corkscrew, as shown in Fig. 1(a), was chosen as a stimulus for three reasons. First, students came from multidisciplinary backgrounds with limited design experience, and a corkscrew was seen as a simple design project which matched the course time constraints. Second, corkscrews are commonly seen in everyday life, and the students could easily grasp user interaction scenarios. Finally, this corkscrew incorporates both lever and rack-and-pinion mechanical principles;

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these typical mechanical movements can provide an ideal example for introducing some commonly used mechanical movements in projects for the design of everyday items. Having completed the concept generation step, each student was asked to select and prototype their favorite concept. Each student was asked to complete this activity in ninety minutes.

Having completed the aforementioned activities, each student was then asked to present the results from their design process and provide feedback on the workshop. Altogether, the concept generation, prototype and summarized statements are the main results used as input for assessment.

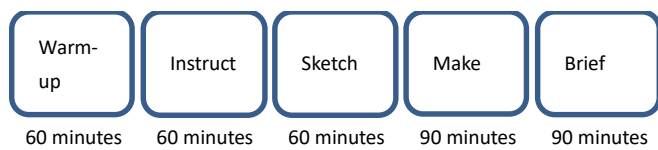


Figure 2. Procedures and durations of the workshop activities

Assessment Procedures

The workshop was conducted by two instructors with three teaching assistants to provide necessary logistic support and prompt responses to student questions or problems. PowerPoint slides were provided to highlight the purpose of each activity.

For the warm-up activity, teams of two students were given an hour to assemble a mechanically cam-driven toy with four wheels. They were asked to follow given component breakdown instructions to get a feel for how the components fit together. However, they were not told either of the toy's moving behavior nor which component need to be glued together to achieve proper functionality. This challenged them to infer how the toy should work in practice and how components needed to be combined to achieve this.

Prior to the concept generation activity, the instructors first demonstrated how a typical corkscrew works, particularly emphasizing the sequence of processes of how a pull-down movement upon a lever would lift the cork, while the rotating insertion of the spiral shaft would cause a roll-up movement of a lever. The abstractions were also presented using a projector. The abstraction part was mapped onto the real object. For example, a straight bar was used to represent the specific shape of the lever. An example of a bee-like corkscrew design was given to the students to demonstrate the idea. Having explained the thinking procedure, the instructors also reminded the students not to stick to a specific shape. For example, the conceptual straight line could be used to represent many shapes of different lengths. Students were encouraged to generate as many potential concepts as possible based on the classic corkscrew. The students

were given sixty minutes to generate potential design concepts.

Once concepts had been generation, students created prototypes using materials including scissors, paper, craft knives, wood, etc. To ensure that the matching rack and pinion components were operational, a rack and pinion was also provided for demonstration purposes.

Evaluation Outcomes

Three types of outcomes were evaluated: Did the method support each student in concept generation, did this approach support prototype making, and did students have a positive overall impression of the workshop activities. Concept generation support was defined as the number of concept classes, and the number of variants in each class, generated by each student. As for prototype making, the quality of the prototype was determined by judging whether each prototype would be functional, and whether a complete set of major components of the prototype was given. Subjective evaluation for preference was determined by concept generation, prototype making, and workshop participation. The thematic network method [8] was used to summarize subjective responses to the course (Fig. 4).

Results

	A ¹	B ²	C ³	D ⁴	E ⁵	Sum ⁶
Student 1	0	1	1	0	0	2
Student 2 ^a	3	0	1	0	2	6
Student 3 ^a	3	5	2	2	0	12
Student 4 ^a	0	2	0	1	0	3
Student 5 ^a	2	1	0	0	0	3
Student 6	0	0	0	1	0	1
Student 7 ^a	2	5	2	1	0	10
Student 8	3	0	0	0	0	3
Student 9	4	2	0	0	0	6
Student 10	1	0	0	0	0	1
Student 11	0	1	0	0	0	1
Student 12 ^b	3	3	1	0	1	8
Total^c	21	20	7	5	3	56
Mean	1.75	1.67	0.58	0.42	0.25	

1: animal-like; 2: human-like; 3: plant-like; 4: artificial product-like; 5: phenomena-like; 6: total number of concepts derived from each student; a: media visual & communication design background; b: industrial design

Table 1. Number of concepts derived from the students in different categories

Generated Concepts

As shown in Table 1, the 12 students generated a total of 56 concepts, or an average of 4.7 concepts per student, with individual students generating between 1 and 12 concepts each. The concepts were grouped into five classes, i.e., animal-like (Fig. 3), human-like (Fig. 4), artificial product-like (Fig. 5), plant-like (Fig. 6), and



phenomena-like (Fig. 7). Humans and animals were the two most popular classes. For the first four classes, concepts were generated based on the method, but phenomena-like concepts are seen as examples of composite thinking incorporating the approach and its implications. For example, the action and context in the example of the drunken man drowning could urge users to drink in moderation.

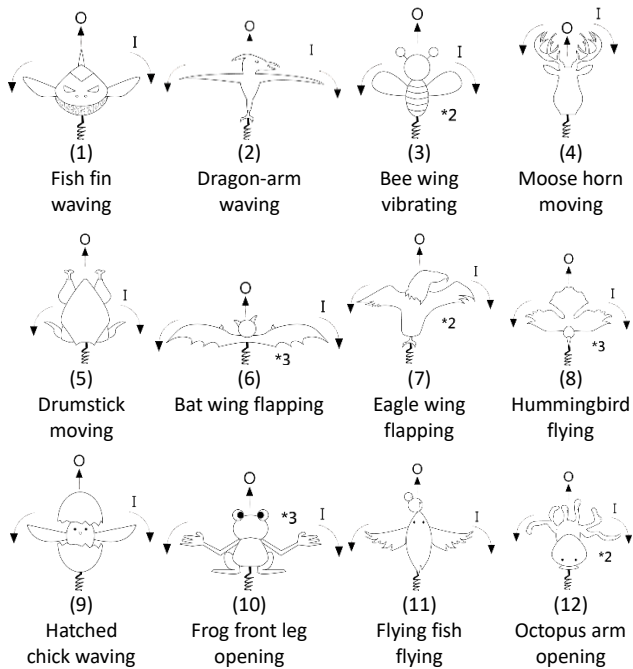


Figure 3. Animal-like concepts.

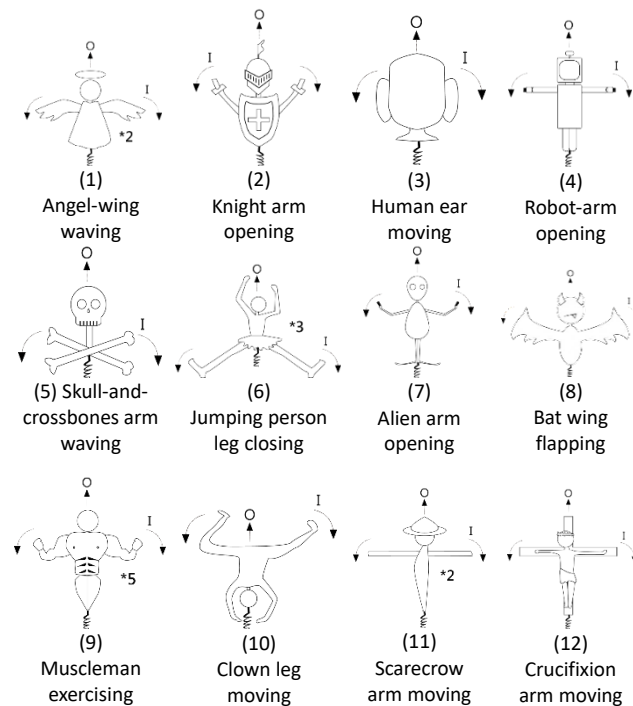


Figure 4. Human-like concepts.

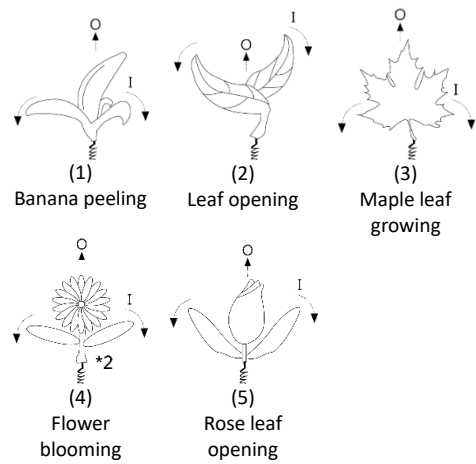


Figure 5. Plant-like concepts.

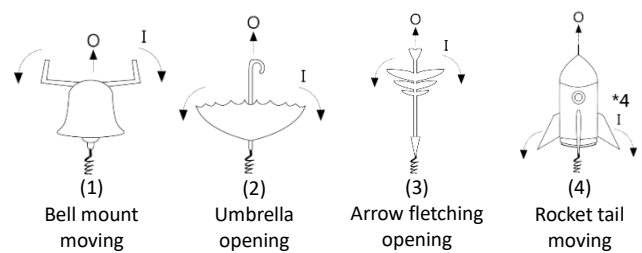


Figure 6. Artificial product-like concepts.

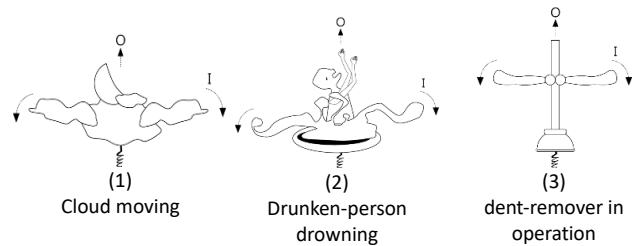


Figure 7. Collection of concepts in phenomena-like category.

Prototype Assembled

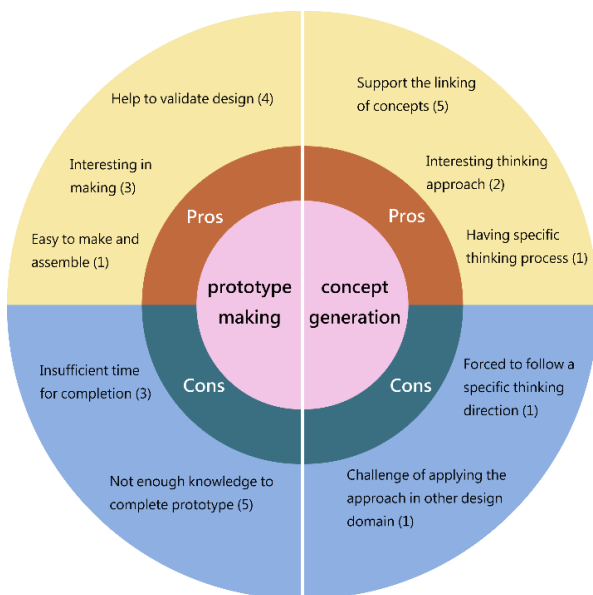
Three of the 12 students produced mechanically movable prototypes incorporating most components. Four were able to make inoperable prototypes with almost all major components. Five students produced inoperable prototype without all major components.

Subjective Evaluation

As for concept generation, according to the 12 students, the pros of the approach (see Fig. 8) included the following: Support for linking concepts (5 respondents), engages student interest in this type of thinking (2 respondents), and features a specific thinking process (1 respondent). However, students also cited potential concerns, including the challenges in applying the approach in other domains (1 respondent), and that the thinking approach also limited students to a specific thinking direction (1 respondent).

In terms of prototype creation, the students stated that the hand-on experience of making a prototype would help to validate design (4 respondents), engaged student interest (3 respondents), and that the prototyping process is relatively simple (1 respondent). The cons include that students lacked sufficient prototyping experience and skill (5 respondents), and were provided insufficient time to complete the prototype (3 respondents).

Figure 8. Concept with original and modified representation.



Discussions

In this paper, we encouraged students to incorporate aesthetically pleasing design concepts into the design of a corkscrew. The classic Anna G Corkscrew and bottle opener [9] presents a human-like design. Aside from aesthetics, the activity did not consider other critical design factors including function, cost, or ease of assembly. Other variations on the family of corkscrews using the same or similar physical principles could be used as a stimulus for tinkering. Other artifacts involving mechanical movement could be used as stimulus as well, e.g., door latch, paper punch, stapler, etc. However, these are not considered in this paper.

This method could be applied to investigate the use of similar mechanical movements in abstract and simplified structures in completely different domain. Such divergent thinking is different from function-based design where a physical principle, e.g., a lever, is merely taken as a starting point that ends with a range of structural variations such as scissors, door handles, etc. The design concept ideas presented here are applied to determine whether they can be directly used as potential solutions. One example is architect Thomas Heatherwick's design [10] for a rolling bridge concept derived from the

movement of a dinosaur's tail. Heatherwick also designed a balanced spinning chair was derived from a spinning top. However, these types of design usually involve an iteratively refined engineering process through extensive research and experimentation so as to eventually derive designs which are both functional and stylish.

Variety and Number of Design Concepts

So, how does the proposed method support students in creating stylish corkscrew designs? Despite their different academic backgrounds, all students were able to come up with at least one design concept in the sixty minute time frame despite having no previous experience in designing such products. Five students generated between six and twelve different concepts in five classes: human-like, animal-like, artificial product-like, plant-like, and phenomena-like, with animal-like and human-like designs proven the most popular. The phenomena-like class of designs incorporated aspects of the product's usage context – i.e., the consumption of alcohol. Based on the generated designs,, the proposed method seems to have potential to support novice designers in creating stylish and meaningful corkscrew designs. Potentially, the method could be used in combination with other approaches (e.g., TRIZ) to generate a broader range of design concepts. Design students tend to generate more concepts than students coming from other academic backgrounds, and such students may require additional support to enhance divergent thinking.

Challenges in Prototype Creation

Only three students were able to complete the prototype in the given time frame. Prototyping can be a challenge for students for the following the reasons. First, students with different academic backgrounds have limited knowledge of mechanical movements in the corkscrew's mechanism. By simply observing and trying the existing design, many students were unable to grasp the fact that the arrangement of level and rack components in their counter-weights and toothed mechanisms are critical for the completion of a prototype that can be operated smoothly. Students were provided with Lego-like components for trial-and-error assembly, but an understanding of such mechanical movements would be helpful for such efforts as designing a functional rack and pinion system component can be difficult for students without previous experience. This challenge could be further helped by providing students to access to fast prototyping tools e.g., 3D printers or critical components.



Subjective Evaluation

Two performance aspects were evaluated, i.e., concept generation and prototyping (see Fig. 8). In terms of concept generation, students can generate design concepts simply by observing and understanding the bond-like structure of the corkscrew. Students found this to be supportive in brainstorming (four comments), and interesting (three comments). Also, one student felt this approach to be comprehensive for concept generation, and one student recognized that using this particular type of mechanism is easy for brainstorming activity. However, one student also argued that selecting one particular mechanism for corkscrew design would limit divergent thinking in concept generation, and one student believed that applying this type of mechanism could prove challenging in other design tasks. To prevent limitations on divergent thinking, we suggest that novice designers consider different mechanisms in isolation. A wider range of design concepts can be developed by gathering all such potential concepts. As for utilizing the learned mechanism in other design cases, we believe that this would be possible if the learner is familiar with mechanical behavior in the abstraction step and can further realize the physical principles involved in rack and pinion systems. However, this needs further investigation.

Limitation

Further tests must be conducted with other target populations (e.g., senior designers) for comparison. This study included 12 novice designers and does not represent a wide range of designers.

Conclusion

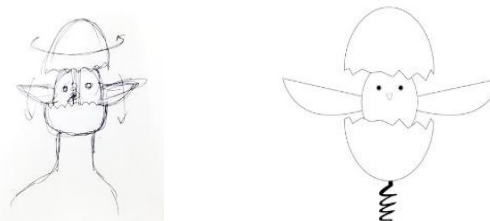
The reported results provide a better understanding of the potential for the proposed method to support learners from different academic backgrounds in generating a range of design concepts and prototyping in a time-constrained conceptual design phase. However, prototyping requires additional support. Future work should apply the proposed approach to other design cases, and in different target populations.

Appendix

Appendix A: Rules of Redrawing Sketches

Figure A1(a) shows the original sketch. To enhance clarity, the concepts shown in this paper were reworked from the original sketches done by participants. The sketches were streamlined, unnecessary lines were removed, the screw component was added, and the

components were redrawn with improved proportionality while maintaining the original design concept. As shown in Fig. B1(b), the egg shell was redrawn, while the hidden component (the screw component) is not shown. The lines representing a bottle were removed and the screw component was added.

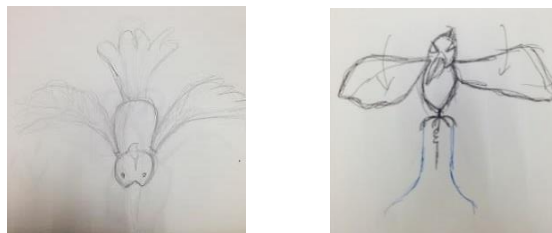


(a) the original sketch (b) the representation modified

Figure A1. Concept with original and modified representation.

Appendix B: Example of Concept Classification

Figure B1(a) shows a bird flying in a downward direction with two wings rolling up and down to remove the cork. Figure B1(b) shows a bird standing upright, flapping its wings to remove the cork. The two concepts are based on a floral motif and share a single operational principle. While the representation of wings is different, at the abstraction level they can be considered to be identical.



(a) Bird-flying-down corkscrew (b) Bird flapping corkscrew

Figure B1. Identical abstraction concepts.

Appendix C: Prototype Classification

Prototypes were assessed in three degrees of completeness: mechanically moveable and incorporating all major components, incorporating all major components but non-operational, and lacking major components and non-operational. Examples are shown below.

Figure C1(a) shows a corkscrew prototype based on the idea of a roasted chicken. The major components are the cover (on the right of Fig. C1(a)), two chicken drumsticks with necessary joint support, the roasting skewer, and two chicken wings. The corkscrew is mechanically moveable by rolling the drumsticks up and down. Figure C1(b) shows the preliminary sketch.

Figure C2(a) shows a corkscrew prototype based on the idea of a jumping frog. The major components are the



main body, and two frog back legs with necessary joint support (on the right of Figure C2(a)). The legs do not move, and thus the prototype is not operational. Figure C2(b) shows the initial concept sketch.

Figure C3(a) shows a corkscrew prototype based on the idea of a drunk person. Neither the moving components nor the necessary joints are complete, thus this prototype is considered to be neither operational nor to include all major components. Figure C2(b) shows the initial concept sketch.



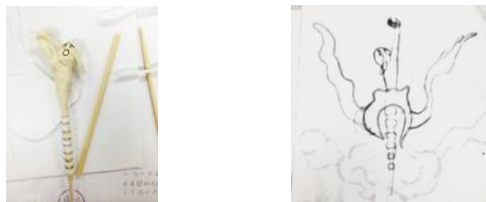
(a) Roasted chicken prototype (b) Initial concept

Figure C1. Example of an operational prototype incorporating all major components.



(a) Jumping frog prototype (b) Initial concept

Figure C2. Example of a non-operational prototype incorporating all major components.



(a) Drunk person prototype (b) Initial concept

Figure C3. Example of a non-operational prototype without major components.

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