Teaching Strategies for Design Realization in Engineering Design Education

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Index Terms: Design Realization, Physical Effect Toolkit, Graphical Thinking, Inverse Mapping.

I. Backgound of the Research

As creativity and innovation become important issues of engineering design education, we found the difficulties to the students for implementing their ideas from our research results on novice engineering students' creativity implementation setback events [1]. One of the difficulties is lack of suitable thinking approach. The students are used to solving design problem still based on analytical approach, not based on synthetical approach. They have difficulty in applying the acquired specific knowledge to their design task, although they have already learned that from related nature science or engineering science courses. However, the design engineer in 21st century needs not only innovative talents but also interdisciplinary abilities to develop new technologies and products. Appropriate teaching aids are therefore necessary for the challenge of engineering design education. Besides teaching the knowledge of engineering science, the design methodology today plays more and more an important roll in the college. Therefore a new requirement on the curriculum of engineering design courses arises.

Based on our experiences in the past years and our concept teaching students to implement their innovative ideas systematically, we deem that three important skills/abilities must be taught to enhance students to realize their concepts more efficiently. These three abilities are:

- How to search suitable physical effect from the requirements of the design task;
- How developing a design structure graphically; and
- How to determine the suitable parameter to fit the specified requirements?

We developed therefore a set of teaching strategies for design realization correspondingly.

II. Consideration and Concepts for Developing Teaching Strategies

A. Situation of learning and teaching engineering design in Taiwan

The characteristic problems of engineering Taiwanese students by the design education today may be following:

- They have difficulties to apply the learned science knowledge to their design in the practice.
- They are strongly influenced by the known design or existed image so that a new and creative solution is rare to find.
- A wide solution spectrum is difficult for them to find.
- Most of them don't get used to search, at least enough, design information as an aid to solve their problems.

B. Concepts from systematical design approach

According to the systematic design methodology the design process can be divided into several phases, from *task clarifying*, *conceptual design*, *embodiment design* until *detail design* [2]. In the stage of conceptual design, the designer finds the principle solutions usually through the function analysis, searching for suitable physical effects and establishing the working structures.

Our teach strategies focus on the conceptual design and consist of the following stages and the corresponding teaching actions:

- searching solution principles by applying the web-based tool "PET – Physical Effects Toolkit"[3],
- developing principle structure by using skills of graphical thinking and representation [4],
- determining quantitative dimensions of solution according to the principle of "inverse functional mapping" [5].

III. Teaching Strategy I: Physical Effects Based Consideration

A. Designing with physical effects

Physical effect can be described quantitatively by means of the physical laws governing the physical quantities involved [2]. It is very important for designers to develop their innovative concepts. Many engineered products contained at least one physical effect. For example the well-known governor for speed control of steam engines was developed according to the centrifuge effect (Fig. 1), which is described by the centrifuge force *F*, mass *m*, rotating radius *r* and rotating speed ω with the relation,

$$F = m\, r\, \omega^2. \quad (1)$$

The function structure of the governor can be therefore regarded as a chain combining various effects whereby the speed ω as input and the displacement *s* for valve-opening as output function quantity. The principle structure can thus be constructed according each effect.

Such the method is very suitable for students to develop their idea into feasible product. However, two issues are necessary to be considered for developing the teaching strategy for application of the physical effects in engineering design:

- How to search the suitable physical effects to fulfill the requirements of the task?
- How to combine various physical effects into a integrated principle solution for the task?

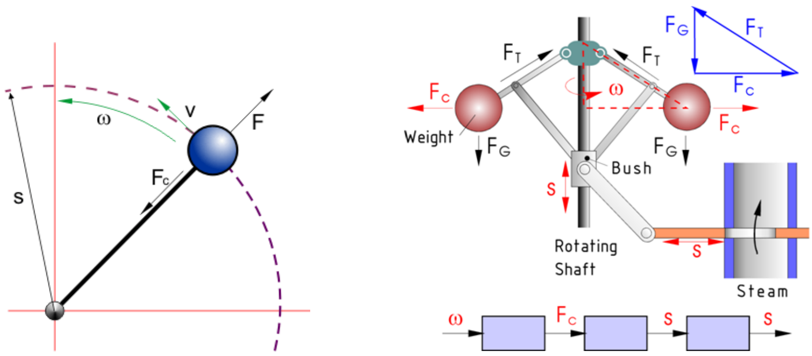


Fig. 1. Principle sketch of "Centrifuge Effect" and its application to "governor".

B. Web-based "Physical Effect Toolkit"

The useful information for designers while in designing scattered in various formats, e.g. books, manuals, catalogues etc. The user, however, needs also great effort to search the possible combination of various effects in the referred materials. They seem to provide not enough aid to students. We have thus developed a web-based design tool -- "PET" (***P****hysical* ***E****ffect* ***T****oolkit*), which is capable of presenting the necessary design information of physical effects in image and animation, and also organizing design information in a uniform format. The architecture is shown in Fig. 2. The main part of PET is a database collecting the well-known physic effects which are sorted according to the physical domains including solid mechanics, fluid mechanics, electrics, thermo-dynamics etc. With the required input and output physical quantity, the specific function structures with corresponding physical quantities as criterion can be established as various effect chains with aid of a search engine integrated in *PET*. Students can obtain the suitable physical effects and the corresponding design information from the corresponding database to fulfill the requirements of the task.

C. Design approach using PET

1) Identify the input and output Function Quantity:

While designing a new technical object, the conditions about the physical quantities, which can be used in the design, are usually not clear. The requirements of the task must be analyzed at first, whereby the input and/or output quantity as well as the constraint quantities are identified.

For effect analysis, three possible combinations of input and output physical quantities can be distinguished.

- Input functional quantity is known and output is also known. The condition is usually to be found for existing design. The variants of design can be constructed only through various physical effects with the same input and output variable or the change of the structure.

- Input functional quantity is known but output is unknown: This condition is especially for designing a measuring instrument.
- Input functional quantity is unknown but output is known: This condition occurs usually if the output functional quantity must be specified while the input functional quantity can be arbitrary to chose.

2) Establishment of effect chains:

The suitable effect chains can be obtained with aid of the effect search engine. Most important is that some intermediate functional quantities must be restricted as used in the effect chains.

3) Evaluation and selection of suitable effect chains

The generated effect chains can be evaluated and selected according to the clarified requirements. In general the effect chains having more than 4 levels are not suitable to be applied in design.

4) Find the principle solution

The principle solution can be constructed with aid of the information provided in the database of "PET", e.g. principle sketches, and application examples of the considered effects.

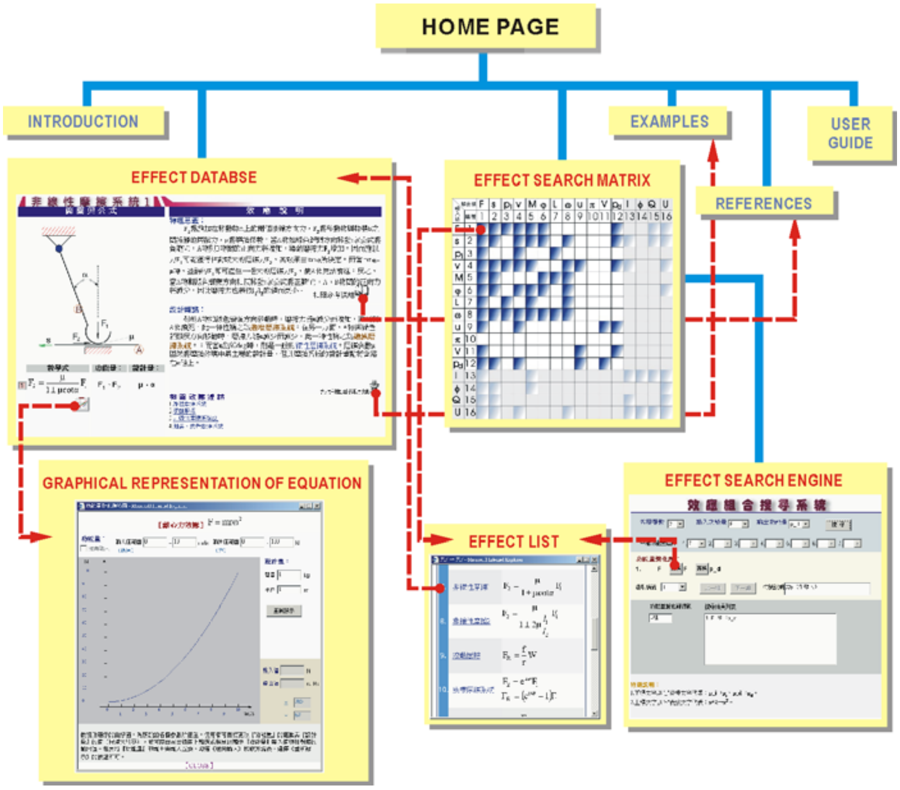


Fig. 2. Web-based Architecture of the design tool "PET"

IV. Teaching Strategy II: Grahical Thinking

A. Importance of graphical representation and thinking in design education

It is often to find out that the problems in our everyday life are solved based on the sequential thinking. This type of problem solving is very intuitive. For product design, however, this thinking behavior cannot clarify the relations between the objects (e.g. problems, functions, effects etc.) exactly. Especially, any new generated idea will be added randomly, regardless the priority and relation of the objects. Graphic thinking, on the other hand, can offer a good visual effect to help the designer to clarify the problems step by step based on the graphics. Furthermore, the "innovative concepts" can be, in certain viewpoint, seen as the reordering or recombination of existing elements! These "elements" should be abstracted in symbolic form in order to serve as tools for problem thinking and solving. Therefore the necessary design information in the form of graphic image can flow from paper, to eyes, brain, and return to hands and finally onto paper again. Through this continuous cycle the ideas will be thus generated, and corrected again, until all the requirements are fulfilled.

However in Taiwan, training of graphic thinking is ignored in engineering design education at universities. Most students couldn't handle the complicated information while in trying to realize their idea. So as we analyzed the difficulties of novices from their design histories, we found out that most of the difficulties arise from lack of suitable skills on graphic representation and thinking. The students are used to giving up their design works on the "drawing board" earlier and turn to work on producing their products quickly. From the conclusion of the experiment on design behavior conducted by Dylla [7], it is no doubt to realize why the students had such a lot of difficulties. They give up the graphical work, which has less complexity of information and then choose the handwork having higher complexity of information to realize their ideas. In general, the design courses of mechanical engineering at the universities, especially in Taiwan, couldn't offer enough solutions for this problem. This is not only because of decreased teaching time in the courses on mechanical drawing, but also because most of teachers and students put their interest in CAD tools not in freehand sketch. They forget that freehand sketch indeed plays an important role on problem solving, [4][6][8][9]

Actually, representation of concepts in graphic form is an important work in design realization. It serves not only as aid of problem solving, but also as representation and communication of ideas between designers and other related persons [4]. Because the information in the sketches records the history of thinking for the design task, the process that designers generate sketches and drawings covers all thinking patterns in the creative engineering design: from design concepts, principle solutions, principle structures, dimensional sizing, until to determination of surface, tolerance/fitting and functional requirements (e.g. strength, rigidity etc.). There are no other efficient methods except graphic representation that can represent all the thinking processes and results. Accordingly, using graphics for thinking and representation of ideas is essential skill for novices before they can realize their creative ideas smoothly.

Training the graphic skill enable the students, on the other hand, not only to represent their concepts on paper but also to think and to analyze their concept from the developed sketches. Our teaching experience showed that students can solve the complicated design problems more easily when they can dominate the acquired graphic skills.

B. Teaching actions and related activities

In our study we will focus on enhancement of the skill on graphic representation of students. We developed a series of exercises to enhance the graphic skill, including free-hand sketching, symbolic representation, concept representation, layout generation, etc. The related topics and essential contents planned for the course are listed in Table 1.

Table 1. Topics and contents of the "graphic representation"

No	Topic	Content	Teaching actions
1	Freehand sketch	Fundamental methods of freehand sketch	Lecture and exercise in class and after class (homework)
2	Symbolic representation	Abstractization, variation, concretization of concepts	Lecture and exercise after class (homework)
3	Concept representation	Principle and method for representation of concept	Exercise in class using gallery method
4	Layout generation	Criticize a existing design and give an improved solution	Integrated exercise in class

1) Freehand Sketch

Although the CAD is nowadays essential design tool, working with pencil on papers is still not to be abandoned. With a good skill of freehand sketch, the designer can not only illustrate her/his idea more clearly but also perform the communication more efficiently. In the course, we conduct a practice on freehand sketch to teach students with the following topics: (a) introduction; (b) handicraft fundamentals; (c) techniques for basic graphic elements; (d) technical forms and standard form[6] [10].

2) Symbolic representation

The design process can be regarded of as a series of information transformation from uncertain situation towards realized object. The successive stages of the process are usually characterized by some kind of graphic models [1]. With the graphic models or symbols, designers can realize ideas more clearly. In order to enhance the conceptualization skill of students, two topics are emphasized: (a) abstractization and concretization; (b) variation of conceptual structure. The book of Tjalve [11] is a very good teaching material and can be applied for the course.

Through abstractization of the technical object, the major characteristics can be remained and used for further variation. A new variant can be thus obtained through concretization of the varied concept. This process can be explained with aid of the example in Fig. 3.

The examples about the variation rules are discussed in the course, such as variation of arrangement, geometry, dimension, number of the working surfaces of technical objects [11]. For example the case of bottle opener can be abstractized into three separated working surfaces. The structure can be varied according to different arrangement of the surfaces. New openers can be thus generated based on the varied structures, Fig. 4. Another method for abstractization and variation is also introduced in the course [11]. The important components of a technical objects can be symbolized and rearranged to obtain variants. For example, the vacuum cleaner in Fig. 4 can be symbolized as combination of motor, dust box and suction nozzle. The variants are obtained through systematic rearrangement of the three basic components.

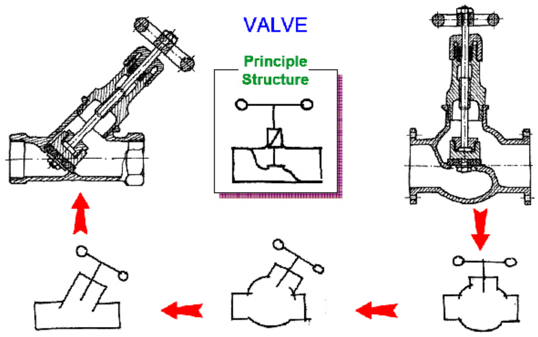
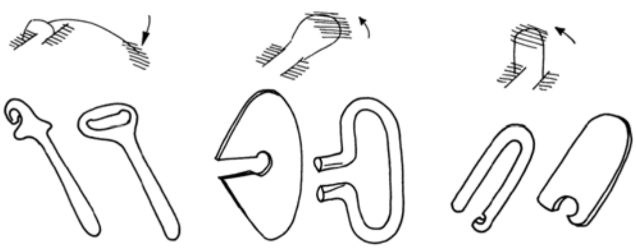
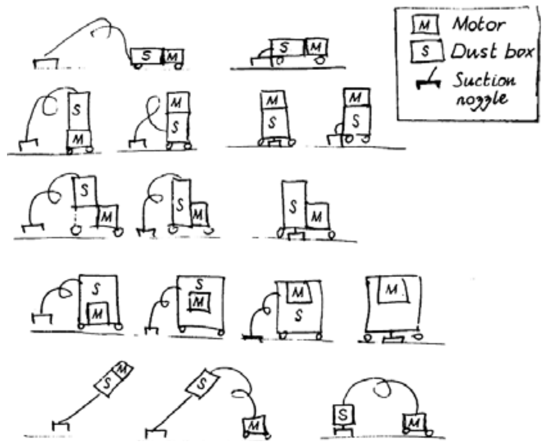


Fig. 3. Abstractization-Variation-Concretization process [11].

The students will also acquire the graphic thinking abilities from an exercise in the course. The question is illustrated in Fig. 5, [11]. From the exercise the students can understand how to obtain variants of street rolls just through rearrangement of the symbolic elements representing roller, engine, and operator. One of the students' sketches is shown in Fig. 5.



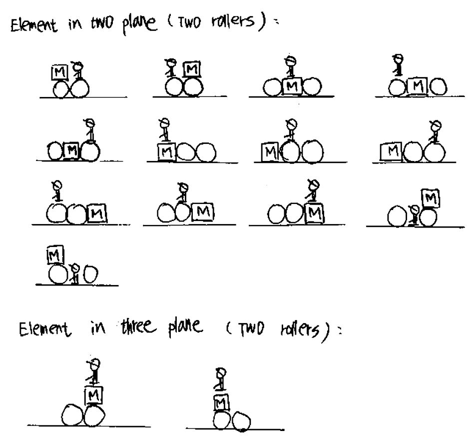
Variation of the bottle opener based on the arrangement of the working surfaces



Variation the vacuum cleaner based on the arrangement of the basic components

Fig. 4. Examples for variation rules

The exercise "Street Rolls".

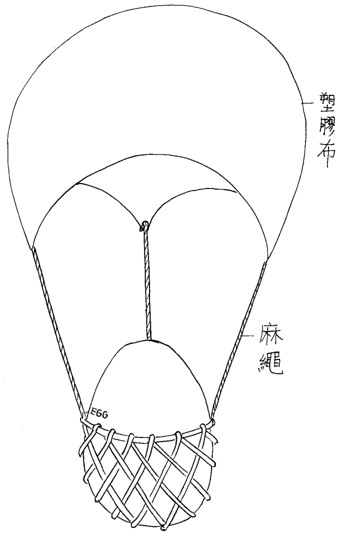


Student's sketch

Fig. 5. Exercise for graphic thinking

3) Concept representaion

After the students have learned how to use symbolic tools to abstractize and to vary their concepts, we conduct an exercise by applying the gallery method [2] to teach them how to use graphic method to represent their concepts clearly. Fig. 6 shows the task and one of the students' sketched concepts.



Task
In order to protect an egg against to be broken by falling from a high level of a building, pleas sketch a suitable device to meet the requirement. You can use any material and any method what you can find out. An example using "parachute" is shown in the figure.

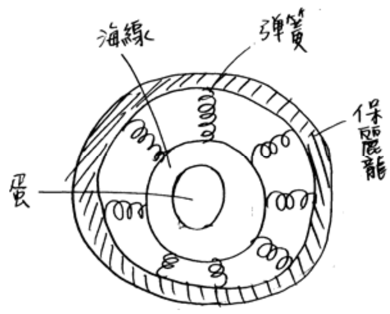
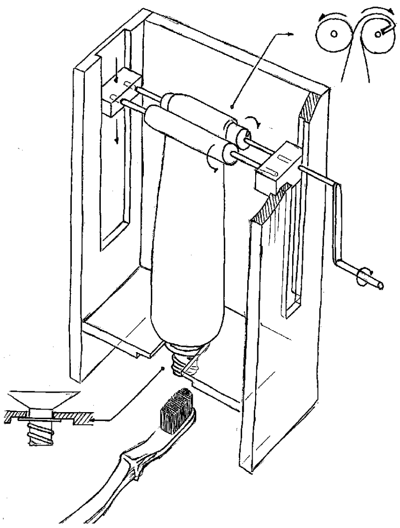


Fig. 6. Task for the exercise using gallery method and a student's sketch for the solution

4) Layout representation

The objective of the exercises is that the students should acquire comprehensive skills and abilities to think, to find out the problems from an existing sketch and also to give a new sketch for improvement. The task and one of the students' improved drawings are shown in Fig. 7.



Task
While brushing teeth, the toothpaste has to be squeezed out. It is often problematical to squeeze the rest of toothpaste, if the toothpaste is used up. Now a team has designed such device as shown in the figure to serve as a tool to squeeze the toothpaste out completely. What are your comments about this device? Does this device need to be improved furthermore? Please sketch down your ideas.

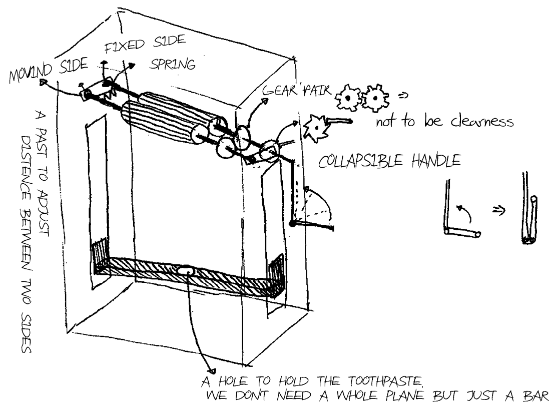


Fig. 7. Integrated exercise for graphic thinking, exercise task and a student's sketch

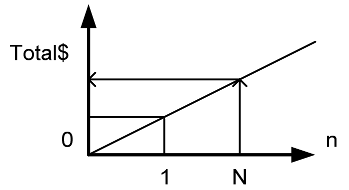
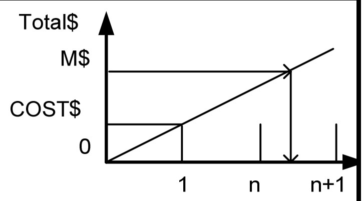
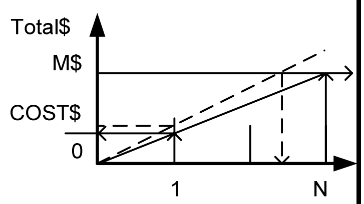
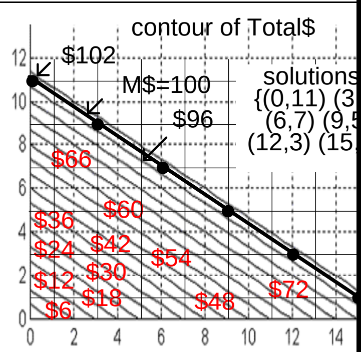
V. TEACHING STRATEGY III: INVERSE FUNCTIONAL MAPPING

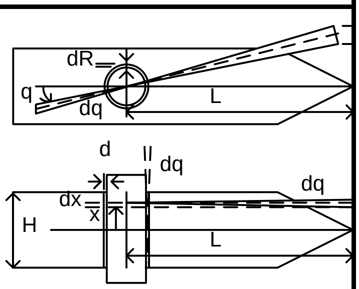
A. Design approach using IFM

Working through elementary exercises and problems, we guided youngsters through different thinking models, Table 2: a) analysis and computation, b) contextual formulation for analytic computation, c) computation on uncertainties and the logics of tolerance bounds, d) problem solving through inverse mapping, namely, solving equations, e) parametric design by inverse mapping in the parameter space, f) problem solving involving multiple variables, graphic representation, search for solution graphically and trial by simulation, automatic control design to manipulate temporal responses, and finally g) structural design exercises for advantageous functional properties. Examples, their functional mapping, and their graphical representations are provided in the following table for contrast.

As the youngsters are taught to work through the problems, few of them would look back, organize, and summarize the thinking paths of these exercises. The approaches to these exercises are seemingly independent tactics. Most commonly, students take table look up and curve look up as typical design process. They do not develop a uniform thinking model to these exercises. Therefore when they encounters their own wild creative ideas, they resort to ad hoc mock up trials instead of a systemic process of literature reviews, functional property research on materials and the nature, functional architecture ingenuity, and the application of inverse mapping for parametric design.

Table 2. Thinking Models of Problem Solving

Thinking Model	Elementary Exercise	Functional Mapping	Graphic Representation
a. Analytic Computation	The price of orange is $9 each. How much does it cost to buy 10 pieces?	Total$ (N; COST$) = N * COST$ = m$	
b. Problem Solving - Contextual Formulation	The price of orange is $9 each. In order to provide one each to 10 pupils, how much budget should we allocate?	Same as above, except need to define Total$ as budget, N as the number of pupils, COST$ as unit price.	Same as above.
c. Analytic Equation Solving – inverse functional mapping	The price of orange is $9 each and we have only $100. How many pieces can we get?	Total$(n; COST$) = M$, solve for n? n = inv_n Total$(M$; COST$) = arg$_{(n)}$ (Total$(.; COST$) = M$)	
d. Problem Solving - Parametric Design – inverse mapping in the parameter space	The price of orange is $9 each and we have only $100. In order to provide one each to 12 pupils, what should be the price that we bargain for?	Total$(N; cost$) = M$, solve for cost$? cost$ = inv_cost$ Total$(M$, N) = arg$_{(cost\$)}$ (Total$(N;.) = M$)	Table V.A.d 
e. Problem Solving – Multivariable Functional Analysis – Graphic Thinking, Trial by Simulation, Judgment of Value	The price of each orange and apple is $6 and $9 respectively. We have only $100. In order to provide one fruit each to 12 pupils and to make the most of our budget, what would be our choices?	Total$((nO, nA); (COSTO$, COSTA$)) < = M$, inv functional solution set {(nO_k, nA_k), k=1,2,3,…} (nO, nA) = arg$_{(nO,nA)}$ (max$_{(<= M\$)}$ Total$((.,.); (COST1$, COST2$))	
f. Problem Solving – Automatic Controls – manipulating temporal effects	How should the storekeeper set the price so that the oranges can be sold out by a targeted date?	Control Stragegy: Ratio_of_sales(price$; (MARKET, ENVIRONMENT)) = (1/(Target_Day-t)), solve for price$(t) at every Day t:	Control Action: price$(t) = inv_price$ Ratio_of_sales(.; (MARKET, ENVIRONMENT)); System Dynamic Results: n(t) = n(t-1) – round (Ratio_of_sales (price$(t); .) * n(t-1)). The process is shown graphically in the expanded Figure below.

Thinking Model	Elementary Exercise	Functional Mapping	Graphic Representation
g. Problem Solving – Functional Structure Design - different amplification, optimality and sensitivity	Financial Leverage and Risk Management by Commodity Options An Easier Demonstrative Example: Try to control the tip position of an arm	Configuration 1: y = dR + L*sin(θ+dθ) Configuration 2: y = x + dx + L* sin(δθ) , note: sin(δθ) = d/H	

[Remark] In the column of functional mapping full upper case represents given or targeted values, all lower case mnemonic represents value to be solved by functional mapping, a mnemonic with only the first letter in upper case is defined by the equal sign, function max(…) represents the maximal solution subjected to the constraint specified between the parantheses, while arg(x) extracts the value of x resulting in the maximal solution.

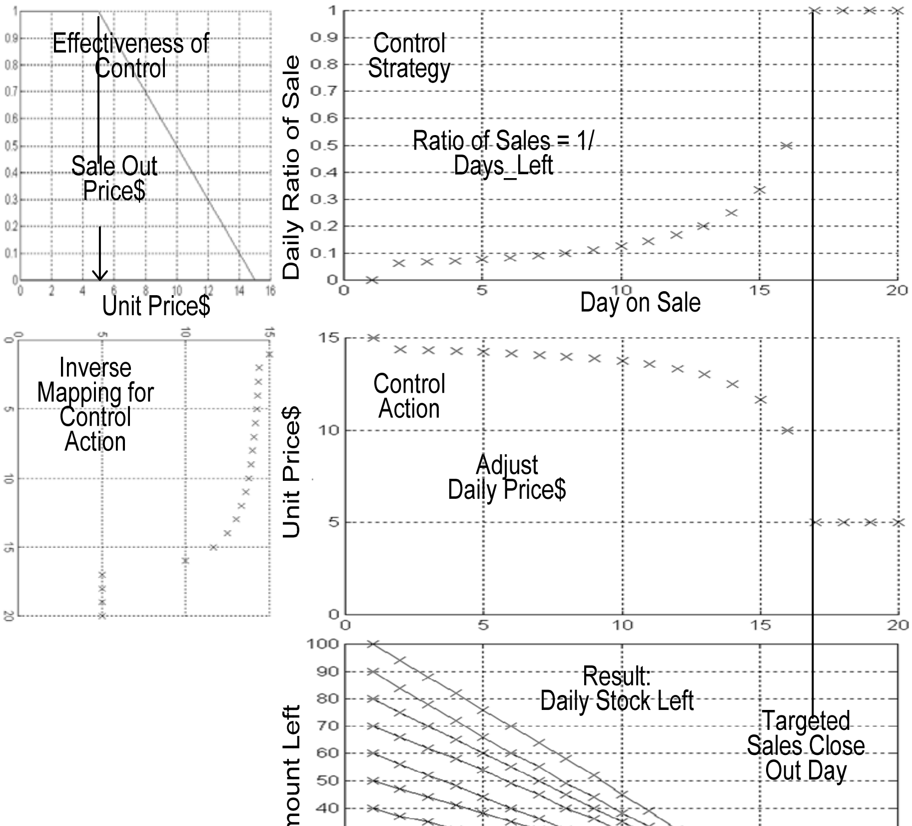


Fig. 8 The Thinking Process of Problem Solving by Automatic Controls

B. Teaching actions and related activities

As many youngsters in Taiwan spend so much time in cram sessions preparing for science and literature exams while so little on hand-on experiments and creation, the thinking process of engineering and design is very much foreign to students entering the University. We do feel the criticality to bring the thinking model of design to the conscious awareness of the students.

We would start a mandatory course, e.g. electric circuits, with the set of fundamental exercises mentioned in the Table 2. Follows with discussion of the functional representations below and the graphical representations of the thinking models, Fig. 8, to set the base tone on the course. On every new set of analysis techniques, new class of components, architecture, or mechanisms, a set of problems exercising various thinking models step by step are devised to reinforce the abstract structure of analysis, design, and verification repetitively.

B.1 Deriving the performance functional from the driving variables given system architecture and material parameters based on physical laws or functionality tests, namely:

$$y = f(x\,;\{z\}, y(0)),\; J = g(y), \tag{1}$$

where the functional format of system response function $\boldsymbol{f}$ is determined by system architecture and the functional characteristics of the component properties, vector $\mathbf{y}$ represents system state variables, $\boldsymbol{y}(\boldsymbol{0})$ represents their initial values, vector $\boldsymbol{x}$ represents driving variables, vector $\boldsymbol{z}$ represents the material property and dimensional parameters, while $\boldsymbol{J}$ represents the performance function and endurance ratings calculated using functional $\boldsymbol{g}$ from the state variables in $\boldsymbol{y}$.

B.2 In parametric design, we specifies targeted performance region $\boldsymbol{J_0}$, some given available parameter range $\boldsymbol{z_0}$, we can solve for admissible domain of the undetermined component material property parameters and dimensional parameters by the following inverse mapping from the driving variables back onto the parameter space:

$$z = \mathrm{inv\_}f_z\,(x \mid J{=}J_0 , z{=}z_0), \tag{2}$$

B.3 For automatic control design, we applies inverse mapping from desirable performance back onto the space of driving variables with given material and dimensional parameters $\{\boldsymbol{z}\}$ and initial value $\boldsymbol{y}(\boldsymbol{0})$ of state variables $\boldsymbol{y}$:

$$x = \mathrm{inv\_}f_x\,(y(0) \mid J{=}J_0\,; \{z\}), \tag{3}$$

B.4 It is possible that the inverse mapping could ended up with empty admissible solution set, we then need to adjust the priorities and trade off among the list of $\boldsymbol{J}{=}\boldsymbol{J_0}$ and $\boldsymbol{z}{=}\boldsymbol{z_0}$. It might even take daring break through in requesting extra ordinary range of material properties or dimensions $\boldsymbol{z}{=}\boldsymbol{z_0}$ or architectural ingenuity for new functional characteristics to squeeze out some admissible solutions.

After going through the step-by-step process a few times consciously, can students execute the exercises of creativity design and implementation with fluent flow and confidence.

VI. ILLUSTRATED EXAMPLES

In the following sections we will illustrate three different study cases extracted from the students' projects in the past years. Each example will focus on the teaching strategy mentioned in the paper.

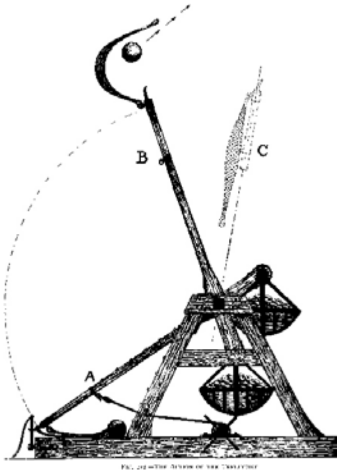
A. Stone thrower

The study case illustrates creative designing with aid of our developed "PET". The task is described in Fig. 9. The intended output physical quantity is the initial speed v of the stone. On the other hand we can use any possible physical quantities as input quantity, as long as it can affect an initial speed of stones.

With aid of the effect search matrix of PET, we can find 9 possible direct effects. Some of the available effects can be applied based on the requirement of physical quantity, but they are not suitable for this case. For example, we can use the voltage U to generate the initial speed v following the "Induction Law", but an external electric energy is necessary.

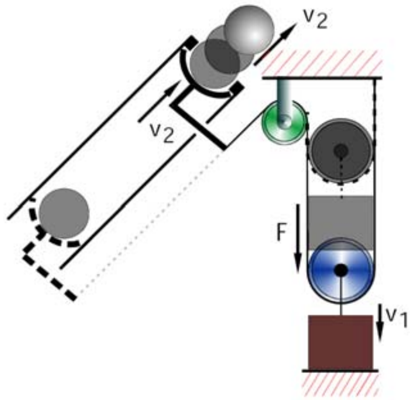
With aid of the search engine of "PET", we can obtain the suitable combinations of physical effect easily. In this case we restrict the searching to maximum four level of combination. In order to reduce the amount of effect chains, we let the intermediate functional quantities as given quantity, here force F and Pressure p_d. The number of possible effect chain by level 4 will be then reduced from 354 to 116. Through further evaluation we can get then 19 effect chains for the design, Fig. 9. From the 19 effect chains we can furthermore select suitable effect chains that can lead to new design of stone thrower. Some of the other chains are similar as the students' design, e.g. No. 4 to 6

Level	No.	Effect-Chain	Selection Remark
2	1	$F \rightarrow F \rightarrow v$	Because the effect "multiplication of force ($F \rightarrow F$)" doesn't lead to better solution, this combination will not be further considered.
	2	$F \rightarrow v \rightarrow v$	A new principle solution can be developed.
	3	$pd \rightarrow F \rightarrow v$	A new principle solution can be developed.
3	4	$F \rightarrow s \rightarrow F \rightarrow v$	Similar as "catapult"
	5	$F \rightarrow v \rightarrow p_i \rightarrow v$	
	6	$F \rightarrow F \rightarrow v \rightarrow v$	The reasonable solution for the effect "Multiplication of force" is that the increased force plays a roll as energy storage. Similar as No. 2.
	7	$F \rightarrow M \rightarrow \omega \rightarrow v$	A new principle can be developed.
	8	$pd \rightarrow F \rightarrow v \rightarrow v$	Using pressure as power source! Next effect chain is same as No. 3.
4	9	$F \rightarrow F \rightarrow s \rightarrow F \rightarrow v$	The reasonable solution for the effect "Multiplication of force" is that the increased force plays a roll as energy storage. Similar as No. 4.
	10	$F \rightarrow s \rightarrow F \rightarrow v \rightarrow v$	A new principle solution can be developed.
	11	$F \rightarrow v \rightarrow v \rightarrow p_i \rightarrow v$	Similar as No. 5. The change of velocity before collision has no influence on final velocity under consideration of conservation of mechanical energy.
	12	$F \rightarrow v \rightarrow p_i \rightarrow v \rightarrow v$	A new principle solution can be developed.
	13	$F \rightarrow v \rightarrow v \rightarrow \omega \rightarrow v$	Same as "Trebuchet".
	14	$F \rightarrow \varphi \rightarrow M \rightarrow \omega \rightarrow v$	Same as "Trebuchet"
	15	$F \rightarrow M \rightarrow \omega \rightarrow F \rightarrow v$	The velocity for stone throwing is generated by the centrifuge force; it is difficult to control the throwing direction.
	16	$F \rightarrow M \rightarrow \omega \rightarrow \omega \rightarrow v$	Similar as No. 7, only the rotating speed is varied.
	17	$p_d \rightarrow F \rightarrow v \rightarrow p_i \rightarrow v$	Using pressure as power source! Next effect chain is same as No. 5.
	18	$p_d \rightarrow F \rightarrow M \rightarrow \omega \rightarrow v$	Using pressure as power source! Next effect chain is same as No. 7.
	19	$p_d \rightarrow F \rightarrow v \rightarrow F \rightarrow v$	



No.2

Task:
Design a device with the energy resource from human for throwing a stone to the max. distance!



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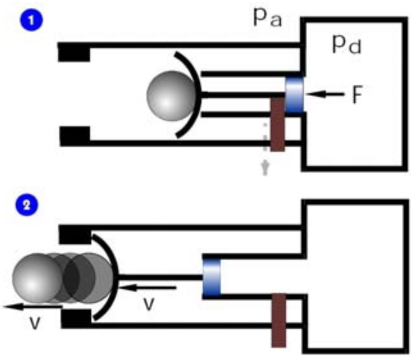


Fig. 9. Design task, solution catalogue of selected effects, and selected solutions for the study case "stone thrower"

B. Bubble Night Light – a productdesign with applicaton of fuel cell

This example illustrates a students' project that was conducted for a competition – "2007 Fuel Cell Creative Application Competition" organized by Antig Technology Co. in Taiwan. All the participants must design innovative products using fuel cell as power source. The students, all from the department of mechanical engineering at NCU, organized a team with four members for this competition. Their design "Bubble Night Light" has won the third prize of the contest. Their innovative device serves as a flower pot, an aquarium and also a night light at the same time. In the following we will present their efforts by applying the skill of graphical thinking to overcome the problems they met.

At the first meeting, the students determined to use LED as the main theme in their design. Through brainstorming and discussion they came to a conclusion with the concept that was integrated from the ideas of the members. They sketched their product concept (Fig. 10) with the following description in their document:

"*The product should have one separable fuel tank with rotate decorations in it and could also place plants on it*".

Starting from this concept, the team began to develop the principle solution in details. In this stage the most important problem was how to rotate the dummy fishes inside the methanol tank. One of ideas is to construct a device with a motored shaft, so that the dummy fishes can be rotated, Fig. . Some problems were raised: the sealing between the shaft and the tank/pot is necessary; the water from the flower pot must be drained through the shaft. After discussion, they determined to use an O-ring as the sealing component and a hollow shaft as drainpipe to solve the problems. The principle solutions were thus developed in two variants, according to (a) direct-drive concept; and (b) belt-drive concept, respectively.

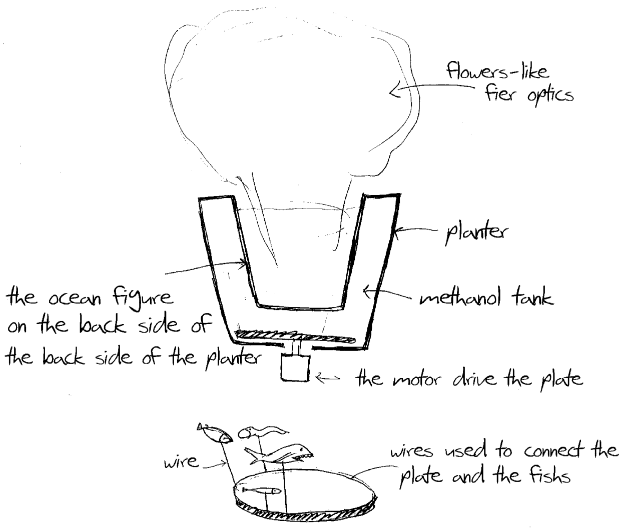


Fig. 10. The original concept of Bubble Night Light.

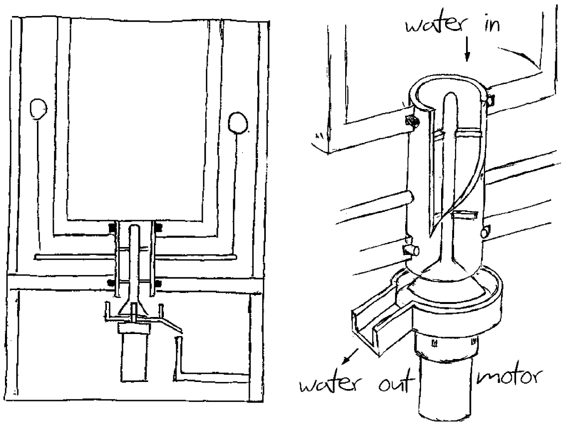
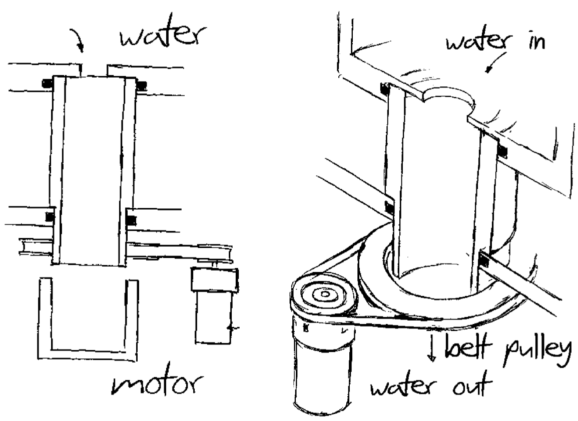
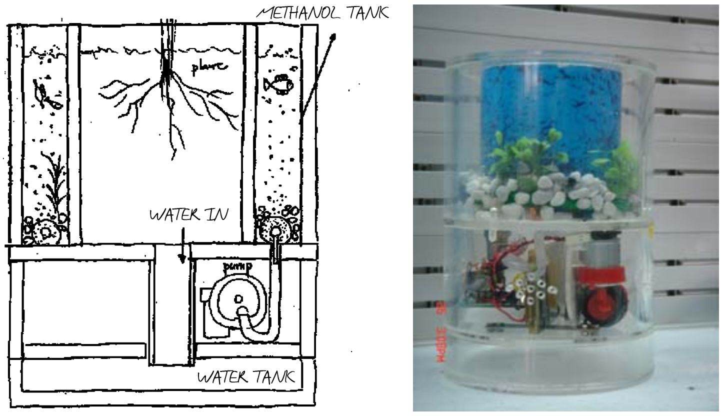
Variant 1 – Direct-drive concept	Variant 2 – Belt drive concept
	

Fig. 11. Two variants with different drive concepts

Both developed variants, however from their point of view, had the disadvantages: complicated and not practicable. They started to search another means to realize the movement of the dummy fishes. As one of the members saw a shaker that can cause water inside turbulent, a new idea was generated that the dummy fishes maybe can move with the turbulent methanol. According to this idea, they presented their final solution as the principle sketch in Fig. 12 shown: using a pump to pump up air into the methanol tank, the bubble will cause the dummy fishes move like real fishes swimming in an aquarium. The prototype of the "Bubble Night Light" was produced according to a layout (not shown here) generated from the principle sketch.



Principle structure Prototype

Fig. 12. The principle structure and prototype of the "Bubble Night Light"

VI. Conclusion and Outlook

The results of our study enable to draw the following conclusions:

- We have developed teaching strategies to enhance the abilities of students for design realization from searching solution principles, developing principle structure, until determining quantitative dimensions of solution.
- Our teaching experience shows that the three abilities discussed in the study, i.e. designing with physical effects, graphical thinking and inverse functional mapping, are indeed important and very suitable for students as novices to acquire abilities for design realization.
- Applying the developed strategies in teaching in the classes is successful from the assessment results. A further and more precision evaluation of the teaching strategies will be conducted in the next years.

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