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The sequence of conceptual information in instruction and its effect on retention*

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Abstract. Two experiments were carried out to study the effect of the sequencing of the information in an instructional program. In both experiments, two different ordering principles were used. These principles were based on the relation between the to be learned concepts. The ordering of the information could be successive or simultaneous. The relationship between concepts is categorized either successive or coordinate. It was hypothesized that a simultaneous presentation would show better learning results than a successive presentation if between the to-be-learned concepts exists a co-ordinate relationship. A successive presentation would lead to better results in case of a successive relationship. Results suggest that the definition of both types of relationships needs refinement. Further the results show that for coordinate related concepts a simultaneous presentation is preferable.

Introduction

Tennyson and Cocchiarella (1986) propose a model for concept teaching, in which concept learning is viewed as a two-phase process: (a) the formation of conceptual knowledge (prototype formation), and (b) the development of procedural knowledge. Conceptual knowledge is formed by the integrated storage of meaningful dimensions selected from known examples and connecting this information to a given domain of knowledge. Conceptual knowledge is more than the storage of declarative knowledge, which implies an awareness of information and refers to 'knowing that.' Conceptual knowledge implies an understanding of 'knowing when and why' to select specific concepts, rules and principles. Procedural knowledge is the retrieval of knowledge used to solve domain-specific problems, and implies a 'knowing how' to use specific concepts, rules and principles (Tennyson, 1988).

The model of Tennyson and Cocchiarella (1986) is composed of two fundamental components of instructional design. Firstly, the instructional design for concept learning should be based on the content structure of a given domain of

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information. This content structure should be analyzed according to the relations between the concepts in the domain of information and according to the variability of the attribute characteristics of each concept in that domain. Secondly, the instructional design should be based on the organization of instructional design variables directly related to specific cognitive processes in concept learning.

Tennyson and Cocchiarella distinguish two basic relations between concepts: successive and coordinate. Successive concepts have clearly discriminable critical and variable attributes, and their production rules are basically independent. Coordinate concepts share multiple critical and variable attributes, and their production rules are more dependent on each other. For example, Tennyson and Cocchiarella analyze the concepts of internal and external punctuation as successive concepts, whereas the different types of poetic feet can be analyzed as coordinate (Merrill and Tennyson, 1977).

When teaching concepts with successive relations, learning is limited primarily to the development of generalizations within a concept class. Discrimination is a less important component than generalization. Instance presentation can be limited to examples only. With coordinate relations, learning also includes the skill to discriminate between classes of concepts. When teaching two or more co-ordinate concepts, examples should be presented as a rational set of closely matched instances (cf. Shumway, White, Wilson and Brombacher, 1983; Tennyson, 1980; Tennyson, Tennyson and Rothen, 1980). Tennyson and Cocchiarella recommend in their instructional design model that successive concepts require a successive presentation order (sequence) of the conceptual information. When teaching concepts defined as coordinate, the examples require a simultaneous presentation order (sequence). The opportunity to compare and to contrast examples from one coordinate concept with examples from another co-ordinate concept improves the development of the discrimination skill.

Tennyson and Cocchiarella report several studies which support their model of concept teaching. Many of these studies used well-defined concepts like equilateral triangles (Tennyson, Chao and Youngers, 1981), or artificial concepts like letter patterns (Shumway, White, Wilson and Brombacher, 1983). Natural concepts, real-world objects like tree, oak, white oak, mammal, horse, etc., mostly have many variable attributes. These variable attributes are not included in the definition of the concept and the values of these attributes vary along the different subordinate concepts. For example, the color attribute is a variable attribute for the concept bird. Different birds have different colors. Because natural concepts have many defining and variable attributes, the production rules of these concepts are more complex than the production rules of well defined concepts like equilateral polygon, which has only three defining attributes (plane, closed figure, all angles are equal), and only two variable attributes (size, and number of angles).

In applying the skills of generalization and discrimination it is supposed that the subject depends strongly on the quality of the developed prototype, the mental representation of a typical category member. This prototype is formed by the integrated storage of meaningful dimensions selected from known examples and the connection of this information to a given domain of knowledge. In this study the instructional design model of Tennyson and Cocchiarella is tested for natural concepts with complex production rules. Their recommendations that coordinate concepts require a simultaneous presentation and that successive concepts need a successive presentation will be applied to an instruction for learning natural concepts.

Experiment 1

The concepts Thuja and Chamaecyparis, two families of conifers, can be classified as coordinate because their production rules are dependent on each other. Because the individual exemplars of both concepts do resemble each other closely with respect to the defining characteristics, there is a possible discrimination error. For teaching these concepts it is hypothesized that a simultaneous presentation would be more effective than a successive presentation.

It is hypothesized that subjects in the simultaneous condition will need less time to study the instructional material than subjects in the successive condition, because the first subjects do not need memory retrieval to compare both conifers. Further, it is supposed that the expected beneficial effects will not be noticed on an immediate posttest. Because of the 'freshness' of the new information all subjects will perform equally well. After some time a decrease of declarative knowledge (knowing what the defining characteristics are) will be noticed with all subjects. For the procedural knowledge (the ability to classify instances correctly) it is expected that subjects in the simultaneous condition will perform better on a retention test than subjects in the successive condition.

Method

Subjects

Forty-seven subjects aged between 14 and 16 years participated in this study. They were male and female pupils of a Dutch primary agricultural school, lower level. To ensure the ecological validity of this study the experiment was performed with subject matter that was part of the school curriculum. The experiments took place during school hours. Participation in this study was compulsory. The scores on the tests, however, were not included in their school grades. The subjects were randomly assigned to the conditions.

Instructional program

Two instructional computer programs describing two kinds of conifers were designed (the Thuja and the Chamaecyparis). These programs differed only in the sequencing of the information about the two families of conifers. The written information and graphical information in both programs were the same. Both programs started with a section on working with the computer (e.g., using the mouse, pushing buttons on the screen, text editing, etc.), and a section about conifers in general and their position in the taxonomy of trees.

In the successive program the third section was about the Thuja and the fourth was about the Chamaecyparis. Each of these two sections started with a general description of the Thuja or the Chamaecyparis. Subsequently, the defining characteristics were described and shown (see Table 1).

In the simultaneous program the third section discussed both conifers simultaneously. Each frame contained information on both types of conifers. So, the first frame adressed the Thuja and the Chamaecyparis in general and in the following frames the defining characteristics were addressed.

In the last section of both programs (recall section) the subject was asked to recall the defining characteristics of both concepts by putting check marks in three-choice items.

Table 1. Defining characteristics of Thuja and Chamaecyparis

Thuja	The joint between two scale-leaves forms the letter V.
	Turpentine-like scent.
	The fruits are cone-shaped.
	The tree has a standing shape.
Chamaecyparis	The joint between two scale-leaves forms the letter Y.
	No scent or bad scent.
	The fruits are bulb-shaped.
	The tree has a hanging shape.

Picture book

The instructional programs were accompanied by a picture book. When a defining characteristic was discussed in the computer program, the subject was asked to turn over a page in a picture book, and closely examine the photographs. Each page contained three color photographs. The upper photograph measured 17 x 17 cm and illustrated the discussed defining characteristic. The lower two photographs measured 8 x 8 cm and illustrated the other two visible characteristics. When the scent of the conifers was discussed in the instructional program, a plastic bag containing a sample leaf was added to the page of the picture book. This bag was removable and the subject was encouraged to take out the leaf and to smell it. The photographs illustrated the other three defining characteristics. The upper two measured 8 x 17 cm and the lower picture 17 x 8 cm. In the simultaneous condition, the pictures on the left page illustrated the Thuja and the pictures on the right page illustrated the Chamaecyparis. In the successive condition, the right page was blank in the Thuja section and the left page was blank in the Chamaecyparis section.

Tests

Test of procedural knowledge
A classification test consisting of twenty branches of conifers was composed. Each branch measured between 10 cm and 15 cm and was presented in a plastic bag. Of these branches there were ten Thujae and ten Chamaecypari. The subjects were allowed to take the branches out of the plastic bags to examine them closely and to smell them, and were asked to make two piles of plastic bags.

Test of declarative knowledge
The subjects were asked to write down the discriminating characteristics of both kinds of conifers.

Apparatus
The instructional program ran on an Apple Macintosh Plus (1Mb) microcomputer.

Design
A repeated measurement design was used to test the hypotheses. The independent variable had two levels: a simultaneous presentation condition and a successive presentation condition.

Procedure
After receiving a brief explanation about the objectives of the study, each subject individually studied the instructional program. If the subject did not manage to answer a question correctly during the instruction, after three trials the computer provided the subject with the correct answer. Immediately after the instruction the classification test was presented. After the classification test, the declarative knowledge test was administered. After a four-week interval, subjects participated in a retention test session, in which both classification test and declarative knowledge test were delivered. Again, the classification test was administered firstly and next the declarative knowledge test.

Data

Program data

During the instruction the computer system created a logging file in which the time spent studying each section was recorded. It also recorded the answers the subjects gave to the questions and the number of errors. Finally it recorded the number of trials in answering the multiple choice items in the last section.

Procedural knowledge data

Three scores were obtained with the classification test: the number of correctly classified Thujae and the number of correctly classified Chamaecypari, both ranging between zero and ten, and finally the sum of these both scores, ranging between zero and twenty.

Declarative knowledge data

Two scores were obtained with the declarative knowledge test: the number of correctly mentioned characteristics of the Thuja and the number of correctly mentioned characteristics of the Chamaecyparis, both ranging between zero and four.

Results

Program data

For the subjects in the successive condition, the times spent in the Thuja section and the Chamaecyparis section were taken together. This was done to compare this time with the time spent in the Conifers section by the subjects in the simultaneous condition. A univariate analysis of variance (ANOVA) showed that the independent variable has a significant effect on the time spent studying the sections about the Thuja and the Chamaecyparis, $F(1,45) = 83.18$, $p < .00$, and on the time spent to study the pictures in the picture book and to examine the sample leaf, $F(1,45) = 12.30$, $p < .00$. Subjects who were in the simultaneous condition spent less time studying the Conifers section ($M = 4.43$ minutes, $SD = 1.52$) than subjects who were in the successive condition ($M = 7.30$ minutes, $SD = 1.66$). Subjects in the simultaneous condition also needed less time to study the pictures and the sample leaf ($M = 5.07$ minutes, $SD = 1.75$) than subjects in the successive condition ($M = 6.77$ minutes, $SD = 1.55$).

The subjects did not differ with respect to the number of errors made in the instructional program, and the number of trials in answering the multiple choice items in the recall section.

Procedural knowledge

An analysis of variance (ANOVA) showed an effect of the experimental treatment on the classification scores on the immediate posttest for the Thuja ($F(1,39) = 6.62$, $p < .01$) as well as for the Chamaecyparis ($F(1,39) = 5.45$, $p < .02$). Subjects in the simultaneous condition classified more Thuja branches correctly on the classification test (M = 6.33, SD = 2.39) than subjects in the successive condition (M = 4.40, SD = 2.41). Subjects in the simultaneous condition also classified more Chamaecyparis branches correctly on the classification test (M = 6.42, SD = 2.11) than subjects in the successive condition (M = 4.80, SD = 2.35).

On the retention test there is no significant difference between the subjects in the simultaneous condition and the subjects in the successive condition.

Declarative knowledge

An analysis of variance (ANOVA) revealed no difference between the two groups' scores on the immediate posttest of declarative knowledge nor on the retention test of declarative knowledge.

Experiment 2

The concepts 'wind flower' and 'insect flower' can be analyzed as successive, because their production rules are basically independent of each other. A discrimination error is only possible at borderline cases. In relation to the recommendations of Tennyson and Cocchiarella, it is hypothesized that in teaching these concepts, a successive presentation would be more effective than a simultaneous presentation.

Again, it is supposed that the expected beneficial effects will not be noticed on an immediate posttest. Because of the 'freshness' of the new information all subjects will perform equally well. After some time a decrease of declarative knowledge (knowing what the defining characteristics are) will be noticed with all subjects. For the procedural knowledge (the ability to classify instances correctly) we expect that subjects in the successive condition would perform better on a retention test than subjects in the simultaneous condition.

Method

Subjects

Forty subjects aged between 12 and 14 years participated in this study. They were male and female pupils of a Dutch secondary school. Participation in this study was compulsory. The subject matter was part of the school curriculum. The scores on the tests, however, were not included in their school grades. The subjects were randomly assigned to the conditions.

Instructional program

Two instructional computer programs describing pollination with wind flowers (flowers of which the pollen is transported by the wind) and insect flowers (flowers of which the pollen is transported by insects) were designed. In one program the two concepts were presented successively and in the other program they were presented simultaneously. The subject matter had not yet been taught in a classroom setting.

The successive instructional program consisted of the following paragraphs: a general introduction in which the flower structure (the stamen, anther, pistil, stigma, etc.) and the principle of pollination were discussed; the concept of an insect flower; the concept of a wind flower; a synthesis, in which the information about the insect flowers and wind flowers was summarized; and a test in which some declarative knowledge about the concepts wind flower and insect flower was examined.

All the instructional paragraphs consisted of several successively presented windows (or frames) with text, in some cases accompanied by a line drawing, and a question about the content of that window. This question was an 'attention focusing' question and it was also a means to ensure that the subject did actually read the text. The next window was presented only if the question was answered correctly. If the question was not correctly answered in three trials, the answer was provided.

The paragraph concerning insect flowers and the paragraph concerning wind flowers started with a window about the particular concept in general. Next, the defining characteristics were explained, one at a time. These characteristics are described in Table 2. After answering the question, an example was presented. This example consisted of a line drawing of a flower, as best example illustrating that defining characteristic (Tennyson, Youngers and Suebsonthi, 1983), accompanied by some text about this particular flower.

The simultaneous instructional program started with the same general introduction. The paragraphs concerning insect flowers and wind flowers were combined in one single paragraph. The first window discussed the insect flowers in general. The second window discussed the wind flower in general. The third window discussed the first defining characteristic of the insect flowers, and the fourth window discussed the related defining characteristic of the wind flowers, and so on. Finally, the same summary and the same test as in the successive program were presented.

To summarise, both programs were composed of the same windows. The information presented was the same for all subjects, but the sequence in which the information was presented differed.

Tests

Two tests were designed: a test of procedural knowledge and a test of declarative knowledge. On a pretest session the two tests were administered just before the delivery of the instructional program. On a posttest session, they were administered immediately after presenting the instructional program, and on a retention test session, two months later, both tests were presented again.

Table 2. Defining characteristics of wind flowers and insect flowers

Wind flower	Pollen transported by the wind. Mostly no nectar. No scent. Mostly greenish or brownish. Featherlike stigma. Extending anthers. Dry, light pollen
Insect flower	Pollen transported by insects. Nectar, to attract insects. Scent. Salient color. Coarse pistil. Fairly short stamen. Rough, sticky pollen.

Test of procedural knowledge

A classification test, consisting of 20 photographs of wind flowers and 20 photographs of insect flowers, was designed. Each photograph was 10 x 15 cm. Subjects were asked to make two piles of pictures: one pile of pictures of wind flowers and one pile of pictures of insect flowers.

Insect flowers usually have very salient colors (yellow, red, etc.), whereas wind flowers are often greenish or brownish. Just paying attention to the color characteristic could possibly result in a high score. By also presenting pictures in black and white, the effect of the color cue was controlled. Ten items were presented in color and ten items were presented in black and white.

Test of declarative knowledge

In this test the subject was asked to write down the characteristics of the two types of flowers and give some examples of both.

Apparatus

The instructional program ran on an Apple Macintosh Plus (1Mb) microcomputer.

Design

A repeated measurement design was used to test the hypotheses. The independent variable had two levels: a simultaneous presentation condition and a successive presentation condition.

Procedure
After receiving a brief explanation about the objectives of the study, the subjects completed the classification test and the declarative knowledge test. Each subject individually studied the instructional program. If the subject did not manage to answer a question correctly during the instruction, after three trials the correct answer was provided. After the instruction the classification test was presented. Then, the declarative knowledge test was given. After a two month interval, subjects participated in a retention test session.

Data

Program data
During the instruction the program created a log file in which the time spent studying each window and the typing time in each window were recorded. The typing time was subtracted from the instruction time per window as it was assumed that when the subject started typing the answer to the question, processing of the information was finished, and so the 'real' instruction time was estimated. The total time spent studying each separate topic, and the time spent to examine the examples were calculated.

Procedural knowledge data
For each item in the classification test the p-value or probability level on the immediate posttest was calculated. If the p-value of an item was not between .20 and .80, it was excluded from further analysis. This means that if an item was classified correctly by more than 80% or fewer than 20% of the subjects it was excluded.

In the analysis 12 items were included, six pictures of wind flowers and six pictures of insect flowers. In each category, three pictures were in black and white and three pictures were in color.

The following scores were obtained with the classification test: the number of correctly classified color pictures of wind flowers (COL.WIND), black and white pictures of wind flowers (BLW.WIND), color pictures of insect flowers (COL.INS), black and white pictures of insect flowers (BLW.INS). Three total scores were calculated: the total correctly classified wind flowers (WIND.TOT), the total correctly classified insect flowers (INS.TOT), and the total correct classifications (TOTAL).

Declarative knowledge data
The declarative knowledge test resulted in six scores: the number of correctly mentioned defining characteristics of each concept, the number of examples given that were also used as examples in the program, i.e., recalled examples, and the number of new or generated examples.

Results

Program data

An analysis of variance (ANOVA) showed that the instructional program (simultaneous vs. successive) has a significant effect on the total time spent studying the program, $F(1,37) = 4.66, p < .038$, on the time needed to study the windows about the insect flowers, $F(1,37) = 8.40, p < .006$, and on the time needed to do the test, $F(1,37) = 4.17, p < .048$. Subjects in the simultaneous condition needed less time to study the program (M = 23.80 minutes, SD = 5.80) and the insect flower windows (M = 5.27 minutes, SD = 1.78), and needed less time to do the test (M = 2.48 minutes, SD = .68), than subjects who were in the successive condition The mean times for subjects in the successive condition were 28.07 minutes (SD = 6.51), 6.91 minutes (SD = 1.76) and 3.14 minutes (SD = 1.24), respectively.

Procedural knowledge

An analysis of variance (ANOVA) on the classification test scores revealed no significant effects on the pretest nor on the immediate posttest. On the retention test a univariate analysis of variance showed that the instructional program had a significant effect on three variables: TOTAL, $F(1,36) = 4.21, p < .04$, WIND.TOT, $F(1,36) = 4.77, p < .03$, and COL.WIND, $F(1,36) = 3.13, p < .08$.

However, the direction of this effect is counter to what was expected. It was expected that subjects in the successive condition would perform better than subjects in the simultaneous condition, but subjects in the simultaneous condition did better (see Table 3).

Table 3. Mean classification scores on the retention test

		variable		
Condition		col.wind	wind.tot	total
Simultaneous				
	mean	2.10	4.10	8.00
	s.d.	.97	1.32	1.49
Successive				
	mean	1.57	3.10	7.05
	s.d.	1.07	1.48	1.35

Declarative knowledge

Univariate analysis of variance revealed no significant effects on the scores of the declarative knowledge questionnaire, nor on the pretest, nor on the immediate posttest, nor on the retention test.

General discussion

The results of the first experiment show that, for coordinate natural concepts, students in a simultaneous presentation condition perform better on the classification test immediately after the instruction than subjects in a successive presentation condition. It also shows that subjects in the simultaneous condition need less time to study the instructional program than subjects in the successive condition.

In contrast with the hypothesis that for succesive concepts a successive presentation would be more effective than a simultaneous presentation, the second experiment shows that for natural successive concepts, subjects in the simultaneous presentation condition perform better on the classification retention test than subjects in the successive presentation condition. Again, it is shown that subjects in the simultaneous condition need less time to study the instructional program than subjects in the successive condition. In both experiments no effect is found of the ordering procedure on the declarative knowledge, whereas it clearly affects the procedural knowledge.

The results of these experiments might suggest that the definitions of 'successive concepts' and 'coordinate concepts' could need some refinement. The physical appearance of the defining characteristics of the concepts wind flower and insect flower indeed do have little overlap. On the other hand, the defining characteristics bear a strong functional similarity.

Although the stigma of a wind flower and the stigma of an insect flower look very different, they serve the very same function: the reception of pollen. Another similarity is that both concepts are parts of the same conceptual domain: botany. So, coordinate concepts can be defined as concepts at the same level of abstraction, with similar production rules, and the defining characteristics have a strong physical and/or functional similarity, and coordinate concepts are part of the same conceptual domain. Successive concepts can be defined as concepts at the same level of abstraction, but they do not have a strong physical or functional similarity. Successive concepts can be part of the same conceptual domain.

The functional and physical similarity and the definition of the conceptual domain interact. This influences the nature of the relationship between concepts. For example, in the conceptual domain of mammals the concepts ponies and cows have a coordinate relationship. However, if the conceptual domain is milk producing animals their relationship can be analyzed as successive.

Using the above presented definition of successive concepts the results of this study present no directions for the instructional design for teaching successive concepts. The concepts in both experiments can be defined as coordinate. As it seems appropriate to suggest that successive concepts require a successive presentation order, it could be recommended that successive concepts should be presented in distinct lessons. For example, the process of distillation and the process of rusting can be analyzed as successive concepts. One instruction showing both processes might confuse a student who tries to find a similarity.

Based on the results of these two experiments it is concluded that for coordinate related concepts a simultaneous presentation of the conceptual information leads to better conceptual knowledge. A simultaneous presentation allows the subjects to compare the defining and variable (physical and functional) attributes and their values of an object from one category with the attributes and values of an object from an other coordinate category without retrieval from memory. Knowledge of both the similarities and the differences between concepts helps to reduce possible discrimination errors.

Retrieval of information is a key factor in the employment of knowledge. The instructional design should be aimed at developing and improving retrieval processes by meaningful integration of new information into memory. Before designing instruction, concepts must be analyzed and organized into conceptual structures which show their superordinate, coordinate and subordinate relationships (Reigeluth and Curtis, 1987). For the design of the within-lesson sequence, Reigeluth and Curtis recommend also that coordinate concepts should be grouped together. A simultaneous presentation of related information improves the acquisition of this information, because understanding the operational structure enables the learner to encode in memory the relational connections (Park and Tennyson, 1986). People make classification decisions on the basis of similarity comparisons to stored examples (Nosofsky, 1988). By comparing and contrasting expository examples of coordinate concepts, the student develops more elaborate and complete conceptual knowledge.

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