

DEVELOPING A WEB-BASED TOOL FOR ENGINEERING DESIGN AND ITS APPLICATION

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Abstract $\frac{3}{4}$ This paper illustrates activities of creativity engineering education at the National Central University in Taiwan. In order to help students to associate their physics domain knowledge with the design project, we develop the “Physical Effect Toolkit -- PET” on web platform. This tool contains three main parts: guideline, searching/generating engine and physical effect database. With aid of this “PET” various possible combinations of effects can be found easily to meet the design requirement. The designer can be also informed the information of related effects from this fully organized toolkit. Finally we illustrate a design case developed with aid of this tool. This web-based design tool should be useful to all who are interested in doing engineering design project.

Index Terms $\frac{3}{4}$ Physical effect, web-based design tool, engineering design, stone thrower.

INTRODUCTION AND BACKGROUND

In each fall semester we will hold a creativity contest for the course “Creative Mechanical Design” at the National Central University, Jung-Li/Taiwan. The participants have to decide themselves the theme, procedures, requirements, and rules of the contest. The theme of the contest in the past fall semester 2001/02 is to design a stone thrower with the greatest distance (refer to Figure 1). After the contest, the students were asked to fill out a survey designed to analyse their thinking and problem-solving behaviour. The results of this questionnaire are quite interesting for the creative engineering education. Below is a summary of the major findings:

- There are about one half students whose idea on stone thrower comes from their own impression, especially from the scene of computer game. Only 11% of them designed their throwers did follow them self-design requirement.
- Near 70% of students have developed only one or two solutions.
- Around 60% of students did not search for related information as an aid of their design works.
- More than 50% of students believed that they couldn't overcome the creativity's barrier because of the influenced of the existed thought or impression.

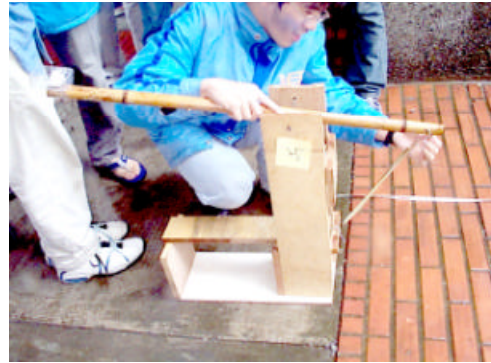


FIGURE 1

STUDENT'S DESIGN: STONE THROWER FOR THE CREATIVITY CONTEST IN THE COURSE “CREATIVE MECHANICAL DESIGN”

The results match our past teaching experience. Currently, the typical problems of Taiwanese engineering students in the design education are:

- They have difficulties to apply the knowledge that have learned to their practical design.
- They are strongly being influenced by the known design or existing idea thus a new and creative solution is rare.
- A wide solution spectrum is difficult for them to find.
- Most of them do not get used to search for, at least enough, design information as an aid to solve their problems.

However, the design engineer in 21st century needs not only innovative talents but also interdisciplinary ability to develop new technology. An appropriate teaching assist is therefore necessary for answering the challenge of engineering design education. Besides teaching the knowledge of engineering, the design methodology today plays more and more an important role in the college. According to the systematic design methodology the design process can be divided into several phases, from *task clarifying*, *conceptual design*, *embodiment design* and *detail design*.

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. While designing an instrument or a mechanical device, for example, we need some physical

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quantities as input and/or output quantities of this mechanical system, just like generate force (acceleration) and initial speed of stone for stone thrower. However it is not easy to search for suitable physical effects that can meet the requirements of the task. From our past experience, even an experienced designer encounters difficulties in searching suitable effects to fulfil the requirements of his design task, not to mention the inexperienced students.

To overcome this difficulty, some German professors [1, 4-6] have recommended several design models. The idea of these models comes from the reference books. They usually contain an ordering matrix (similar as the index of books) and collection chart of physical effects (similar as the text part of books). Through the ordering matrix the designer can find the suitable effects out of the collection charts with corresponding index. Some researchers have recently preceded further studies on applying the effects to the design. For instance, Finkelstein et al. [2] establish a knowledge-based system (KBS) and implement a convergent method based on physical laws for designing concept of instrument system. Žavbi and Duhovnik [7, 8] apply an algorithm using Analytic Hierarchy Process to generate a physical effect chain to meet the requirements of design task.

The design information from these existing models, however, was dissimilar in various formats (books, manuals, etc.). The user needs also more effort to look for the possible combination of various effects. Such models therefore seem to provide not enough help to students. We begin thus to develop web-based design tool -- "PET" (*Physical Effect Toolkit*), which is capable of presenting the necessary design information of physical effects in the form of image and animation and organizing design information in a uniform format.

FUNDAMENTAL OF PHYSICAL EFFECT ANALYSIS IN ENGINEERING DESIGN

Physical laws, Effects and Functions

Physical effect can be described quantitatively by means of

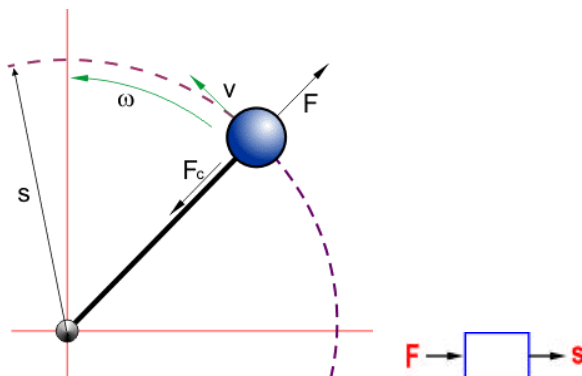


FIGURE 2

PRINCIPLE SKETCH OF "CENTRIFUGE EFFECT". THE EFFECT CAN BE ALSO REGARDED AS BLACK BOX WHEREBY THE FORCE AS INPUT AND THE DISPLACEMENT AS OUTPUT VARIABLE.

		Solid Mechanics (Translation)				Solid Mechanics (Rotation)				Fluid Mechanics				Electrics				
		F	S	p	v	M	φ	L	ω	u	π	V	p _t	I	φ	Q	U	
Output		No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Solid Mechanics (Translation)	F	1																
	S	2																
	p _t	3																
	v	4																
Solid Mechanics (Rotation)	M	5																
	φ	6																
	L	7																
	ω	8																
Fluid Mechanics	u	9																
	π	10																
	V	11																
	p _t	12																
Electrics	I	13																
	φ	14																
	Q	15																
	U	16																

FIGURE 3

THE EFFECT SEARCH MATRIX. THE COLORED FIELD IN THE MATRIX MEANS THAT A DIRECT RELATION BETWEEN THE INPUT AND OUTPUT QUANTITIES EXISTS.

the physical laws governing the physical quantities involved [5]. For example the centrifugal effect is described by the centrifugal force F , mass m , rotating radius r and rotating speed ω with the relation,

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

If a device is developed to control a rotating speed ω , for example, we can use this centrifugal effect. With the principle sketch, shown in Figure 2, the output quantity is the centrifugal force F and the input quantity is the displacement s (the change of radius). The mass m and the rotating speed ω are regarded here as constant. Through further developing the principle structure into a suitable mechanism we may obtain the well-known solution – control valve in steam engine invented by Watt.

Functional Quantities and Design Quantities

From the example mentioned above, we can see that the laws of physics are expressed in terms of physical quantities. Through defining the various quantities as variable or constant, we may have different solution even though the same physical law. The variable quantities in the physical law appear usually as the required functions and the designer in general determines the values of constant quantities. We call therefore the variable quantities as *functional quantities* and the constant quantities as *design quantities*.

In order to construct a systematic database of effects, the laws of physics and effects should be organized according to the functional quantities. The classification of various functional quantities are listed here according to the domains suggested by Roth [6]:

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- *Solid mechanics (Translation)* domain: force (F), velocity (v), displacement (s), impulse (p_i);
- *Solid mechanics (Rotation)* domain: torque (M), angular velocity (ω), angle (ϕ), angular impulse (L);
- *Fluid mechanics* domain: pressure (p_a), volume rate (u), pressure impulse (p), volume (V);
- *Electrics* domain: current (I), voltage (U), charge (Q), flux (Φ);
- *Thermodynamics* domain: entropy rate (dS/dt), entropy (S), temperature (T);
- *Pseudo-thermodynamics* domain: heat (Q_w), heat rate (dQ_w/dt).

The domain “Thermodynamics” and “Pseudo-thermo-

dynamics” will be further developed and thus not appear in the present work.

Roth [6] has developed an “Effect Search Matrix” for quick finding of physical effects between the functional quantities (see Figure 3). As long as the rectangle is colored, a direct relation exists between the input and output quantities, i.e. the physical effect can be found. Each color rectangle will be linked to the corresponding database of effect or equation.

Effect Chain

Sometimes there will be no direct relation between the specified input and output functional quantities while using the search matrix for design task. Nevertheless we can also

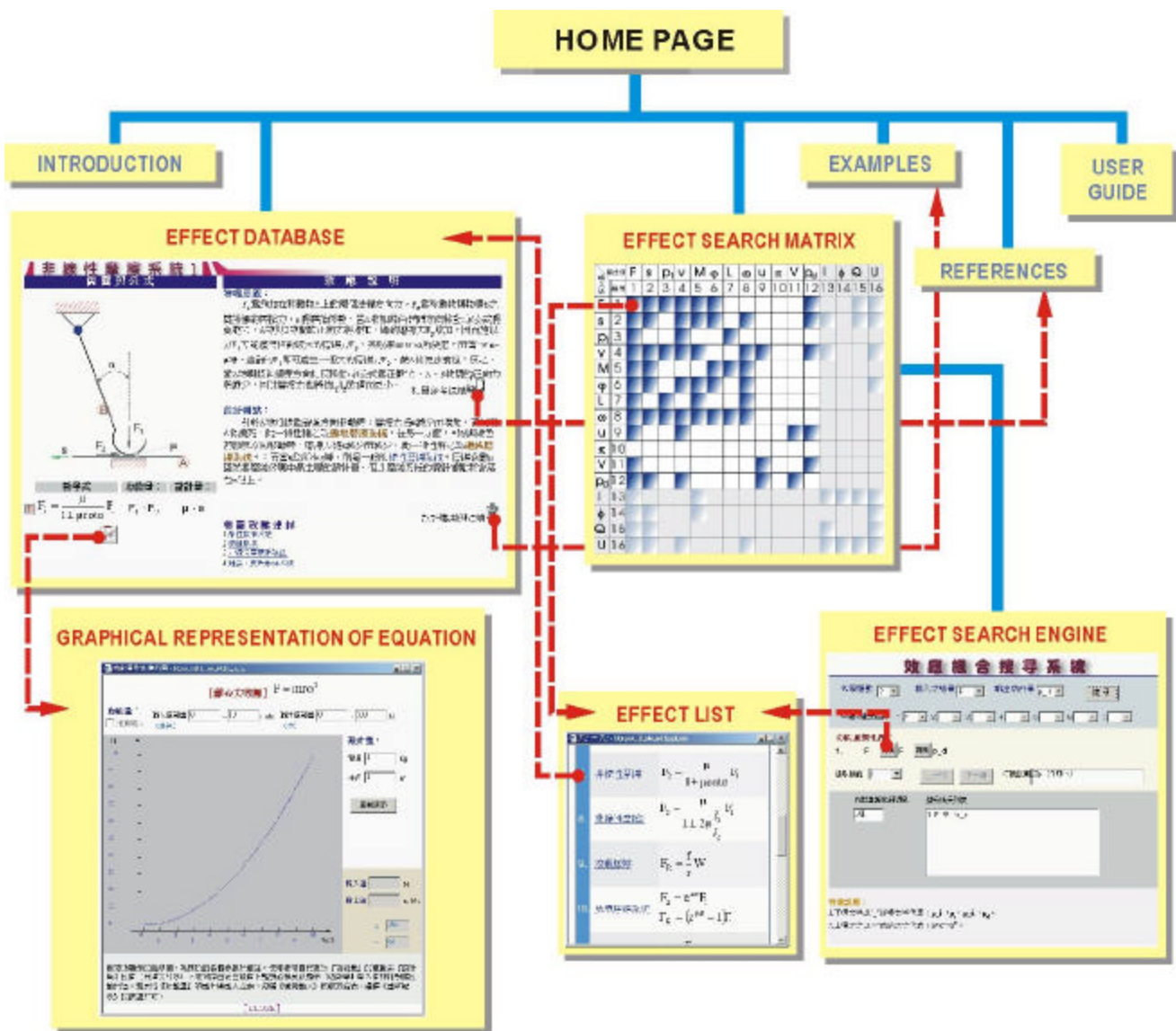


FIGURE 4
WEB-BASED ARCHITECTURE OF THE DESIGN TOOL “PET”

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apply chain law to establish a combination of various effects to meet the requirement. In the same way we may also use this chain law to find a combination of several effects out of the search matrix to improve the design.

Design Strategy for Searching Suitable Effects to Meet Required Functions

When designing a new technical object, the conditions about the physical quantities, which can be used in the design, are usually not clear. We can thus distinguish three possible combinations of input and output physical quantities for effect analysis. For each combination we may have corresponding design strategy for searching effects.

- Input functional quantity is *known* and output is also *known*: The usual condition 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, for example, to measure force, the many physical quantities can be the output variables.
- Input functional quantity is *unknown* but output is *known*: This condition occurs usually if the output functional quantity must be specified but the input functional quantity can be unlimited, e.g. by designing the stone thrower which the input variable must be initial speed of stone but the input energy source is free to select.

WEB-BASED DESIGN TOOL OF PHYSICAL EFFECTS – A SHORT DESCRIPTION

In order to overcome the barrier of applying the physical effect to the conceptual design, some requirements for developing the computer aided design tool are necessary:

- A database of physical effects is necessary and should be completed.
- The database should be constructed based on the engineering design so that the engineer can understand easily.
- The database should be accessed easily and user-friendly.

The web-based tools that can offer not only easily accessible and well-illustrated database but also quickly finding appropriate effect chains.

Architecture of the web-based Design Tool

The structure of website⁴ of “PET” is shown in Figure 4. The first level contains six main parts: *introduction*, *effect database*, *effect search matrix*, *examples*, *user guide* and *reference*. From “introduction” the user can get the

⁴<http://cedesign.me.ncu.edu.tw/medesign/effects/index.htm> (in Chinese).

necessary information of the theory of physical effect analysis in the engineering design viewpoint. Some design cases using this “PET” will be presented as “examples” for understanding how to apply this tool to the design task. For further study on the physical effects, the related materials will be collected in “reference”. The remaining but important parts are described below.

- **Search Matrix** is similar to Figure 2. We add here the hypertext-link function to the “Search Matrix”. Through clicking on the colour rectangle a window with “**Effect List**” will appear. By selecting suitable effect the corresponding database will appear in another window to offer further information of this physical effect for designing.
- **Search Engine** is programmed in Java-applet. Through defining the “*level of effect*”, “*input quantity*”, “*output quantity*” and “*intermediate quantity*” this search engine will generate a list of possible combinations of effect. For each effect chain the user can utilize the link-function of individual effect to get more design information.
- **Database of Physical Effects** contains five different information sources: “*principle sketch*”, “*formula*”, “*physical meaning*”, “*viewpoint of design*” and “*hyperlinks*”.
- **Graphical Representation of Equations**: After selecting the suitable physical effect for the solution of the task, the designer will further determine the design quantities for this effect. Using this tool the designer can vary the value of the design quantities until the relation of input and output quantities meets the requirement of design task.

CASE STUDY – STONE THROWER

We have use the theme of the students’ contest in the past undergraduate semester, namely the stone thrower, as a case study to illustrate creative designing with aid of our developed “PET”. At first we will discuss the concepts of the students’ designs. Although some of their final designs don’t work very well, we can still identify some clever ideas from them. We can also find these ideas later from the solutions developed with “PET” again.

Design of the undergraduate students

Our analysis show that undergraduate students applied 9 various effects in their design works of stone thrower (see Table 1). These effects are used in individual form or combined as an effect chain to generate the initial speed of stone. Most students used the “*Helical Spring Effect*” to generate enough force. That is maybe due to theirself experience. The principles of their design are summarized in No. 1 to 9 in Figure 5. In total of 9 different principles only three various type of primary effect are used to generate the initial speed for throwing the stone.

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No	1	2	3	4	5
Primary Effect	Impulse	Lever	Spring Force	Spring Force	Spring & Lever
Effect-Chain	$F \rightarrow v \rightarrow p_i \rightarrow v$	$F \rightarrow v \rightarrow v$	$F \rightarrow s \rightarrow F \rightarrow v$	$F \rightarrow s \rightarrow F \rightarrow v$	$F \rightarrow s \rightarrow F \rightarrow v \rightarrow v$
Principle Sketch					
No	6	7	8	9	10
Primary Effect	Spring & Lever	Spring & Lever	Spring Force	Pressure	Pressure
Effect-Chain	$F \rightarrow s \rightarrow F \rightarrow v \rightarrow v$	$F \rightarrow \varphi \rightarrow F \rightarrow v$	$F \rightarrow s \rightarrow F \rightarrow v$	$p_d \rightarrow F \rightarrow v \rightarrow F \rightarrow v$	$p_d \rightarrow F \rightarrow v$
Principle Sketch					
No	11	12	13	14	
Primary Effect	Pulley	Gravity	Pressure	Lever	
Effect-Chain	$F \rightarrow v \rightarrow v$	$F \rightarrow M \rightarrow \rightarrow v$	$s \rightarrow F \rightarrow v \rightarrow v$	$F \rightarrow v \rightarrow p_i \rightarrow v \rightarrow v$	
Principle Sketch					

FIGURE 5

THE PRINCIPLE SOLUTION FOR DESIGN OF "STONE THROWER". THE EFFECTS ARE GENERATED WITH AID OF THE WEB-BASED TOOL – "PET". THE SOLUTION OF THE UDERGRAUATE STUDENTS ARE SIMILAR AS THE PRINCIPLE SOLUTIONS OF NUMBER 1 TO 9.

Concept Developing with Aid of "PET"

We give a brief description of the procedure of concept design when using "PET":

- **Effects Generating:** The intended output physical quantity is the initial speed v of the stone. However, the input quantity is not limited, i.e. we can use any possible

TABLE 1

ANALYSIS OF THE DESIGN OF THE UDERGRAUADUATE STUDENTS

Physical Laws	Applied	Percentage
Newton's second law	49	100.0%
Impulse	1	2.0%
Lever effect	21	42.9%
Helical spring effect	32	65.3%
Torsion spring effect	3	6.1%
Cantilever beam	4	8.2%
Pressure	1	2.0%
Reaction force	1	2.0%

physical quantities as long as it can effect an initial speed of stones. With defining the velocity v as output variable, we can thus have 9 possible direct effects available. Although some effects can be applied creatively in the design, they are however 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 must be supplied.

- **Effect Chain:** With aid of the search engine of "PET", we can find 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 increased effect chains, we can specify the so-called *intermediate functional quantities*, 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 19 effect chains for the

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design (see Figure 6).

- **Principle Solutions:** From the 19 effect chains we will furthermore select 5 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.

CONCLUSION

Through comparing the design of undergraduate students and the design with aid of the tool "PET" on the theme "Stone Thrower", we may conclude as following:

- Integration of the engineering methodology and the science knowledge is helpful for teaching the creative

design courses in college.

- Using the web-based design tool is suitable for further development the design tool, especially to sort the useful information from various resources in the internet
- Applying physical effect to design is beneficial for developing new technical product. This is significant for designer today who needs creative talent as well as interdisciplinary ability to develop new technology.
- With the aid of design tool "PET" the designer can not only overcome the barrier to physical laws but also save the effort in searching suitable information of physical effect.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support from the National Science Council of the R.O.C. through the project NSC 90-2511-S-008-001.

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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 $F \rightarrow v \rightarrow v$	Same as the students' solution No. 2 in fig. 6. However another effect can be also used for this effect chain. 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", same as the students' solution No. 3 and 6.
	5 $F \rightarrow v \rightarrow p_1 \rightarrow v$	Same as the students' solution No.
	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 role as energy storage. Similar as No. 4.
	10 $F \rightarrow s \rightarrow F \rightarrow v \rightarrow v$	Same as the students' solution No. 4. However another effect can be also used for this effect chain. A new principle solution can be developed.
	11 $F \rightarrow v \rightarrow v \rightarrow p_1 \rightarrow v$	Similar as No. 5. The change of velocity before collision has no influence on final velocity under consideration of conservation of mechanical energy.
	12 $F \rightarrow v \rightarrow p_1 \rightarrow v \rightarrow v$	A new principle solution can be developed.
4	13 $F \rightarrow v \rightarrow v \rightarrow \omega \rightarrow v$	Same as "stone thrower".
	14 $F \rightarrow \varphi \rightarrow M \rightarrow \omega \rightarrow v$	Same as "stone thrower" and also same as the students' solution No. 5.
	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 $pd \rightarrow F \rightarrow v \rightarrow p_1 \rightarrow v$	Using pressure as power source! Next effect chain is same as No. 5.
	18 $pd \rightarrow F \rightarrow M \rightarrow \omega \rightarrow v$	Using pressure as power source! Next effect chain is same as No. 7.
	19 $pd \rightarrow F \rightarrow v \rightarrow F \rightarrow v$	Same as the students' solution No. 2

FIGURE 6

LIST FOR EVALUATION OF SEARCHED EFFECT CHAINS