INSTRUCTIONAL THEORIES IN ACTION

Lessons Illustrating Selected Theories and Models

edited by

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8 Lesson Blueprints Based on the Elaboration Theory of Instruction

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FOREWORD

History

This theory was first developed by Reigeluth and Merrill to extend Merrill's Component Display Theory to the macro level, that is, to provide prescriptions for selecting, sequencing, synthesizing, and summarizing instructional content. Its development was guided by a dissatisfaction with Gagné's hierarchical, parts-to-whole sequence and by the metaphor of the "zoom lens" as an alternative. Careful analysis revealed that the sequences proposed by Ausubel, Bruner, Scandura, Paul Merrill, Don Norman, and others were all consistent with the zoom-lens metaphor. The development of the theory proceeded by analyzing the differences among these sequencing strategies, identifying the situations for which each was most appropriate to use, and extending, modifying, and operationalizing the optimal strategy for each situation. Like the Component Display Theory, this theory is indicative of the highly integrative, multiperspectived approach to prescriptive theory construction that is greatly needed at this point in the development of our knowledge about instruction.

Unique Contributions

Given that the sequencing strategies prescribed by this theory largely preexisted the theory, the major contribution of this theory is probably the integration of the various kinds of elaborative sequencing strategies into an internally consistent set of prescriptions that were all guided by the goal of building stable cognitive structures in a meaningful, subsumptive (Ausubel), or assimilative (Mayer) way. Another contribution is the considerable effort that has gone into operationalizing each of these sequencing strategies so as to provide detailed guidance for instructional designers.

However, one of the three sequencing strategies, the one based on principles (used in this chapter), entailed considerably more creative modification and extension. Another of them, the one based on procedural content, was also modified to a simplifying-assumptions approach from the shortest-path approach.

Furthermore, the Elaboration Theory was perhaps the first to place any emphasis on strategies to synthesize the instructional content, that is, to explicitly teach the interrelationships within the content. Finally, this theory may be the only one that specifically allows for some learner control over the selection and sequencing of the content.

Similarities

As with Merrill's Component Display Theory, the integrative roots of the Elaboration Theory have resulted in many prescriptions being similar to those of other instructional theories. The simplifying-assumptions approach for the procedure-based elaboration sequence is quite similar to (and was derived from) Scandura's shortest-path approach. The general-to-detailed approach for the concept-based elaboration sequence is quite similar to (and was derived from) Ausubel's progressive-differentiation sequence. And the prescription for systematic review is similar to (though more detailed than) the Gagné-Briggs prescription for enhancing retention (Event 9). These and other similarities are identified with Editor's Notes.

Issues to Think About

Are there any other useful kinds of simple-to-complex sequences besides the three prescribed by Elaboration Theory? Are there any other important kinds of relationships to synthesize? Gagné's hierarchical sequence has been integrated into all three of the Elaboration Theory's sequencing strategies, but should Landa's and Scandura's prescriptions for the selection of content also be integrated? If so, how? Finally, given the lack of empirical research support for most of the Elaboration Theory's prescriptions, how much confidence can we have in its validity?

STUDY QUESTIONS

1. What is the difference between summarizing and epitomizing?
2. What is a simple-to-complex sequence based on concepts?
3. What is a simple-to-complex sequence based on procedures?

4. What is a simple-to-complex sequence based on principles?
5. What kinds of synthesizers are prescribed, and how do they differ from each other?
6. What characteristics should a summarizer have?
7. When and how often should summary and synthesis occur?
8. What is the most important basis for deciding how long a lesson should be?

C.M.R.

INTRODUCTION

The purpose of the Reigeluth-Merrill Elaboration Theory of Instruction (Reigeluth, 1979; Reigeluth, Merrill, M. D., Wilson, B. G., & Spiller, R. T., 1978; Reigeluth & Stein, 1983) is to make life easier for instructional designers by integrating current knowledge about what the overall structure and sequence of a course or curriculum should be like. The Elaboration Theory presently prescribes seven major strategy components:

1. An elaborative sequence for the main structure of a course (and curriculum).
2. A variety of prescriptions for sequencing within individual lessons of a course (including a learning-prerequisite sequence).
3. Summarizers.
4. Synthesizers.
5. Analogies.
6. Cognitive strategy activators.
7. A learner-control format.

Elaborative Sequence

The most important prescription of the Elaboration Theory is the use of a special kind of simple-to-complex sequence. There are many possible varieties of simple-to-complex sequences, some of which have better effects on learning than others. Gagné's (1985) learning-prerequisite sequence (see chapter 2 of this book), Bruner's (1960) spiral sequence, Ausubel's (1968) subsumptive sequence, Norman's (1973) web sequence, and the shortest-path sequence (P. F. Merrill, 1980; Scandura, 1973) are all kinds of simple-to-complex sequences. The elaboration approach to sequencing integrates and builds upon all of these sequencing strategies. Both an analysis of the structure of knowledge and an understanding of learning theories and cognitive processes have been used to design the elaborative sequence.

The Elaboration Theory's instructional sequence is much like the following approach to studying a picture through the zoom lens of a camera. A person starts with a wide-angle view, allowing him or her to see the major parts of the picture and the major relationships among the parts, but without any detail. Once the person zooms in on a part of the picture, the person is able to see more about each of the major subparts. After studying those subparts and their interrelationships, the person can then zoom back out to the wide-angle view to review the other parts of the whole picture and to review the context of that one part within the whole picture. Continuing in this ''zooming in'' pattern, the person gradually progresses to the level of detail and breadth desired.

Similarly, the Elaboration Theory starts the instruction with a special kind of overview containing the simplest and most fundamental ideas, called the ''epitome'' (because it epitomizes the content). Then, subsequent lessons add complexity or detail to a part or aspect of the overview in layers (called ''elaborations''). Each lesson also reviews content and teaches relationships between the most recently presented ideas and those presented earlier. This pattern of elaboration followed by summary and synthesis continues until the desired level of complexity has been reached. The elaborative sequence can allow considerable freedom for the learner to select which part to zoom in on next and how far to zoom in on each one of the major ideas.

The elaborative sequence has two major features: The earlier ideas *epitomize* rather than summarize the ideas that follow; and the sequence is based on a *single* content orientation (Reigeluth & Stein, 1983). To epitomize is to present a few of the most fundamental and representative ideas at a concrete, application (or skill) level (Reigeluth, 1979). Then subsequent lessons add complexity or detail to one part or aspect of the overview in layers (elaborations).* The nature of the elaborations will differ depending on the content orientation: whether the instruction should focus primarily on ''what'' (concepts), ''how'' (procedures), or ''why'' (principles). Careful analysis has shown that virtually every course holds one of these three to be more important than the other two. Hence, the Elaboration Theory proposes that the nature of the simple-to-complex sequence must differ depending on the kind of content that is considered to be most important to the goals of the instruction.

In carefully reviewing the sequencing strategies of Bruner, Ausubel, P. F. Merrill, and others, Reigeluth and M. D. Merrill found that each of these strategies used a simple-to-complex sequence. However, each of those sequences

*This kind of macro-level sequencing is very different from the few theories in this book that address macro-level sequencing at all, with the exception that Scandura's sequence based on the complexity of paths through a rule (p. 164) is very similar to one of the three kinds of elaboration sequences described later in this Introduction.

was elaborating on a different dimension. That is, Bruner used *principles*, while P. F. Merrill utilized *procedures*, and *concepts* were the primary target of Ausubel's sequence. In all the work that has been done on sequencing, elaborations based on concepts, principles, and procedures are the only three we have found, although additional ones may be identified in the future. This finding is consistent with M. D. Merrill's (Merrill & Wood, 1974; Merrill, 1983) identification of just three content types for generalizable knowledge. Therefore, the Elaboration Theory proposed three different ways of elaborating, based on those three content types:

Conceptual Elaboration. If the goals of a course are primarily conceptual in nature, as is usually the case in an introductory biology course, then the elaborative sequence should follow the process of meaningful assimilation of *concepts* to memory (Ausubel, 1968; Mayer, 1977). First, according to Elaboration Theory (Reigeluth & Darwazeh, 1982), you analyze and organize the concepts into conceptual structures, which show their superordinate, coordinate, and subordinate relationships. Then you design the instructional sequence by selecting the most important, comprehensive, and fundamental conceptual structure and sequencing its concepts from the top down (i.e., from the most general and inclusive concepts to progressively more detailed and less inclusive concepts.* Finally, other concepts and other types of content, including learning prerequisites (Gagné, 1968), must be ''fleshed'' onto that ''skeleton'' of a sequence at the point where each is most relevant. Details of this sequencing strategy are described by Reigeluth and Darwazeh (1982). The result is a ''blueprint'' for the course similar to that shown in Fig. 8.1.

Procedural Elaboration. On the other hand, the goals of your course might be primarily procedural (addressing the ''how''), as in an English composition course. In this case, the elaboration sequence should follow the optimal process of *procedural* skill acquisition. Your first activity as a designer is to identify the simplest possible version of the task (usually equivalent to the shortest ''path'' through the procedure in P. F. Merrill's 1980 path analysis methodology)† and to identify the ''simplifying assumptions'' that define that simplest version. Your next task is to design the instructional sequence by gradually relaxing the simplifying assumptions in the order of most important, comprehensive, and fundamental ones first, such that progressively more complex paths are taught. Then

*Although this sequence goes from the top down in a ''conceptual structure,'' whereas Gagné's hierarchical sequence goes from the bottom up in a learning hierarchy (which on the surface looks much like a conceptual structure), both sequences go from simple to complex, and the elaboration sequence is consistent with (i.e., does not in any way violate the principles of) the hierarchical sequence.

†This is similar to Scandura's sequence that starts the instruction with the simplest path through a rule and proceeds to teach progressively more complex paths one at a time (p. 164).

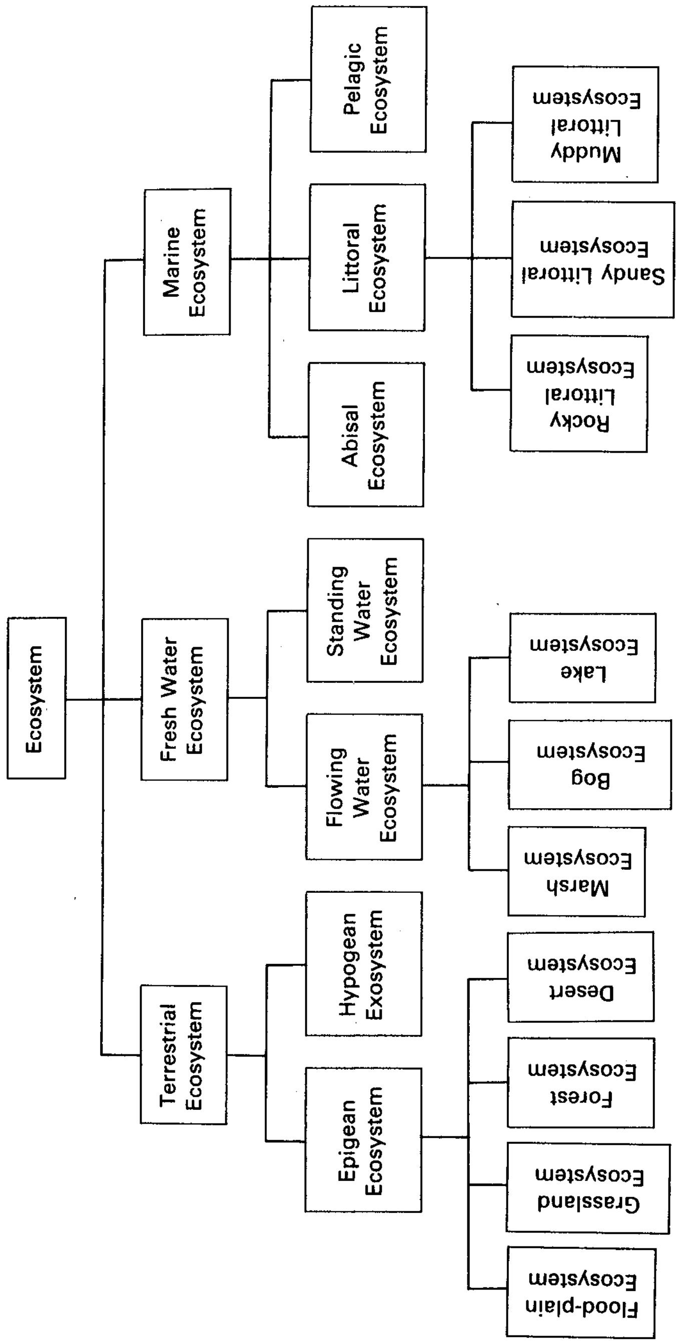

FIGURE 8.1a A kinds-conceptual structure for a conceptual blueprint.

the other types of content, including concepts, principles, learning prerequisites, and remember-level information, are "plugged into" that sequence at the point where each is most relevant. Details of this sequencing strategy are described by Reigeluth and Rodgers (1980). The result is a "blueprint" for the course similar to that shown in Fig. 8.2.

Theoretical Elaboration. The final possibility is that the goals of your course are primarily theoretical (addressing the "why"), as in an introductory economics course. In this case, the elaboration sequence follows the psychological process of developing an understanding of natural processes (primarily causes and effects), which is usually similar to the order of the historical discovery of such knowledge. After identifying the breadth and depth of principles that should be taught, you design the instructional sequence by asking the question, "What principle(s) would you teach if you had the learners for only one hour?" and ". . . one more hour?" and so on. This process continues until all the principles have been arranged in a sequence that progresses from the most basic and observable principles to the most detailed, complex, and restricted principles (see Comments 1, 2, 4–9, 11, 12, and 15). During this process, it is often helpful to look at an earlier principle and ask "Why?" "Which way?" "How much?" or "What else?" to identify more complex principles that elaborate on the earlier one (see Comments 16, 17, and 19). Other types of content are then plugged into that sequence at the point where each is most relevant (see Comments 20 and 23). The result is a "blueprint" for the course similar to that shown in the next section of this chapter.

Within-Lesson Sequence

Next, you need to design a sequence for all content *within* each lesson (see Comment 24). The Elaboration Theory offers several guidelines here:

1. For a conceptual organization present the easiest, most familiar organizing concepts first, for a procedural organization present the steps in the order of their performance,* and for a theoretical organization present the simplest organizing content first (see Comments 3, 10, 13, and 28).
2. Usually put supporting content immediately after the organizing content to which it is most closely related (see Comments 27 and 30).
3. Put each learning prerequisite immediately before the content for which it is prerequisite (see Comments 26, 29, and 32).†

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*This is a "forward-chaining" sequence, and Landa's "snowball principle" is also a forward-chaining sequence (p. 122).

†This is Gagné's notion of learning prerequisite (p. 22), which is also prescribed by Gropper (p. 58). However, here it is used on a much narrower scale of sequencing—within approximately a one-hour unit of instruction.

Lesson	Level	Elaborates on lesson	Conceptual Organizing Content	Supporting Content				
				Conceptual	Theoretical	Procedural	Learning Prerequisites	Verbal Information
1	Epitome	—	Ecosystem	Abiotic environment Biotic component Food chain Producer Consumer	Population is controlled by food supply and predators The biotic component is dependent upon the abiotic environment	How to identify food chains in an ecosystem	System Environment Predator	Approximate ratio of prey to its predators
2	1	1	Terrestrial ecosystem Fresh water ecosystem Marine ecosystem	Adaptation —physical —behavioral Community	Adaptations help the animal to survive in its ecosystem. Water cycle O_2–CO_2 cycle Material cycle	How to create a composte heap	Terrestrial Marine Evaporation Condensation Water vapor Decomposer	The most common adaptations for each of the three kinds of ecosystems
3	2	2	Epigean (above-ground) ecosystem Hypogean (subterranean) ecosystem	Soil components Kinds of organisms that live in these kinds of ecosystems Kinds of soil	Adaptations and how they help survival in each ecosystem	How to observe life in hypogean ecosystems	Subterranean	The most common hypogean food chains The most common adaptations for hypogean
4	2	2	Standing-water ecosystem Flowing-water ecosystem	. . .	. . .	. . .	. . .	. . .
5	2	2	Littoral ecosystem Pelagic ecosystem Abysal ecosystem	. . .	. . .	. . .	. . .	. . .
6	3	3	Flood-plain ecosystem Grassland ecosystem Forest ecosystem Desert ecosystem	Kinds of climate Kinds of animals that live in these kinds of ecosystems	Seasonal changes Effects of people on each of these ecosystems	How to help preserve each of these kinds of ecosystems	Pollution Conservation Extinction Endangered	The most common food chains for each of these kinds of ecosystems The most common adaptations for each
7	3	4	Marsh ecosystem Bog ecosystem Lake ecosystem	. . .	. . .	. . .	. . .	. . .
8	3	5	Rocky littoral ecosystem Sandy littoral ecosystem Muddy littoral ecosystem	. . .	. . .	. . .	. . .	. . .
. . .								

FIG. 8.1b Part of a conceptual blueprint.

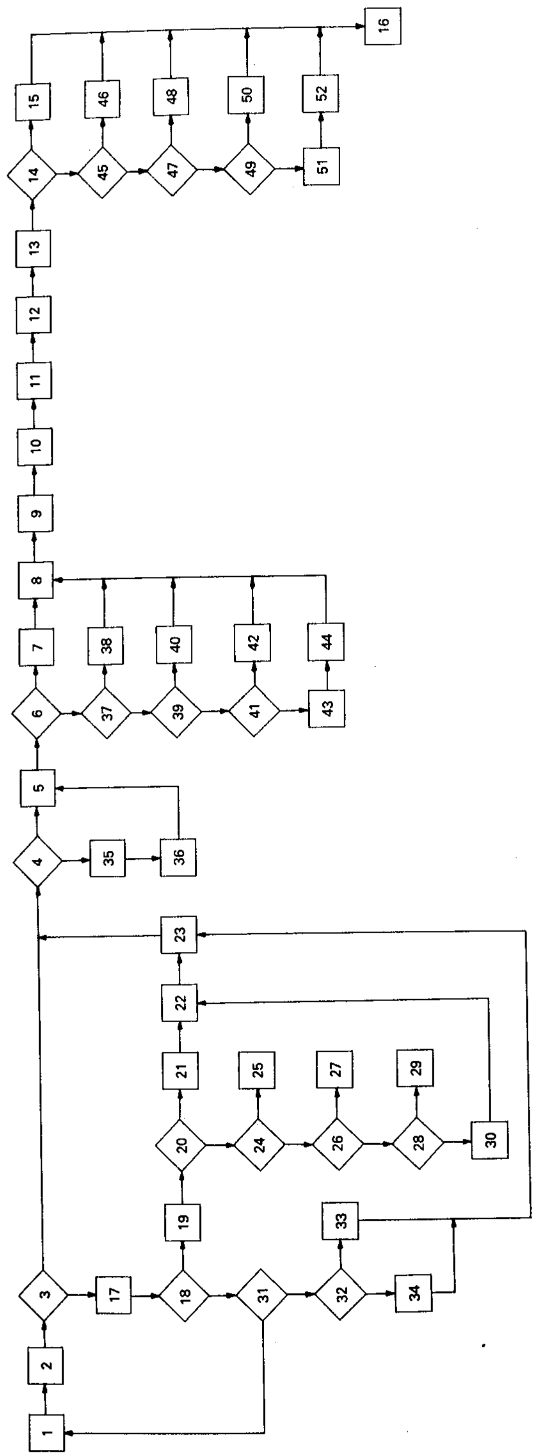


FIG. 8.2a. Flowchart for the procedural blueprint.

Lesson	Level	Elab's on	Organizing Content	Simplifying Conditions
1	Epitome	--	1 Identify "given" substance. 2 Identify "to find" substance. 5 Identify units of "given" substance. 7 Use 1 mole per atomic formula unit or molecular mass as conversion factor. 8 Convert to moles of "given" substance. 9 Identify coefficient of "given" substance. 10 Identify coefficient of "to find" substance. 11 Set up mole ratio. 12 Find moles of "to find" substance. 13 Identify "to find" required units. 15 Use atomic, molecular, or formula unit mass per 1 mole as conversion factor. 16 Check the solution.	A A chemical equation is given (cuts steps 3, 17-34). B The equation is balanced (cuts steps 4, 35-36). C "Given" unit is grams (cuts steps 6, 37-44). D "To find" unit is grams (cuts steps 14, 45-52).
2	1	Lesson 1	3 Decide if a chemical equation is given. 17 Identify reactants and products. 19 Identify type of chemical compound based on composition 21 Classify compound as binary molecular. 22 Use rules of chemical nomenclature to write the chemical formula for each reactant. 23 Place reactants on left side and products on right side of yield symbol in chemical equation.	Relax condition A (adds steps 3, 17-34). E Names of reactants and products are given (cuts steps 18, 31-34). F Compound is composed of 2 nonmetals (cuts steps 20, 24-30).
3	1	Lesson 1	4 Decide if the equation is balanced. 35 Determine number of each element on both sides of equation. 36 Assign stoichiometric coefficients to each reactant and product to make each element on reactant side equal to each element on product side.	Relax condition B (adds steps 4, 35-36).

FIG. 8.2b. Part of a procedural blueprint. None of the supporting content is shown.

4	1	Lesson 1	6 Decide if "given" unit is grams. 38 Use 1 mole per 6.02 x 10 atoms, molecules, or formula units as converstion factor. 14 Decide if "to find" unit is grams. 46 (Same as step 38)	Relax conditions C & D (or H, I and/or J, depending on lessons taught). G Unit is a no. of atoms, molecules, or formula units.
5	2	Lesson 2	18 Decide if names of reactants and products are given. 31 Decide if analytical data are given for reactants and products. 32 Decide if molecular weight is given. 33 Find empirical formula. 34 Find molecular formula.	Relax condition E (adds steps 18, 31-34).
6	2	Lesson 2	20, 24, 25, 26, 27, 28, 29, 30.	Relax condition F (adds steps 20, 24-30
7	1	Lesson 1	37, 40, 45, 48	Relax conditions C & D (or G, I, and/or J, depending on lessons taught). H Unit is volume of solution.
8	1	Lesson 1	39, 42, 47, 50	Relax conditions C & D (or G, H, and/or J, depending on lessons taught). I Unit is volume of a gas at STP
9	1	Lesson 1	41, 43, 44, 49, 51, 52	Relax conditions C & D (or G, H, and/or I, depending on lessons taught). J Unit is volume of a gas not at STP.

FIG. 8.2b. *(Continued)*

4. Group coordinate concepts together (see Comment 31).
5. Teach a principle (meaningful understanding of processes) before a related procedure (see the Lesson Outline on page 270).

Other macrostrategy components are integrated into the lesson sequence, such as summarizers, synthesizers, analogies, cognitive-strategy activators, macrolevel motivational components, and macrolevel learner-control options (see Reigeluth & Stein, 1983).

Summarizers

A summarizer is a strategy component used to systematically review what has been learned (Reigeluth & Stein, 1983). It provides (a) a concise statement of each idea or fact that has been taught; (b) a typical, easy-to-remember example; and (c) some diagnostic, self-test practice items for each idea. *Lesson* (internal) summarizers usually appear at the end of each lesson (see Comments 33 and 35–42), whereas "set" (unit) summarizers summarize all of the ideas and facts that have been taught so far in an entire set of lessons (see Comment 43). A "set" of lessons (or unit) is all those lessons that elaborate directly on a single lesson.*

Synthesizers

A synthesizer is used to interrelate and integrate ideas. It is intended to (a) provide the learner with a valuable kind of knowledge; (b) facilitate a deeper understanding of the individual ideas; (c) increase the meaningfulness and motivational appeal of the instruction (Ausubel, 1968; Keller, 1983); and (d) increase retention. The Elaboration Theory presently prescribes three types of synthesizers, each of which interrelates ideas of a single content type (Reigeluth & Stein, 1983): conceptual (see Comment 33), procedural (see Comment 40), and theoretical (see Comment 38). As with summarizers, these may be *lesson* (for a single lesson) or *set* (for a whole unit) synthesizers. Furthermore, it is possible to provide contextual synthesis at the beginning of a lesson (see Comment 25) or post synthesis at the end of a lesson or unit (see Comment 35).†

Analogies

An analogy takes new information and relates it to a more familiar and hence more meaningful context of organized knowledge that the learner already possesses (Ortony, 1979; Verbrugge & McCarrell, 1977). It reminds the learner of

*Gagné-Briggs's theory is the only other one in this book that explicitly prescribes review as an instructional strategy (p. 21).

†Synthesis appears in several forms in several other theories in this book (e.g., Landa's "snowball principle," p. 122).

something more concrete within the learner's experience in order to prepare him or her for understanding a more abstract, complex type of idea (Curtis & Reigeluth, 1984; Reigeluth, 1983).*

Cognitive-Strategy Activators

A cognitive-strategy activator, which activates the learner's use of a "generic skill," can be used for any content area. It may be *embedded* into the instruction, as is the case when a mnemonic or analogy is presented, or it may be *detached*, as is the case when the learner is only provided with the directions to use a previously learned cognitive strategy (Rigney, 1978), such as "think up an analogy" or "try to come up with a mnemonic."†

Learner Control

Learner control may offer the learner options for the selection and sequencing of his or her content and instructional strategies, and thereby control over how he or she will study and learn (M. D. Merrill, 1983, 1984; Reigeluth & Stein, 1983). Learner control of *content* offers selection of any lesson for which the learner has already acquired the prerequisites (see Comment 22), whereas learner control of *instructional strategies* offers selection of the type, order, and number of such microstrategy components as examples, practice items, and alternative representations (see Chapter 7), and type and timing of such macrostrategy components as summarizers, synthesizers, and analogies (see Comment 35).‡

In summary, the Elaboration Theory prescribes the following strategy components:

1. An elaborative sequence of lessons (either conceptual, procedural, or theoretical).
2. A within-lesson sequence for each lesson, including any necessary learning-prerequisite sequences.
3. A summarizer for each lesson.
4. A synthesizer for each lesson.
5. Analogies as needed.
6. Cognitive-strategy activators as needed.
7. Learner control to the extent appropriate.

*Analogies are also prescribed by Keller (see companion volume) as a motivational strategy component.

†This kind of prescription is overlooked by most other theories.

‡This is the same as Merrill's "learner control" (p. 209), except that it applies to control over macro-level strategy components whereas Merrill's applies to control over micro-level strategy components.

LESSON PREFACE

The Elaboration Theory of Instruction provides prescriptions for structuring and sequencing courses or even a whole curricula, but it provides no guidance for teaching those bits of knowledge and individual skills that comprise the course or curriculum. The latter guidance must be sought from a theory that deals with prescriptions such as those proposed by Merrill or Collins and Stevens. Such theories are completely compatible with and complementary to this theory.

Because the Elaboration Theory provides no guidance as to how to teach each individual skill or piece of knowledge, it is not beneficial to present a completed lesson to illustrate the theory. Rather, the following pages present *outlines* of several related lessons in a curriculum. The outlines illustrate for a specific set of subject matter most of the Elaboration Theory's prescriptions without the distracting lesson details that are beyond the scope of the Elaboration Theory.

The lesson outlines in this chapter include only those parts of a science curriculum that are in some way related to the six objectives used throughout this book:

1. Students will be able to classify previously unencountered lenses as to whether or not they are convex lenses.
2. Students will be able to define focal length.
3. Students will be able to explain or predict what effect different convex lenses will have on light rays.
4. Students will be able to explain the way in which the curvature of a lens influences both the magnification and the focal length of different lenses.
5. Students will be able to state from memory the three significant events in the history of the microscope.
6. Students will be able to use a previously unencountered optical microscope properly.

Step 1

The first decision that was made in creating the outlines for the instruction was to decide whether the simple-to-complex sequence should be based on conceptual knowledge (*what* are the important classes of things), procedural knowledge (*how* does a person accomplish certain things), or theoretical knowledge (*why* do certain processes occur). Given that the objectives emphasize an understanding of the behavior of light (a dynamic natural process) more than classes of things (concepts) or means to achieve ends (procedures), a theoretical organization was selected.

Simple-to-complex sequencing occurs on a number of different levels. We have found it useful to think in terms of the following levels:

ELEMENTS SEQUENCED	*APPROXIMATE INSTRUCTIONAL TIME*	*APPROXIMATE SCHOOL TIME*
Individual ideas within a lesson	1 hour	1 day
Lessons within a unit	5 hours	1–2 weeks
Units within a module	25 hours	1–2 months
Modules within a course	150 hours	1 year
Courses within a curriculum	varies	varies

It seemed that theoretical knowledge (natural processes) was the most important kind at all of these levels.

However, it is quite common for different types of content to be used as the basis for the simple-to-complex sequencing at different levels. For example, a biology course could be comprised of modules that are sequenced based on *concepts,* such as an introductory module on "life," followed by modules on "plant life" and "animal life," followed by "mammals," "reptiles," "birds," and so on. Each such module could then be comprised of units that are sequenced based on *principles* that relate to that concept, such as the effects of climate, habitat, predators, etc. on the evolution of its physical characteristics, social behavior, diet, etc. Then each such unit could be comprised of lessons that are sequenced based on *procedures* or rules that relate to that principle, such as steps that the animal follows in mating, hunting, nesting, or even steps that the student follows in dissecting, and so forth.

Step 2

Given that a theoretical organization was chosen, the next task was to select and sequence all the theoretical content that should be taught in the curriculum. After "brainstorming" to list all the principles (usually statements of causes or effects), we needed to arrange them into a simple-to-complex sequence. We started by listing the most obvious ones (in this case, the principles specified by the objectives) and then began to "epitomize"; that is, to look for the simplest principle or principles that are among the most basic, observable, and representative of the whole set of principles for the curriculum. Several useful heuristics for doing this include: (a) ask a subject-matter expert (SME) what principle he or she would teach if it was possible to teach only one; and (b) ask an SME to identify what principles were discovered earlier. These techniques result in the identification of progressively simpler principles—principles in which fewer things happen but the things that do happen are the "essence" (i.e., the most important and observable aspects) of the larger set of principles.

Using these techniques, we found three major ways of simplifying an understanding of what happens to light when it passes through a convex lens.

1. Type of lens.
The first dimension for simplifying is related to the convex lens. The behavior of light as it passes through a *concave lens* (as opposed to a convex one) is simpler, because there is no focal point and hence there is no effect of the image being inverted beyond the focal point while being normal before the focal point. The behavior of light as it passes through a *prism* is simpler still, because there are no curved surfaces and hence all light rays of the same frequency remain parallel after passing through it. The behavior of light as it passes through *plane glass* is even less complex, because both surfaces are parallel and hence all rays end up going in the same direction as before they passed through the glass. And finally, the behavior of light as it merely passes from *one medium into another* (as opposed to going both into and out of a medium) is still less complex, because there is only one surface instead of two and hence only one change in the direction of the light rays instead of two.

2. Reflection.
A second dimension for simplifying what happens to light is that what happens when it is *reflected* is simpler than what happens when it is refracted. When it is refracted, light changes velocity and direction, whereas when it is reflected, it just changes direction. Also, the change in direction is precise and intuitive: the angle of reflection equals the angle of incidence; whereas when it is refracted, the change in direction depends on several factors, including the density of the medium and the sharpness of the angle of incidence.

3. Waves/Particles.
A third dimension for simplifying is that light behaves like *waves* in some ways and like *particles* in others. Hence, understanding the behavior of waves alone or of particles alone is simpler, and understanding the behavior of particles alone is the simplest, because waves have such behaviors as interference, which are related to their wavelength and amplitude, while particles do not.

Step 3

After we simplified to the level of student entering knowledge, we needed to make sure that we had gone far enough in the opposite direction: that we had identified all of the more complex principles that the students should learn in the course or curriculum. Several useful heuristics for identifying more complex principles include: (a) asking "What else happens?"; and (b) asking such questions as "Why?" "Which way?" and "How much?" Each of these is illustrated in the lesson outlines and commented upon below.

Remaining Steps

Finally, we allocated supporting content to each elaboration, completing the selection of all content; we allocated all content to individual lessons; and we sequenced the content within each lesson.

As a final comment, it should be known that, in violation of Elaboration Theory procedures, we did not have a subject-matter expert (SME) to work with in the design of this blueprint. Had an SME been available, the same Elaboration Theory prescriptions that we used here would have resulted in a better product and one with which science education experts would find fewer shortcomings and points of disagreement. Although this blueprint is not one that we would want to implement without further consultation and revision, it does nevertheless, in its present form, still serve as a good illustration of the prescriptions of the Elaboration Theory.

LESSON: COURSE OUTLINES

[1] **Module 1: General Science (Approx. Sixth Grade[1])**

Unit 1: Earth Science

. . .

Unit 2: Biology

. . .

Unit 3: Chemistry

. . .

Unit 4: Physics

[2] *Lesson 1: How Particles Behave*

Use balls on a flat table to teach the following (expository or discovery approach may be used):

[3] a. *Linear Movement.* They move in a straight line, unless acted upon by something.

b. *Reflection.* They bounce off a surface.

[1]The grade levels are completely arbitrary (they could have been eighth, ninth, and tenth), and so in fact are the divisions (modules, units, lessons). The specific pattern shown here was selected becaue it seemed viable for interspersing this content with the rest of a typical high school curriculum. But a course tailored for an interested adult might enable him or her to study these three courses in order during a single year.

[2]It is doubtful that any of the basic sciences (Earth Science, Biology, Chemistry, Physics) can be viewed as a more complex iteration of any other basic science; any relationships among them are insufficient to warrant arranging them in an elaborative sequence. Hence, their order is arbitrary with respect to Elaboration Theory criteria.

c. Something like *Refraction.* They change direction and speed when the inclination of the surface is changed.

d. *Absorption.* They stop (lose their energy) when they collide into styrofoam.

[4] *Lesson 2: How Waves Behave*

Waves in a water tank:

a. *Rectilinear Movement.* They move in a straight line perpendicular to the wave, unless acted upon by something.

b. *Reflection.* They bounce off a surface.

c. Similar to *Refraction.* They change direction and speed when the density of the fluid changes and when the depth of the fluid changes.

d. *Interference.* When two waves cross, the trough of one cancels out the crest of the other, and the troughs and crests of one magnify the troughs and crests, respectively, of the other.

e. *Transmission.* They require a medium in which to move.

f. *Absorption.* They stop (lose their energy) when they collide into a "soft" or steeply inclined surface.

[5] *Lesson 3: How Light Behaves*

A pencil of light:

(the simplest case of each of the following behaviors is taught in such a way that students can predict what light will do in those cases).

a. *Linear Movement.* Light moves in a straight line unless acted upon by something. (Demonstration of a pencil of light).

b. *Reflection.* Light bounces off things. (Demonstration of a pencil of light on a plane mirror.)

[6] c. *Refraction.* Light bends as it passes from one medium to another. "When light goes from one medium to another, it bends." (Demonstration of a stick or pencil of light in water.)

d. *Diffraction.* When light bends, some of its parts bend more than others, causing those parts to separate from each other. (Demonstration of a pencil of light through a prism onto a surface.)

[7] e. *Interference.* When two light waves cross, the trough of one cancels out the crest of the other, and the troughs and crests of one magnify the toughs and crests, respectively, of the other. (Demonstration of light through two slits onto a surface that is moved away from the slit.)

f. *Transmission.* Light requires no medium in which to move.

g. *Absorption.* Light stops (loses its energy) when it strikes a black surface.

Module 5: Physics
(Approx. Ninth Grade)

Unit 1: Particles

. . .

Unit 2: Waves

. . .

[8] Unit 3: Light

Lesson 1: Linear Movement and Transmission

. . .

Lesson 2: Reflection

a. Effects of a plane mirror on light and image
[9] • image is reversed (L ⟨-⟩ R)
• rays bounce but remain parallel to each other

b. Effects of a convex mirror on light and image
• no image
• rays disperse

[10] c. Effects of a concave mirror on light and image
• smaller image before 2FL (Focal Length), enlarged image after 2FL
• normal image before FL, inverted image after FL
• rays converge to a point, then disperse

[11] *Lesson 3: Refraction*

[12] a. Effects when light passes from one medium into another
• apparent position and size of image usually change
• rays bend but remain parallel to each other

b. Effects when light passes from one medium into and out of another
[13] • plane glass
image remains the same
rays continue in same direction and parallel to each other
• prism
image remains the same
apparent location of the image is different
rays go off in a different direction but are basically parallel to each other
white light is broken into colors (diffraction)
• concave lens
no image
rays disperse
• convex lens
[14] an image is formed at a plane beyond FL

smaller image if before 2FL, enlarged image if after 2FL
normal image if before FL, inverted image if after FL
parallel rays converge at a Focal Point (FP), then disperse
rays from the same point on the object converge at a point beyond the FP, then disperse

Lesson 4: Diffraction

Lesson 5: Interference

Lesson 6: Absorption

[15] ## Module 17: Light (Approx. Twelfth Grade)

Unit 1: Rectilinear Propagation and Transmission

. . .

Unit 2: Reflection

. . .

Unit 3: Refraction

[16] *Lesson 1: Into a Medium*

What else happens?

a. A portion of each ray is reflected off the surface, while the rest is
[17] refracted into the new medium.

b. The sharper the angle between the ray and the surface, the more of each ray that is reflected and the less that is refracted.

c. When the angle is equal to or sharper than the critical angle, all of the ray is reflected.

Why, which way, and how much do light rays bend at the interface?

d. The higher the optical density, the lower the speed of the light.

[18] e. If they pass into a denser medium, the light rays bend toward the normal.

f. The greater the difference in optical density between two media, the more the light rays bend.

g. Index of refraction (n) $= \frac{c_i}{c_r} = \frac{\sin i}{\sin r}$

h. Relationship between critical angle and index of refraction: $\sin i_c = \frac{1}{n}$

Why and which way does the apparent size of the object change?

i. When the rays bend, they change their distance from each other.
j. When the rays bend toward the normal, they become farther apart.

Why does the change in the apparent size of the object differ with the angle of the surface?

k. The more slanted the surface, the more the light rays bend from their initial direction.

[19] *Lesson 2: Into and Out of Plane Glass*

Principles a–k in Lesson 1 remain of importance, but we can also add:

Why do rays continue in the same direction and remain basically parallel?

a. (Lesson 1e) If they pass into a denser medium, the light rays bend toward the normal.
b. If they pass into a less dense medium, the light rays bend away from the normal.
c. On entering glass, rays bend toward the normal by a certain amount, and on leaving the glass they bend away from the normal by the same amount.
d. Since the entering and exiting surfaces are parallel, the normals are parallel, and hence the rays are returned to their original direction.

[19] *Lesson 3: Into and Out of a Prism*

Principles a–k in Lesson 1 remain of importance, but we can also add:

Why do rays change direction but remain basically parallel?

a. (Lesson 2a) If they pass into a denser medium, the light rays bend toward the normal.
b. (Lesson 2b) If they pass into a less dense medium, the light rays bend away from the normal.
c. (Lesson 2c) On entering glass, rays bend toward the normal by a certain amount, and on leaving the glass they bend away from the normal by the same amount.
d. Since the entering and exiting surfaces are not parallel, the normals are not parallel, and hence the rays are not returned to their original direction.

[19] *Lesson 4: Into and Out of a Concave Lens*

Principles a–k in Lesson 1 remain of importance, but we can also add:

Why and which way do rays disperse (diverge)?

a. (Lesson 3a) If they pass into a denser medium, the light rays bend toward the normal.
b. (Lesson 3b) If they pass into a less dense medium, the light rays bend away from the normal.
c. (Lesson 3c) On entering glass, rays bend toward the normal by a certain amount, and on leaving the glass they bend away from the normal by the same amount.
d. (Lesson 3d) Since the entering and exiting surfaces are not parallel, the normals are not parallel, and hence the ray is not returned to its original direction.
e. Since the difference in angle between the two normals increases with distance from the center of the lens, the amount that rays change their direction increases with distance from the center of the lens.
f. The more curved the lens, the more sharply the rays disperse.

[19] *Lesson 5: Into and Out of a Convex Lens*

Principles a–k in Lesson 1 remain of importance, but we can also add:

Why, which way, and how much do rays converge to a point, cross, and then disperse?

a. (Lesson 4a) If they pass into a denser medium, the light rays bend toward the normal.
b. (Lesson 4b) If they pass into a less dense medium, the light rays bend away from the normal.
c. (Lesson 4c) On entering glass, rays bend toward the normal by a certain amount, and on leaving the glass they bend away from the normal by the same amount.
d. (Lesson 4d) Since the entering and exiting surfaces are not parallel, the normals are not parallel, and hence the ray is not returned to its original direction.
e. (Lesson 4e) Since the difference in angle between the two normals increases with distance from the center of the lens, the amount that rays change their direction increases with distance from the center of the lens.
f. The more curved the lens, the more sharply the rays converge. The image will therefore be larger as long as it is beyond the focal length. Also, the focal length will be shorter.
g. Relationship between object size and distance and image size and distance: $s_o/s_i = d_o/d_i$.
h. Relationship between object distance, image distance, and focal length:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{F}.$$

	Course Unit Lesson	Elab's on	Organizing Content*	Simplifying/ Elaborating Conditions	Supporting Content: Concepts	Supporting Content: Procedures	Supporting Content: Learning Prerequisites**	Supporting Content: Information
[21]	1 4 1	—	Linear Movement Reflection (Refraction) Absorption	Particles	. . .	. . .	. . .	. . .
[22]	1 4 2	1 4 1	Rectilinear Movement Reflection (Refraction) Interference Transmission Absorption	Waves	. . .	. . .	. . .	. . .
	1 4 3	1 4 1 1 4 2	Linear Movement Reflection Refraction Diffraction Interference Transmission Absorption	Light Plane surface Reflection & re-fraction	. . .	. . .	. . .	. . .
	5 1 1 . . .	1 4 1	. . .	. . .	. . .	. . .	. . .	. . .
	5 2 1 . . .	1 4 2	. . .	. . .	. . .	. . .	. . .	. . .
	5 3 1	1 4 3	. . .	. . .	. . .	. . .	. . .	. . .
	5 3 2	1 4 3	Effects of -plane mirror -convex mirror -concave mirror	Light Reflection All surface types	. . .	. . .	. . .	. . .
[23]	5 3 3	1 4 3 5 3 2	Effects of -1 plane surface -plane glass -prism -concave lens -convex lens 3	Light Refraction All surface types	Kinds of optical instruments (telescope, microscope, binoculars, camera lens, etc.). Critical angle Kinds of concave lenses. Kinds of convex lenses.	How to use a microscope. 6 How to use a telescope.	Apparent location Apparent size Apparent position Plane glass Prism Concave lens Convex lens 1 Image Eye piece Coarse adjustment knob Fine adjustment knob	Object Medium Common uses of prisms Common uses of concave lens and convex lens Focal length 2 Focal point History of lenses and optical instruments 5 How lenses are made
	5 3 4	1 4 3 5 3 3	. . .	. . .	. . .	. . .	. . .	. . .
	5 3 5	1 4 3 5 3 4	. . .	. . .	. . .	. . .	. . .	. . .
	5 3 6	1 4 3	. . .	. . .	. . .	. . .	. . .	. . .
	17 1 1 . . .	5 3 1	. . .	. . .	. . .	. . .	. . .	. . .
	17 2 1 . . .	5 3 2	. . .	. . .	. . .	. . .	. . .	. . .
	17 3 1	5 3 3	(See listing in outline)	Light Refraction How much? What else? Why? Which way? 1 plane surface	. . .	. . .	. . .	. . .
	17 3 2	5 3 3	(See listing)	Same except: -plane glass	. . .	. . .	. . .	. . .
	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

*See lesson outline for details # indicates objective # specified for this book. Objective 4 is taught in Lesson 3.3.5 (f). **Only unmastered prerequisites are listed.

FIG. 8.3. A partial curriculum blueprint showing the simple-to-complex sequence of principles along with

COURSE BLUEPRINTS

[20] The Course Outlines just presented show only the organizing content (principles) and sequence. Clearly, other kinds of content are also important, and they are shown together with the organizing content in Course Blueprints (see Fig. 8.3). Because these blueprints were developed for illustrative purposes only and without the help of a subject-matter expert, the supporting content is included for only one of the lessons. It would ordinarily be included for all lessons.

[21]

[24]

LESSON OUTLINE

Within-Lesson Sequence for:

Module 5: Physics
Unit 3: Light
Lesson 3: Refraction

[25] *Initial synthesizer:* context and demos of most important causes and effects.
Context: State that refraction is but one aspect of the behavior of light. Very briefly review each of the behaviors: linear movement and transmission, reflection, refraction, diffraction, interference, and absorption. State that this lesson will explore just refraction.
Demonstrations: What happens to an object when seen

- from a different medium?
- through plane glass?
- through a prism?
- through a concave lens?
- through a convex lens?

[26] 1a. Teach prerequisite concepts (for 1b) at remember level: object, medium, apparent location, apparent size, apparent position.
b. Teach principle at application (skill) level: When an object in one *medium* is seen from another, its apparent location and size change, but its apparent position remains unchanged. The greater the angle of the surface, the more the object's apparent size changes.
[27] c. Teach supporting concept at application (skill) level: critical angle.
d. Teach principle at application level: When light passes from one
[28] *medium* into another, its rays bend at the surface but remain parallel to each other.
2a. Prerequisite concept (for 2b and 2c) at application level: plane glass.
b. Principle at application level: When an object is seen through *plane*

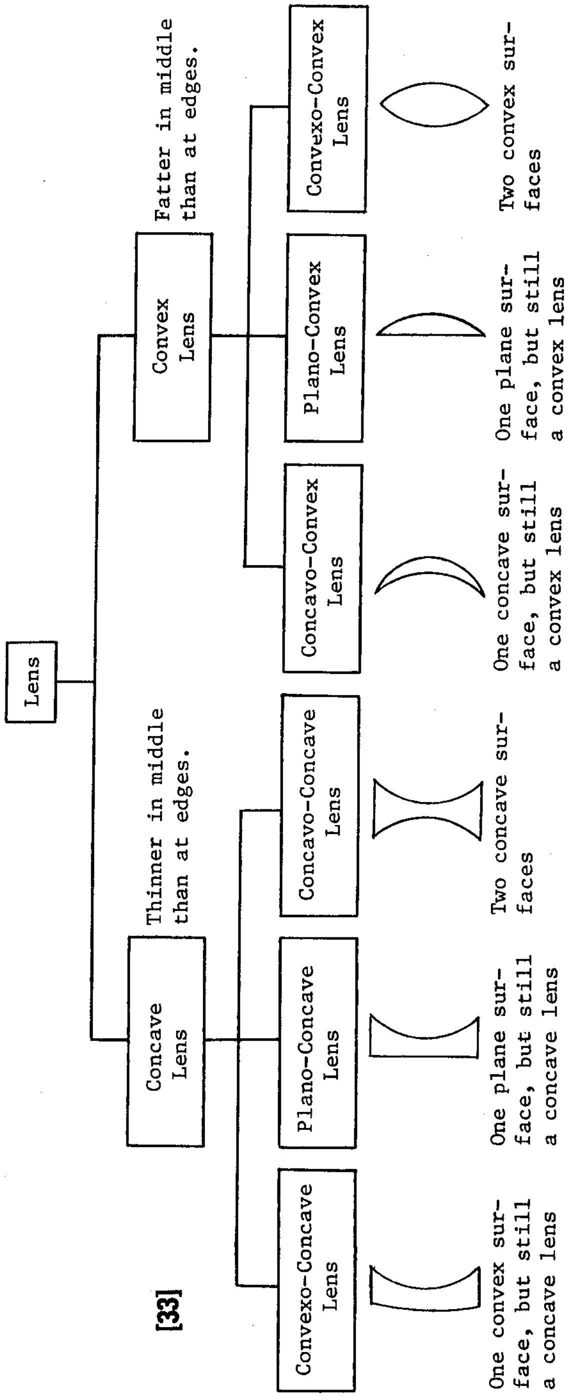
glass, its apparent location, apparent size, and apparent position remain unchanged.
c. Principle at application level: When light passes into and out of *plane glass,* its rays continue in the same direction and remain parallel to each other.
[29] 3a. Prerequisite concept (for 3b and 3c) at application level: prism.
b. Principle at application level: When an object is seen through a *prism,* its apparent location changes, but its apparent size and apparent position remain unchanged. Some colored outlines may appear.
c. Principle at application level: When light passes into and out of a *prism,* its rays change direction but remain basically parallel to each other. Also, while light is broken into colors.
[30] d. Supporting information (remember level): Common uses of prisms.
4a. Prerequisite concepts (for 4b, 4c, 5b, and 5c) at application level:
[31] Concave lens, convex lens, image.
b. Principle at application level: When an object is seen through a *concave lens,* it has no clear image.
c. Principle at application level: When light passes into and out of a *concave lens,* its rays disperse (spread out).
d. Supporting information (at remember level): Common uses of concave and convex lenses.
[32] e. Supporting concepts at application level: Kinds of concave lenses (plano, concavo, convexo), kinds of convex lenses (plano, concavo, convexo). Present a conceptual synthesizer-summarizer after teaching all of these concepts (see Fig. 8.4 for an example).
5a. Prerequisite concepts (for 5b and 5c) at remember level: focal length (FL), focal point (FP).
b. Principle at application level: When an object is seen through a *convex lens,* its image
- is formed at a plane beyond FP
- is smaller than the object when it is formed closer than 2 FL.
- is the same size as the object when it is formed at 2 FL.
- is larger than the object when it is formed farther than 2 FL.
- is normal when it is formed closer than FP.
- is inverted when it is formed farther than FP.

c. Principles at application level: When parallel light rays pass into and
[34] out of a *convex lens,* they converge to a point at FP, where they cross and then disperse. When rays from the same point on the object pass through a *convex lens,* they converge to a point beyond the focal point and then cross and disperse.
d. Supporting concepts at application level: Kinds of instruments that use convex lenses (microscope, telescope, binoculars, cameras, etc.)

How to read this chart: Each box contains a concept that is a kind of what's directly above it.

Example: Concave lens is one of two kinds of lens.
What is the other kind of lens?
What are the three kinds of concave lenses?

[33]



The correct answers to the above questions are on p. 73.

FIG. 8.4. A combination summarizer—synthesizer for related concepts.

e. Prerequisite concepts (for 5f) at remember level: Eyepiece, coarse adjustment knob, fine adjustment knob.

f. Supporting procedures at application level: How to use a microscope properly, how to use a telescope properly.

g. Supporting information at remember level: Significant events in the history of lenses and optical instruments.

h. Supporting information at remember level: How lenses are made.

Summarize, including theoretical synthesizer. (This part of the lesson is further illustrated next.)

LESSON SUMMARIZER AND SYNTHESIZER FOR LESSON 5.3.3

[35]

Review

Terms to Remember

The following are the concepts you should remember:
(Prototypical illustrations of the concepts would appear as in Fig. 8.5.)

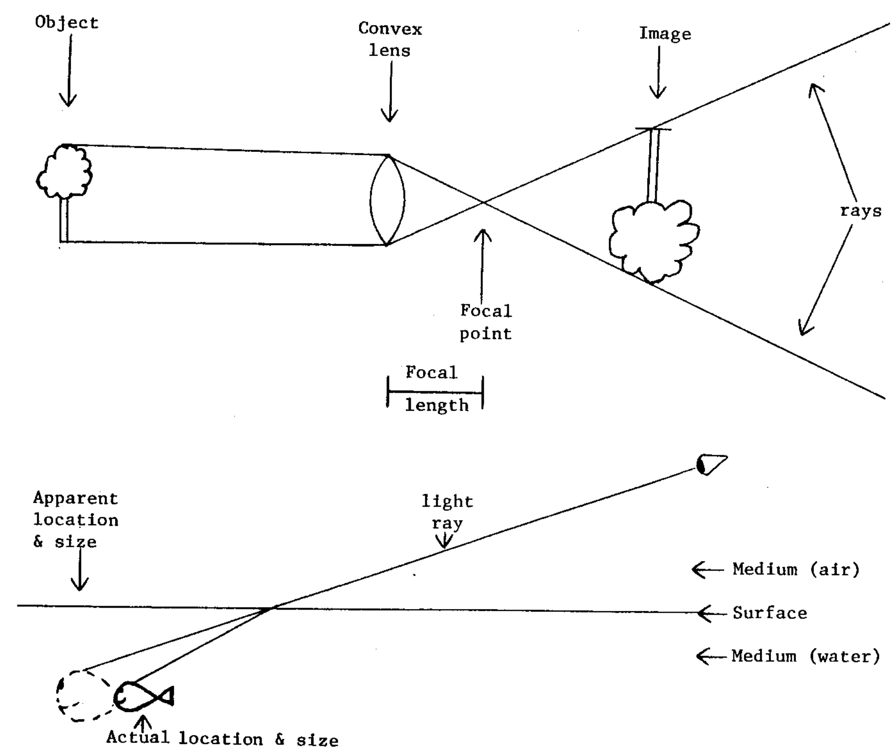


FIG. 8.5

Self-test

Directions:

1. Cover the right side of this page with a piece of paper.
2. Try to state the definition of the first term.
3. Move the paper down just enough to see if your definition was right.
4. Do the same for each remaining term.

	1. Object	something which is viewed or projected.
	2. Medium	a substance through which light can pass.
[37]	3. Apparent location	where the object appears to be.
	.	
	.	
	.	
	6. Critical angle	all of the light is reflected.
	.	
	.	
	.	
	13. Convex lens	fatter in middle.
	.	
	.	
	.	
	17. Convexo-concave lens	one convex surface but still thinner in middle.

Principles to Remember

(Prototypical illustrations of the five sets of principles would be placed here. For example:)

1. . . .

.
.
.

5. Effects of a *convex lens.*

[38]

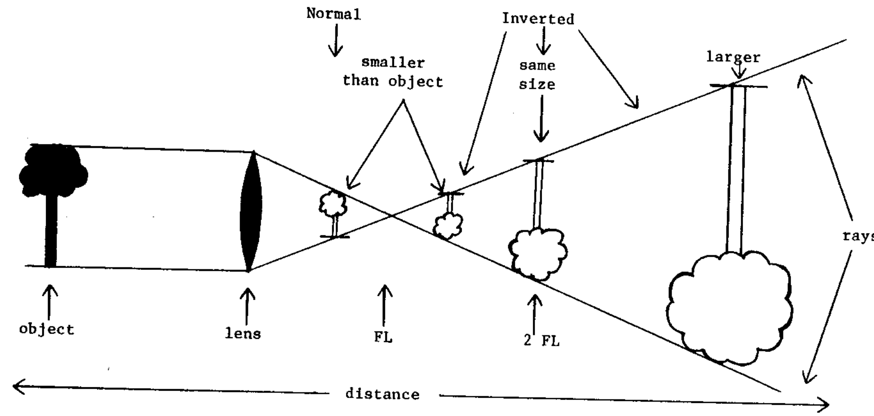


FIG. 8.6

Self-test

Directions:

1. Cover the two right-hand columns below with a piece of paper, leaving the column headings visible.
2. Try to answer the questions.
3. Move the paper down just enough to see if your answer was right.
4. Do the same for each remaining principle.

	WHEN LIGHT DOES THIS:	WHAT HAPPENS TO ITS IMAGE?	WHAT HAPPENS TO ITS RAYS?
[39]	1. passes into another medium	apparent location and size change a bit.	they bend but remain basically parallel.
	2. passes through plane glass	is unchanged.	are unchanged.
	.		
	.		
	.		
	5. passes through a convex lens	is a point at FL. is small when closer than 2 FL. is large when farther than 2 FL. is inverted when farther than FL.	they converge at FL, cross, and disperse.

Procedures to Remember

[40] To use a microscope properly, remember to do the following:

(Diagram of a microscope with numbered steps and arrows pointing to appropriate parts of microscope.)

To use a telescope properly, remember to do the following:

(Diagram of a telescope with numbered steps and arrows pointing to appropriate parts of telescope.)

Self-test

[41] Imagine that you have a microscope and a specimen in front of you. Close your eyes and go over in your mind the steps that you would follow to use the microscope to look at the specimen. Try to picture exactly what you would do for each step.
Then open to this page to check whether you missed any steps or did any of them in the wrong order.

(Same for telescope)

Facts to Review

You should remember the following information:

1. Glass globe with water	magnifying glass	engravers 3,000 years ago.
2. Glass lenses	magnifying	late 1200's A.D.
3. Compound microscope	Zacharias Janssen, Dutch spectacle maker.	1590 A.D.

[42] *Self-test*

1. Use a piece of paper to cover all but one column.
2. Try to remember each item in the other column.
3. Then change columns.

[43]

[44]

COMMENTS

1. With respect to elaborative sequencing of modules in a course, there is a module to elaborate on each unit in Module 1. For example, Module 5 elaborates on the Physics Unit in Module 1 (see Fig. 8.7). There is also a module to elaborate on each unit in Module 5. For example, Module 17 expands on the Light Unit in Module 5 (also see Fig. 8.7). Similarly, what was taught in a single lesson in Module 1 ("How Light Behaves") receives a full unit (a set of lessons) in Module 5 (Unit 3, Lessons 1–6). And what was taught in a single lesson in Module 5 ("Refraction") receives a full unit in Module 17 (Unit 3, Lessons 1–5). Elaborations would, of course, continue beyond the few levels shown in Fig. 8.7. It should be noted that some lessons at virtually any level of elaboration may not have other lessons that elaborate further on them. This outline does not show what courses the modules would be grouped into for reasons explained in footnote 1.

2. This is the epitome lesson. With respect to elaborative sequencing of lessons in a unit, only the three lessons most closely related to the lesson objectives for this book are outlined in this unit. One can readily see that Lessons 1 and 2 both provide more concrete and less complex versions of fundamentally the same principles as those taught in Lesson 3 on the behavior of light. Lesson 1 is the simplest, "epitome" version because particles can be seen and touched, and they have fewer behaviors. Lesson 2 is the first level of elaboration because

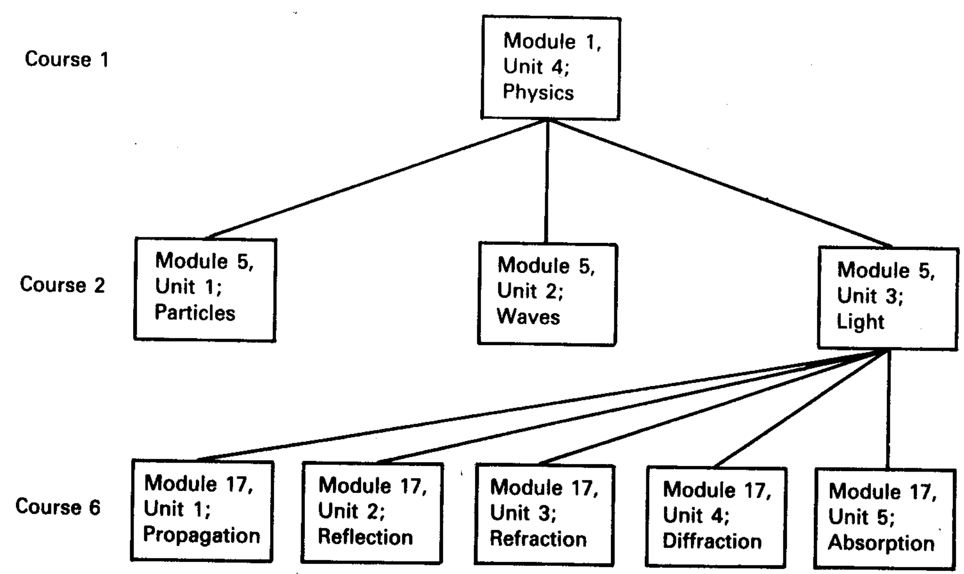


FIG. 8.7

wave behavior is considerably more complex than that of particles. Lesson 3 is the second level of elaboration because light behaves like particles in some ways and like waves in others. Hence, Lesson 3 elaborates on Lesson 2 as well as directly on Lesson 1. Also, light particles cannot be touched and light waves cannot be seen, making the behavior of light still more difficult to understand than that of either particles alone or waves alone. It should be clear that the simple-to-complex sequence of the three lessons is based on the particle-wave-light dimension discussed in the Lesson Preface.

3. This section illustrates elaborative sequencing of individual ideas within a lesson. The principles that have been allocated to Lesson 1 are a simplification on *all three* dimensions of elaboration mentioned in the Preface to Lesson Outlines: refraction-reflection, light-wave-particle, and convex-concave-prism-etc. The Elaboration Theory prescribes that the sequence should expand on the most important and most representative dimension first. In this case, we decided that knowledge of the variety of behaviors (e.g., linear movement, reflection, refraction) is more important and more representative of the whole domain of knowledge than their distinct applications to waves and light. (However, it might be appropriate to make it clear to students from the beginning that waves and light do behave very similarly to particles, and that the students will learn more about them later in the module.) The remaining dimension (convex-concave-prism-etc.) requires prior elaboration of the particle-wave-light dimension and hence would be the last dimension for elaboration.

Therefore, with respect to sequencing of individual ideas within a lesson, the principles within the lesson are presented in a simple-to-complex sequence based on the refraction-reflection dimension: reflection is taught before something similar to refraction, and the principle of linear movement is even simpler than, and hence taught before, reflection. As a result, Lesson 1 deals only with the behavior of particles, such as rubber balls or billiard balls, meaning that this lesson is, as a whole, a simplification based on the particle-wave-light dimension discussed earlier.

Please keep in mind that only principles are shown here, and that various kinds of "supporting content" (i.e., related concepts, procedures, and information, including Gagné-type learning prerequisites) are later plugged into this "organizing" sequence at the most appropriate point. Such a complete sequence of ideas within a lesson is illustrated later in this chapter.

4. Lesson 2 is a level-1 elaboration because it elaborates on the epitome (Lesson 1). It begins elaborating on the second most important dimension of elaboration: the particle-wave-light dimension. It elaborates on Lesson 1 by dealing with the way *waves* behave rather than with the way particles behave. It is more complex than Lesson 1, first because it entails more principles, such as those relating to interference and transmission, and second because the similar principles are usually more complex, such as rectilinear movement of waves being more complex than simple linear movement of particles. The behavior of waves is taught before the behavior of light because it is simpler (see next comment).

5. Lesson 3 is a level-2 elaboration because it elaborates on Lesson 2 (and, incidentally, also directly on Lesson 1). It further elaborates the same dimension as did Lesson 2 (particle-wave-light). The additional principle is diffraction (although one could argue that refraction is also a new principle). And the principles that are similar to those in Lesson 2 are also more complex for light, such as the way it moves, which is a combination of particle movement and wave movement. This lesson is also more difficult because it is less concrete: you cannot touch the particles of light nor see the individual light waves.

6. Notice that the introduction to refraction in this lesson is at the very simplest level of the third dimension of elaboration: the convex lens–concave lens–prism–etc. dimension. The same is true for all of the other principles in this lesson.

7. Notice that one form of systematic review is built in by cycling back (as in Bruner's "spiral curriculum") to what are basically the same principles in a new, more complex application or context. For those who believe that "process" is an important part of the curriculum, this sequence leads students through the same process of discovery of similarities that characterized the historical development of the discipline. This kind of sequence is perhaps even more important for a discovery approach to instruction, such as that advocated by Bruner or by Collins and Stevens (see chapter 6). However, it also shows that an expository mode can give students some of the excitement of, and feel for, the process of discovery. Chapter 7 of Lindsay and Norman (1977) also illustrates such an expository treatment of the process of discovery. This kind of sequence is equally useful and exciting in the social sciences and humanities. And of course the systematic review function of this kind of sequence should not be underrated.

8. This unit elaborates on Lesson 3 of Module 1 ("How Light Behaves"). A comparison of the contents of this module with the Unit on Physics in the previous module illustrates how the "epitome" principles in the first can be elaborated upon in the second module. Specifically, there is a unit that elaborates on each of the three lessons in Module 1; and there is a lesson that elaborates on each principle that was taught in the earlier module (reflection-refraction, etc.).

9. This principle is basically a review of the principle that was taught under reflection in Lesson 3 of Module 1. It is elaborated a little bit by pointing out that the light rays remain parallel to each other and that the image is reversed. Many students may have realized this already, but it had not been explicitly stated or demonstrated as such previously. This lesson is a level-3 elaboration because it elaborates on a level-2 elaboration (Lesson 3 of Module 1).

10. These next two principles elaborate on the first one (and therefore on the corresponding principle from Module 1) by introducing complexity from the

third dimension of elaboration (convex-concave-etc.) as it applies to reflection. Notice how, in effect, each principle in Lessons 2 and 3 is comprised of a special case (e.g., plane mirrors, convex mirrors, concave mirrors), each of which results in different effects on the behavior of light within that category of behavior (e.g., reflection). The behavior of light is more complex when it is reflected off a **convex mirror,** because the rays are no longer parallel and the image is enlarged. The behavior is even more complex when light is reflected off **a concave mirror,** because the rays converge to a focal point and the image is inverted after the focal point and changes size with distance from the mirror.

11. With respect to sequencing *lessons,* notice that Lessons 2 and 3 have much in common. For example, the effects of a concave mirror are very similar to the effects of a convex lens. However, reflection off a mirror is simpler to understand because there is only one surface that matters, whereas with refraction by a lens there are two, nonparallel surfaces that one must consider. Also, when light is reflected, it just changes direction, whereas when light is refracted, it changes velocity and direction. Furthermore, the change in direction is precise and intuitive with a mirror: The angle of reflection equals the angle of incidence; whereas when it is refracted, the change in direction depends on several factors, including the density of the medium and the sharpness of the angle of incidence.

12. Again, this principle is basically a review of the principle that was taught under refraction in Lesson 3 of Module 1. As with the first principle in Lesson 2, it is elaborated slightly. Notice that each set of principles is comprised of two principles: one that describes the effect of something on the image of an object and one that describes its effect on the direction and relative position of the individual rays. The latter is a more complex elaboration on the former because (a) it explains why the image is affected the way it is; (b) there are many rays that often undergo various changes, and it is difficult to show all the changes that the multitude of rays undergo; and (c) the image is more concrete than the rays—it can be seen.

13. These principles progressively elaborate on the first in this lesson by introducing complexity from the third dimension of elaboration as it applies to refraction, just as was the case for Lesson 2 of this module. What happens to light when it passes *from one medium into another* is less complicated than what happens when it passes *into and out of* a medium because in the former situation there is only one surface at which the light rays bend, whereas in the latter there are two surfaces. *Plane glass* is simpler than a *prism* because the former's two surfaces are parallel. A *prism* is simpler than a *concave lens* because both of its surfaces are straight, whereas the concave lens has at least one curved surface. And finally, a *concave lens* is simpler than a *convex lens* because the latter focuses rays to a point and inverts the image of an object.

14. These principles and the various concepts and information associated with them represent the majority of the objectives established for this book (see Comment 34 for details).

15. With respect to sequencing *modules,* this module illustrates a second level of elaboration because it elaborates directly on the principles in the first level of elaboration, the Physics module. Each unit in this module elaborates on a lesson in the unit on light in Module 5, and each lesson in this module elaborates on one of the specific cases from Module 5 (see Fig. 8.7). This need not necessarily be the case. It would not be uncommon for each lesson here to elaborate on some characteristic that cuts across many or all of the cases from the earlier elaboration.

16. This lesson elaborates on the first principle in Lesson 3 of Module 5. In fact, each lesson in this unit elaborates on a different level of the third dimension of elaboration in that earlier lesson: into a medium, plane glass, prism, concave lens, and convex lens. Therefore, each of these lessons serves to review a part of what was learned in Lesson 3 of Module 5. Notice that each lesson elaborates on the earlier principle or principles by presenting principles that answer the questions, "Which way?" and "How much?" Directionality and quantification are two of the most common ways of elaborating on simple principles, but answering the questions "What else happens?" and "Why?" are also very common.

17. Most of the principles that answer "What else happens?" "Why?" "Which way?" and "How much?" are common to all of the types of lenses and whatnot that cause light to refract. Therefore, this first lesson is considerably longer than any of the others in this unit, but its principles are continually reviewed as they are applied to different situations (lenses, etc.) in the following lessons.

18. Continuing our earlier discussion of compatibility with both discovery and expository approaches to instruction, it should be evident that this lesson lends itself well to a project or "episode" approach such as that advocated by Bruner (1960). Given the level of knowledge that the students already have about the behavior of light as it refracts, it would not be too difficult for them to discover many of these principles (with a little bit of help and guidance). Bruner's notion of discovery-oriented episodes that have a clear beginning, middle, and end could easily be extended to expository episodes if discovery is inappropriate (i.e., time is short or students have already learned how to discover principles).

19. It can readily be seen that each of these progressively more complex situations (lenses, etc.) requires progressively more principles to explain the behavior of light at a similar level of understanding.

20. After identifying and listing all the principles that should be taught in each lesson of each course in the curriculum, the Elaboration Theory indicates that supporting content should be identified for each lesson. When this activity is complete, you will have selected *all* of the content that is to be taught, and you will have allocated *all* of that content to lessons and sequenced *all* of those lessons. Although it is not necessary to break down the supporting content into "concepts," "procedures," "learning prerequisites," and "information," we

have found it helpful for reducing the chances of the designer overlooking important supporting content. "Information" refers to all of the remember level in M. D. Merrill's (1983) taxonomy or all of Gagné's (1977) verbal information. The other three types of supporting content are Merrill's use-a-generality level or Gagne's intellectual skills. "Learning prerequisites" are listed separately to remind the instructional designer to identify such prerequisites not only for the organizing content but also for both of the first two types of supporting content.

21. One of the additional benefits of this kind of sequence is its clear communication of the adage, "The more you learn, the more you realize how little you know." It raises questions, broadens horizons, stimulates thought, and creates realizations that might not otherwise have surfaced. It truly helps to create a meaningful understanding of the sort that Ausubel, Bruner, and Dewey all advocated but did not clearly operationalize.

22. Because many lessons elaborate on two lessons at the same time in this curriculum, the degree of learner control over selection and sequence of content is more limited than usual. However, many options could (should) still be provided to learners. After mastering Lesson 1.4.1, the learner could choose between 1.4.2 and 5.1.1. Similarly, after 1.4.3 has been mastered, the learner could choose between 5.1.1 (and perhaps 5.1.2, 5.1.3, etc.), 5.2.1 (and perhaps 5.2.2, 5.2.3, etc.), 5.3.1, and 5.3.6, depending on his or her interest in the various aspects of particles, waves, or light. And after all of the 5.3's have been mastered, the learner could be allowed to choose among *any* of the lessons in Module 17. Of course, it is not necessary to wait until all of the 5.3's are mastered before selecting various lessons in Module 17; 17.1.1 can be selected as soon as 5.3.1 has been mastered.

23. Notice that the supporting concepts are all learned as concept classification tasks (the use-a-generality level). In contrast, two concepts are listed under "Information" because concept classification is not their desired learning outcome—rather, meaningful understanding (remember-paraphrased in M. D. Merrill's taxonomy) is desired. The same applies to the procedures; note that "How lenses are made" is a procedure listed under "Information."

24. After allocating all the content to lessons and sequencing those lessons, the designer should plan the sequence for all content *within* each lesson. This Lesson Blueprint illustrates sequencing of individual ideas within one of the lessons in the Course Blueprints. This is the most detailed level for which the Elaboration Theory has prescriptions. This level of sequencing is usually designed *after* all of the lessons in a course have been sequenced because revisions are often made on earlier parts of the overall sequence while one is working on the later parts of it.

The Elaboration Theory does not make any prescriptions relating to discovery versus expository, inquiry versus noninquiry, educational game versus nongame, individualized resources versus lecture versus discussion versus tutoring versus group activities. Nor does it make any prescriptions relating to sequencing examples or practice items, selecting media, or using management strategies. The Elaboration Theory is highly compatible with all of these alternatives, and these are all important kinds of prescriptions that should be included in any truly comprehensive theory of instruction. On a recent project, the author was able to complete some initial work on such integration of prescriptions (Reigeluth, Doughty, Sari, Powell, Frey, & Sweeney, 1982).

For example, for a public high school audience, motivation is a major concern. Hence, it would probably be beneficial to use some form of inquiry (see chapter 5). Inquiry, as distinct from discovery, would begin the instruction with a major question, such as "How can you create a projected image that is inverted and twice as large as the object?" Then the following instruction, which could be either expository or discovery, would be directed toward answering that question. It might also be beneficial to use a discovery approach occasionally, but probably not too frequently due to time limitations. Much of the practice could occur through especially designed educational games (preferably computer games) that require the student to predict effects of certain lenses on light rays or to discover the causes of certain light ray patterns. Lasers and space wars might make one exciting context for such educational games.

The purpose of this discussion is to clearly identify important aspects of instruction that the Elaboration Theory does not include. It should be noted that we are not aware of any such methods with which the Elaboration Theory cannot or should not be used.

25. The initial synthesizer is really a lot more than a synthesizer. It provides external synthesis (relating the lesson content to the "larger picture") and facilitates some measure of internal synthesis (interrelating the organizing content that is to be taught in this lesson). The **external synthesis** takes the form of a statement of context that (a) reviews the organizing content that was taught in the lesson upon which this lesson elaborates and (b) explains which aspect of that organizing content is being investigated in this lesson. The **internal synthesis** provides some advance indication of the *interrelationships* among the ideas that are to be taught: how they relate to each other. But those interrelationships are not explicitly taught at this point. As with virtually everything else, analysis must precede synthesis; and therefore explicit internal synthesis must wait until the student has analyzed and understood each element (each principle).

But if it does not explicitly teach the important interrelationships, what does it do? In the case of both principles and procedures, *demonstrations* are generally the most effective way to show those interrelationships. But if the organizing content had been concepts, then something like the combination summerizer-synthesizer shown in Fig. 8.4 would generally be best. In addition, besides indicating important interrelationships, a demonstration is ideal for serving a variety of other purposes that an initial presentation should serve: It provides a concrete presentation of the *objectives* of the lesson and something in the way of a *preview* of the organizing content, and it stimulates *interest* in the content of the lesson. Research has shown that objectives are often of little value to learners. This is probably because objectives are usually too abstract to communicate meaningfully to learners. Therefore, the Elaboration Theory proposes use of a concrete demonstration of the most important (terminal) capabilities that the learner will acquire from the lesson, to overcome this problem while still accomplishing the basic purpose of an objective. And it simultaneously serves the preview, motivational, and synthesis functions mentioned earlier.

26. 1b on this page is the first principle to be taught in this lesson. However, all of its unmastered prerequisites (1a) must be taught first. These prerequisites were identified by performing a standard Gagné-type hierarchical analysis on the principle.

27. Nonprerequisite supporting content (information, concepts, and procedures) for the first principle (1b) is taught immediately after the principle (see 1c). The one exception to this rule is that highly related concepts should always be taught together. For example, kinds of convex and concave lenses are best learned together because they are coordinate concepts (see Comment 31).

28. As was indicated in the Course Outlines, another version of the principle is now presented (1d) that describes what happens to the light rays rather than what happens to the image of an object. This sequence is based on the observation → deduction process of the development of knowledge (changes in the image are observed, but the behavior of the rays is deduced), which is also a concrete → abstract sequence of instruction.

29. Again, the principles are immediately preceded by their unmastered prerequisites.

30. Again, nonprerequisite supporting content immediately follows its most relevant organizing content.

31. Even though "convex lens" is not a prerequisite concept for the principle of 4b, it is taught here because it is the only coordinate concept that concave lens has: every lens is either concave or convex. Therefore, to learn concave lens, the students simultaneously learn convex lens, and they might as well learn its label while they are at it.

32. If there were any learning prerequisites for this supporting content, they would immediately precede the particular supporting concept for which they were prerequisite.

33. This conceptual synthesizer-summarizer is intended to make sure that the concepts are organized in a proper and stable manner in the student's memory. The brighter students may not need it, but the slower students may even need some extra explanation to be able to benefit from it. Notice that, unlike most synthesizer-summarizers, this one is not at the end of the lesson. It is placed here because all of the content that it contains has already been taught at this point.

This summarizer-synthesizer illustrates a number of important characteristics. First, a summarizer should present a *concise generality* for each idea (in this case, concepts). A concise generality should contain just enough critical words to stimulate recall of the generality. In this summarizer the concise generalities are either placed beside or below the corresponding concept box. Secondly, a summarizer should usually provide a *prototypical example,* preferably in visual form. Line drawings are ideal for concepts. All critical attributes should be visible. Thirdly, a synthesizer should show simply, and with a minimum of words, the major *relationships* among the ideas. In this case, it should show which concepts are kinds of which other concepts. Fourthly, a summarizer-synthesizer should encourage active processing of the relationships and should also provide an opportunity for low-risk *self-test* (see the questions at the top of the page), complete with the availability of immediate feedback (see the statement at the bottom of the page). To prevent premature "peeking" at the answer and to ensure that the student in fact responds to the questions, computer-based instruction is ideal. This is but one of many forms that a summarizer-synthesizer could take, but the four basic components should be present in all forms.

34. The prerequisite concepts (5a), the principle (5c), the supporting procedure (5f), and the supporting information (5g) represent four of the objectives established for the lessons in this book (numbers 2, 3, 6, and 5, respectively). Objective 1 is taught in 4a just above, and objective 4 is taught in Module 3, Unit 3, Lesson 5, Topic f.

35. This lesson (internal) summarizer-synthesizer illustrates a number of characteristics. As in the conceptual summarizer-synthesizer, this one contains *concise generalities,* but the generalities are arranged in such a way that they can be used expositorily as a summary or inquisitorily as a *self-test* (practice). Preferably, they will be used both ways. This synthesizer-summarizer also contains a *prototypical example* of each generality, in this case line drawings again. All of these characteristics are provided for concepts, principles, and procedures. Because many of the concepts are prerequisites for the principles, they are reviewed first. Finally, the information is reviewed. In a learner-controlled system, the learner would be able to access the summarizer-synthesizer on demand at any time during, and perhaps even before or after, the lesson.

36. These are prototypical examples of the concepts. Only a few are illustrated here; the remaining ones would also be included so that all concepts that were introduced in this lesson would be reviewed.

37. These serve either as generalities (definitions) for the same concepts or as practice on the generalities, depending on whether or not the student peeks at the right side of the page. In computer-based instruction, this can be controlled, preferably in a way that only requires a covert response before the right side is shown. It is often good to include some practice on instances, also (that is, practice in classifying new examples and nonexamples of the concepts). Note

that the generalities (on the right side) are reduced to a few key words, because their purpose is to trigger recall of acquired knowledge rather than to create new understanding.

38. This is a theoretical synthesizer as well as a summarizer. There is one drawing for each of the five pairs of principles. The first set of principles can easily be integrated with each of the remaining four (i.e., the process in the first is a part of the processes in the remaining four), so they can be explicitly integrated. However, the remaining four can only be compared and contrasted; they cannot be explicitly synthesized with a theoretical synthesizer because they are not parts of the same process (causal chain).

The theoretical synthesizer in Fig. 8.6 uses a prototypical example to show the causal relationship between distance of the image and both the image's position (normal or inverted) and size. Furthermore, the enlarged circle shows how the principles for "into a medium" fit in with the principles for a convex lens. Although this theoretical synthesizer does not use the arrows and boxes that characterize many theoretical synthesizers, it explicitly communicates the interrelatedness of the processes (the chain of causes and effects). A dynamic demonstration on computer or video disk would be even better, because a process (cause-effect) is being illustrated.

39. As with the concepts, these serve either as generalities or as practice on the generalities. Practice on instances could also be included.

40. This is a procedural synthesizer. It shows the order of the many steps that make up the complete performance of the task. For more complicated procedures, a flow diagram would probably be better than just a listing of the numbered steps. In either case, relating the steps (generality) to a picture or drawing of a microscope (prototypical example) is important.

41. Again, the student could be asked to use the procedure on a new (previously unencountered) microscope, but most students probably would not take the time to do it.

42. Again, a computer would be ideal for making sure that the learner does the active cognitive processing called for in this self-test.

43. A unit (set) summarizer-synthesizer (often referred to as an *expanded epitome*) would contain all the same elements as this one. The only difference is the scope of the content being summarized and synthesized; it would include all of the content from all of the lessons that elaborate directly on a single lesson.

44. Many examples of analogies are available elsewhere (see, e.g., Curtis & Reigeluth, 1984), and examples of cognitive strategy activators were provided in the introduction to this chapter. Therefore, because of space limitations, examples of these two strategy components are not provided here.

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9 An Application of the ARCS Model of Motivational Design

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FOREWORD

History

This is another theory that arose out of the desire to integrate the current state of our knowledge into a prescriptive form that would be useful to instructional designers and teachers. It integrates prescriptions from a broad range of theoretical perspectives, including social learning theory, environmental theories, humanistic theories, and aspects of attitude theory, decision theory, attribution theory, cognitive evaluation theory, equity theory, cognitive dissonance theory, locus of control, and learned helplessness. Unlike all of the other theories in this book, this one is not intended to stand alone; its prescriptions are intended to supplement other instructional theories. Perhaps for that reason, it takes a very different form than the other theories; it prescribes individual motivational strategies in a smorgasboard fashion to meet the individual motivational requirements of the situation. Any module of instruction could require anywhere from none to all 12 of the kinds of strategies Keller has identified. Like the Component Display Theory and Elaboration Theory, this theory is also indicative of the highly integrative, multiperspectived approach to prescriptive theory construction that we need so much at this point in the development of our knowledge about instruction.

Unique Contributions

The most obvious unique contribution of this theory is that it is perhaps the first, and certainly the only one in this book, to explicitly address the use of motivational strategies. Furthermore, it has done so in an eclectic, comprehensive