Chapter 8

Theoretical Elaboration Sequencing: How To Do It

This chapter provides guidance on how to design, and conduct analyses for, theoretical elaboration sequences. Chapters 4-7 provided similar guidance for hierarchical, procedural, simplifying conditions, and conceptual elaboration sequences. I strongly recommend you have a firm understanding of the theory of theoretical elaboration sequencing from Chapter 3 before you begin this chapter.

As discussed in Chapter 3, to design a theoretical elaboration sequence, you need to identify principles that are simpler or more complex versions of each other. Then you design a sequence that teaches the simplest principles first and gradually works down to progressively more complex ones, one level of complexity at a time, in either a topical or spiral fashion. So, again, the most difficult part of the design process is analyzing principles for their elaborative relationships with each other. The theoretical analysis process is described first, followed by the sequence design process.

Theoretical Analysis Process

How To Do It

One rule of thumb for conducting a theoretical analysis is to identify principles in the content domain of interest in the order they were discovered, because the simplest ones were usually discovered first (Reigeluth & Sari, 1980). Hence, their order of discovery often represents a sound elaboration sequence. An alternative rule of thumb is to ask your SMEs what principles they would teach if they only had one hour with a student (including time for demonstrations and practice), and then if they only had one more hour, and so forth (Reigeluth & Sari, 1980). This is based on the assumption that the most basic, most comprehensive principles would be chosen first, followed by ones that elaborate on them. Yet another rule of thumb is to conduct a theoretical analysis by (a) identifying all the important "theoretical areas" (clusters of related principles) in the content domain of interest, (b) identifying as many relevant principles as you can in each area, and (c) asking the question, "What principles are more complex (or simpler) representations of the same causal phenomena addressed by another principle?" (Reigeluth, 1987). The simpler ones are then taught first, followed by progressively more complex ones until the desired level of complexity has been reached. The following guidance is based on this third rule of thumb. In the next section, an example of this guidance process is provided, followed by an example of the resulting analysis. You may want to refer to those as you read through this guidance.

1. Prepare. Prepare for analysis. [No change from previous ones.]

- Establish rapport with a SME. Again, try to have a SME who also has experience teaching the content domain of interest to the target student population.
- Identify the nature of the content domain in general.
- Identify the characteristics of the learners in general.
- Identify the delivery constraints of the instruction in general.

2. Analyze and select principles. Identify all the principles that the learner needs or wants to learn. This can be done by using the following substeps.

2.1 Make sure the SME understands the definition of a principle as a cause-effect relationship. Also, make sure the SME understands the notions of superordinate, coordinate, and subordinate (complexity) relationships among principles (see Figure 8.1 for an example of those varieties of relationships.

2.2 Help the SME identify all the "theoretical areas" of relevance in the content domain.

- Theoretical areas are clusters of related principles. For example, in economics, there are principles of micro economics, macro economics, international economics, labor economics, and so forth.
- The theoretical areas can often be divided into kinds or parts. For example, within micro economics, there are principles for the demand side (consumption) and the supply side (production).
- Relevance will usually be determined by the learner, the teacher, and/or the sponsor of the instruction (employer, school community, state education system,

etc.). And it may be constrained by the amount of learning time available for the "course."

2.3 For each theoretical area, help the SME identify the broadest, most basic and inclusive principles, followed by progressively narrower, more detailed and complex principles, until the desired level of complexity has been reached.

- You may find one or more of the rules of thumb mentioned earlier to be of help in doing so.
- Organize each progressive level of principles in such a way that it is clear which principles elaborate on whch others (which are more complex representations of the same causal phenomena in others).
- Whenever possible, organize the principles on a given level in a given theoretical area into one or more causal models. This will help to make sure that no important causal relationships have been left out on that level.
- Make note of any duplications—that is, principles that are utilized in more than one theoretical area. This will be very helpful information for Step 3.

2.4 Help the SME and at least one other SME to check to make sure that all principles identified are appropriate to include in this course and that no important principles have been left out.

3. Identify supporting content. Help the SME to identify all the remaining domain content that the learner needs or wants to learn, and identify the principle (or causal model) to which each piece of it is most closely related and with which it should therefore be taught. This decision needs to be made before the sequencing can be done, because sequencing and grouping decisions must be done together (see Chapter 3), and you don't know how big a group (how much learning time) a given principle or causal model will take until you know how much supporting content should be learned in the same learning learning episode. This can be done by using the following substeps and guidelines.

3.1 For each of the theoretical areas you identified in Step 2, help the SME to identify all **concepts** that are important for each level of principles, and identify the principle (or causal model) to which each concept is most closely related and with which it should therefore be taught.

- You will probably find it helpful to identify concepts separately for each "set" of principles on any given level. A set of principles is all those principles that elaborate on a single higher-level principle.

- You will probably find it helpful to state each principle in the terms in which it would be presented to the learner, or the terms the learner would use to express it after learning it.
- Many of the concepts will be prerequisites (simpler component parts) of the principles. For these cases, you can use the conceptual analysis process described in Chapter 4.
- Sometimes a concept will best be allocated to a specific principle on a given level of principles, and sometimes to a whole causal model.
- You can use a lettering or numbering scheme to indicate which supporting content will go with which levels, causal models, or individual principles.

3.2 Help the SME to identify all **procedures** (sets of steps) that are important for each level of principles, and identify the principle (or causal model) to which each is most closely related and with which it should therefore be taught.

- You may prefer to do steps 3.1, 3.2, and 3.3 for just one set of principles, then recycle through all three steps for another set, and so forth. Or you may prefer to identify concepts for all sets of principles first, then identify procedures for all of them, and so forth.
- Again, you can use a lettering or numbering scheme to indicate which procedures will go with which levels, causal models, or individual principles.

3.3 Help the SME to identify all other important kinds of content, such as **information, understandings, thinking skills** (including learning strategies and metacognitive skills), **attitudes and values, and even dimensions of emotional, social, and spiritual development,** and identify the principle (or causal model) to which each is most closely related and with which it should therefore be taught.

- Again, you can use a lettering or numbering scheme.

Examples of the Analysis Process and Its Results

Here are examples of both the process for conducting a theoretical analysis and the results of that analysis for a K-6 science textbook series, using the guidance provided in the previous section.

1. Prepare. Prepare for analysis.

I met several times at the beginning of the summer with my primary SME, a fourth-grade teacher who had recently served on the science textbook selection committee for her school and was very interested in teaching science. My focus was on getting to know each other and building trust. We each exchanged reflections on our teaching experiences (I had taught high school science) and our teaching philosophies. I also tried to get a sense for the aspects of science that she felt were most important for students to learn by the sixth grade. She told me about the two extremes of students in her school (the most gifted and the most disadvantaged) and what sorts of things interested them the most. She also indicated there were few constraints, because she had the same group of kids all day for all subjects.

2. Analyze and select principles. *Identify all the principles that the learner needs or wants to learn.*

2.1 Make sure the SME understands the definition of a principle as a cause-effect relationship. Also, make sure the SME understands the notions of superordinate, coordinate, and subordinate (complexity) relationships among principles.

We discussed these issues, I showed her some examples of principles and their superordinate, coordinate, and subordinate relationships, and I asked her to give me some examples. She showed an excellent understanding of what I was talking about, but said that what I was calling principles, she had thought of as "concepts of science." [Add an example?]

2.2 Help the SME identify all the "theoretical areas" of relevance in the content domain.

After I explained what I meant by "theoretical areas," my SME started by identifying the major sciences: physical sciences, biological sciences, and earth sciences. She also said that science process skills were very important: observing, experimenting, and so forth. Then she broke each of these down into sub-areas, as shown in Figure 8.1. Some of the initial breakdowns, like "kinds of life forms," were not really theoretical areas, so some feedback and adjustments took place.

Physical sciences
- Changes in matter
- Forces and motion
- Energy

Biological sciences
- Plants
- Animals
- People
- Ecosystems

Earth sciences
- Geology
- Meteorology
- Astronomy
- Oceanography

Process skills
- Observing/measuring/classifying
- Experimenting
- Inferring/predicting/solving problems
- Communicating

Figure 8.1 The theoretical areas in a K-6 science curriculum

2.3 For each theoretical area, help the SME identify the broadest, most basic and inclusive principles, followed by progressively narrower, more detailed and complex principles, until the desired level of complexity has been reached.

I asked my SME which area she would like to begin with, and it was the physical sciences. I then asked her to identify at least three candidates for "the broadest, most basic and inclusive principles" in each sub-area. The results are shown in Figure 8.2.

Physical sciences

Changes in matter
- The characteristics of solids, liquids, and gases:
  - size, color, hardness, texture, shape, smell, taste
- Behavior of solids liquids and gases:
  - take up space, keep or change their shape, etc.
- Ways matter can change:

location, temperature, emit light, emit sound

Forces and motion

Simple causes of motion (push, pull)
What makes something hard to move or makes it stop moving?
Simple causes of sinking and floating (heavy, light, water pushes up)

Energy

Simple causes and effects of heat (fire, sun; cook, warm, dry)
Simple causes and effects of light (sun, fire, light bulbs; see)
Simple causes and effects of sound (hitting, rubbing; warning, talking, music)

Biological sciences

Plants

...

Figure 8.2 The broadest, most basic and inclusive principles for each theoretical area (only part of the total is included here)

Then I asked another SME to review Figure 8.2 with us, and we made some revisions (see step 2.4 below). With consensus on this foundation, I then worked with the primary SME to further analyze each theoretical area down to the level of complexity expected of sixth graders. A sample of the results is shown in Figure 8.3.

2.4 Help the SME and at least one other SME to check to make sure that all principles identified are appropriate to include in this course and that no important principles have been left out.

I met with my secondary SME to establish rapport in a similar manner as with my primary SME. Then the three of us met to talk about the listing of basic principles. The second SME felt that the theoretical areas were right on target, but that some important basic principles were left out. A valuable discussion ensued in a collaborative, win-win sort of atmosphere, and both

Physical sciences

Changes in matter

1. The characteristics of solids, liquids, and air: size, color, hardness, texture, shape, smell, taste.
    2. What bends, what breaks, what stretches, what flows?
    2. Most physical properties are determined by the kind of material matter: color, taste, texture, hardness, maleability, density.
    2. Some properties are changed by: forces, temperature, moisture, light. (See A below for duplicate breakdown.)

1. Behavior of solids, liquids and gases: take up space, keep or change their shape, etc. Matter can change: location, temperature, emit light, emit sound.
    - 3. Some properties are changed by: forces, temperature, moisture, light. A
        - 4. Chemical changes: When two kinds of materials are combined, they can become a different kind of material with different properties.
        - 4. Ways energy can change matter: location, shape, phase, properties.
            - 5. In chemical reactions, tiny particles come apart and recombine. Heat is given off when they come apart, and is required to combine them.
            - 5. Particles are neither created nor destroyed in a chemical reaction.
                - 7. Basics of atomic theory.
                - 7. Behavior of acids and bases. B
    - 2. Phase changes: Simple causes and effects of ice melting, water evaporating and condensing, freezing (adding and removing heat).
        - 3. When a substance changes phase, some of its properties change: a solid does not change size or shape, a liquid changes shape but not size, a gas changes shape and size.
            - 4. Basic kinetic theory: a gas is made up of tiny particles moving very fast, pushing; sticking together loosely and slowing down when they condense; stick rigidly when freeze, etc.
                - 5. Large amounts of energy are absorbed and given off during phase changes.
        - 3. Effects of temperature and pressure on volume of a gas.
            - 5. Gas laws (qualitative). High pressure can change a gas to a liquid, with large energy transfers.
        - 3. Conservation of volume: the volume of a liquid does not change when you change its shape.
        - 3. Conservation of matter: the amount of matter does not change when you change its phase.
    - 2. Solutions: Causes and effects of solids dissolving (conservation of matter), saturation, stir to speed up rate of dissolving.
        - 5. What happens when a substance dissolves?
        - 5. Ions' effect on electric currents in a solution.
            - 6. Behavior of acids and bases. (See B above.)
            - 6. Ways of separating mixtures.

Figure 8.3 A sample of the breakdown of principles in one of the theoretical areas. Numbers indicate levels of complexity.

SMEs felt the revised listing was better than either of them would have created alone. It is what is shown in Figure 8.2.

3. Identify supporting content.

3.1 For each of the theoretical areas you identified in Step 2, help the SME to identify all concepts that are important for each level of principles, and identify the principle (or causal model) to which each concept is most closely related.

After helping my primary SME to understand what I meant by concepts, we took each of the sub-areas in order, and started with the most basic principles and worked down one level at a time. For example, for "Physical sciences," we started with "changes in matter." Within this sub-area, we identified concepts for all the level-1 principles:

1. The characteristics of solids, liquids, and air: size, color, hardness, texture, shape, smell, taste.
2. Behavior of solids, liquids and gases: take up space, keep or change their shape, etc. Matter can change: location, temperature, emit light, emit sound.

The concepts we identified for each of these principles are shown in Figure 8.4. Note that the SME decided that it was not important at this level for the students to be able to identify different textures, each of which would be an additional concept. The goal was for the students to know what texture is and to recognize that it differs from one object to another.

For principle 1:
Solid, liquid, air, size, color, hardness, texture, shape, smell, taste.

For principle 2:
(Solid), (liquid), gas, space, (shape), matter, location, temperature, light, sound.

Parentheses indicate the concept has alread been identified for another principle

Figure 8.4 An example of concepts associated with each principle

We found it more convenient to move on to steps 3.2 and 3.3 for this set of principles, and then come back to this step to take one of these principles and identify the concepts for the set of principes that elaborate on it.

3.2 Help the SME to identify all procedures that are important for each level of principles, and identify the principle (or causal model) to which each is most closely related.

After helping my primary SME to understand what I meant by procedures, we took the same set of principles and tried to identify relevant procedures (sets of steps), but we didn't find anything. For example, we were not interested at this point in the students being able to measure the size of solids; we just wanted them to understand that size does differ from one to another. So we listed no procedures.

3.3 Help the SME to identify all other important kinds of content, and identify the principle (or causal model) to which each is most closely related.

Again, I began by helping my SME to understand what I meant by each of these additional kinds of supporting content. Then we took the same set of principles and tried to identify relevant information or facts. We came to the conclusion that some information or facts should and would likely be learned, but that different teachers might use different solids and liquids in conducting the lesson on this set of principles, and that it would be unnecessary and even counterproductive to specify any particular ones.

So we moved on to understandings for this set of principles. Since the principles themselves represented the relevant causal understandings, we focused on conceptual understandings. Here, we felt the students needed to understand the concepts identified earlier (particularly their coordinate, subordinate, and experiential relationships), in addition to being able to identify them (concept classification). So they were listed.

For principle 1:
Experiential, coordinate, and subordinate relationships for:
solid, liquid, air, size, color, hardness, texture, shape, smell, taste.

For principle 2:
Experiential, coordinate, and subordinate relationships for:
(solid), (liquid), gas, space, (shape), matter, location, temperature, light, sound.

Parentheses indicate the concept has alread been identified for another principle

Figure 8.5 An example of concepts to be understood

Then we moved on to thinking skills for this set of principles. Here is where we felt the science process skills came in. Earlier we had identified sub-areas for the process skills (see Figure 8.1), which were as follows:

- Observing/measuring/classifying
- Experimenting
- Inferring/predicting/solving problems
- Communicating

We felt that all of these could be used to some extent with these principles, but they could also be used with almost any others. So how can we decide what to include here? We decided we needed to identify a good simple-to-complex sequence for each of these process skills, and then match up those sequences with appropriate levels in the theoretical elaboration sequence we were presently designing. We decided that the SCM would be most appropriate for designing each of these process skills sequences (see Chapter 6). We figured we could either finish this theoretical elaboration sequence first and then design the SCM sequences, or stop our current work, design the SCM sequences, and then resume working on the theoretical elaboration sequence. We felt it would be helpful to have both types of sequences completed before we decided which process skills should be taught in which parts of the theoretical elaboration sequence, so we could appropriately "pace" the development of each process skill within the curriculum. Thus, we elected to continue working on our theoretical elaboration sequence. But, I am including a sample of the result of this SCM analysis in Figure 8.5 so you can get a better sense of what I am talking about here.

Process Skill: Classifying

1. Classsify (objects, events) based on one characteristic (property).
2. Develop your own basis (one characteristic) for classifying.
3. Classify based on one function (property).
4. Develop your own basis (one function) for classifying.
5. Develop two or more bases (one property each) for classifying the same set of objects or events.
6. Classify based on two properties (characteristic and/or function) using a classification key and scheme.
7. Classify based on quantitative measurements.
8. Develop your own basis (two properties) for classifying and make a corresponding classification key and scheme.
9. Construct two or more classification schemes for the same set of objects or events.

Figure 8.5 A sample of an SCM sequence for the science process skills

Next, we addressed attitudes and values. The SME felt that it was important for the students to like science, to not be afraid of it, and to want to behave like little Sherlock Holmeses, always investigating the world around them. When I asked about particular attitudes and values related to the principles we had identified, she couldn't come up with any, so we were left with just the general ones, which she felt were important to work on in every learning learning episode of the course.

Finally, I asked about emotional, social, and spiritual development. She said that she felt all three were important to work on throughout all parts of the school day. She wanted to develop the students' abilities to recognize their own feelings and emotions, to control their impulses, to resolve conflicts peacefully, to cooperate with each other, to empathize with each other, and to develop caring friendships. She also wanted students to come to understand the sanctity of nature. Again, she didn't see specific principles to which these aspects of development could be attached, but felt that they should be constantly addressed throughout the course, when the "teachable moments" arose.

This completed the identification of all the content to be taught in the textbook series, and thus concluded the analysis process.

Theoretical Elaboration Sequence Design Process

How To Do It

You design a theoretical elaboration sequence by teaching sets of principles that are higher in a theoretical structure before teaching ones that are directly below them. Below is some guidance on how to do that. In the next section, an example of this guidance process is provided, followed by an example of the resulting sequence. You may want to refer to these as you read through this guidance. (Step numbers continue from the analysis.)

4. Decide on learning episode size. Decide how big your episodes (groupings of content) should be, based on any delivery constraints.

- The same guidelines apply as for hierarchical sequencing, such as "too big is bad" and "too small is bad" (see p. 4-9).

5. Decide on approach. Decide what approach you want to use to group the skills in each learning learning episode.

- You could group them so as to take a **spiral** approach to theoretical elaboration sequencing by teaching all the principles on the top level of each theoretical structure, then teaching all those on the next level down, and so forth.
- You could group them so as to take a **topical** approach by moving as far down a "leg" of the theoretical structure as quickly as possible for one learning learning episode, and then moving on to other "legs" in other episodes, always trying to get as far down as you can as soon as you can.
- Of course, other options are also possible.

6. Group and sequence episodes. Using your decisions from Steps 4 and 5, group the principles in your theoretical structure into episodes, and arrange those episodes in an elaboration sequence.

6.1 Decide whether or not the learners will be allowed to make sequencing decisions, and if so, which decisions.

- As we discussed in Chapter 4, some sequencing decisions may be unwise to give to the learners, whereas others could beneficially be made by them.
- It is important to know if learners will be allowed to make sequencing decisions because some redundancy across episodes is often needed when they are given that freedom.
- The issue of "which decisions" in 6.1 is basically deciding what options the learner will have after completing each learning episode. The options are the episodes that the learner will be allowed to choose next.

6.2 Rank the theoretical areas. Rank order the theoretical areas from the most basic, fundamental, and comprehensive one, to the least.

- Usually one area contains the most inclusive and important of all the principles that were selected for instruction (i.e., the principles that are involved in the greatest number of all the other theoretical areas for the course, and that are the most important principles in relation to the goals of the course).

6.3 Make any learning episode sequencing decisions that should not be left up to the learners, as determined in Step 6.1.

- The primary criterion for learning episode sequencing decisions should be the principle of theoretical elaboration, which states that a broader, more general principle should be learned before a narrower, more specific one that elaborates on it.
- Another criterion is to follow the rank-order of the theoretical areas, either in a spiral fashion or in a topical fashion.
- Notwithstanding these two criteria, I recommend you usually provide as much learner control over sequencing as you can within your cost-effectiveness constraints.
- If cost-effectiveness constraints prohibit you from providing that much learner control, a third criterion for learning episode sequencing decisions is learning load. Learning load is defined as the amount of difficulty and time it takes a learner to learn the content to the extent desired. The learning-load

criterion entails making the learning load fairly even across the episodes. Learning load is influenced by the amount of content to be learned, the familiarity of the content to the learner, and undoubtedly other factors. If there is much overlap between two coordinate episodes (e.g., some of the same prerequisite skills or understandings are required in both), then the learning episode that is learned later will be easier to learn. These factors should all be balanced against each other in making additional sequencing decisions.

7. Design the within-learning episode sequence. Help the SME to sequence all content within each learning episode. This can be done by using the following substeps and guidelines.

7.1 Identify any additional unmastered learning prerequisites for any of the content in the learning episode. (See Chapter 4.)

7.2 Decide whether or not the learners will be allowed to make any sequencing decisions within each learning episode, and if so, which decisions. Doing Step 7.3 simultaneously will help you decide.

- There will almost always be trade-offs. Allowing learners to make decisions will increase motivation and metacognitive skill development, but will take more learner time and effort. The value placed on each of those costs and benefits will tend to vary from one situation to another.

7.3 Use the following guidelines to identify any within-learning episode sequencing decisions that might be beneficial to make for the learners, and design the corresponding sequences.

- Teach a prerequisite just before it will be needed, preferably right after the learner realizes it is needed.
- Teach coordinate concepts together, comparing and contrasting them with each other.
- Teach understanding before related performance skill.
- Teach simpler and more familiar content before more complex and less familiar content.
- Teach broader, more inclusive, less detailed ideas before narrower, less inclusive, more detailed ideas.
- Allow the learner to make as many selection and sequencing decisions as you can, within your cost-effectiveness constraints, but be sure to provide

opportunity for learner reflection or feedback on the soundness of the learner's decisions.

This completes the theoretical elaboration sequence design process. An example of this process is described next.

Examples of the Design Process and its Results

Here is an example of both the process for designing a theoretical elaboration sequence and the results of that design process for the K-6 science textbook series, using the guidance provided in the previous section.

4. Decide on learning episode size

The publisher of the textbook said they wanted one textbook for each grade, K-6, and they wanted each textbook to have units and each unit to have chapters. We decided to treat each chapter as a learning episode, as defined in the Elaboration Theory. Due to the flexibility the typical elementary teacher has with time, my primary SME and I decided that we did not need to have a rigid size for each chapter, in terms of student learning time, at least through the fourth grade. For the fifth and sixth grades, she recommended that each chapter take about two weeks, and about five hours per week.

5. Decide on approach.

After discussing the spiral and topical approaches, we decided that all of the theoretical areas and sub-areas should be taught every year, so that the students wouldn't forget too much about one sub-area before it was dealt with again in the curriculum. But we also decided that a given sub-area should only be dealt with during one time period in a year, so that any materials that are set up in the classroom would only need to be set up once per year. We were tempted to go with twice a year, but in the end decided against that. So we ended up with a fairly topical sequence.

6. Group and sequence episodes.

6.1 Decide whether or not the learners will be allowed to make sequencing decisions, and if so, which decisions.

After considerable discussion, my primary SME and I decided that there should be very little learner control over sequencing because it made things much easier for the teacher if all the students were working on the same sub-area and even the same problems and activities at the same time, given the way most schools are currently organized. But we decided to keep our eyes out for places where the students could be given some control over the sequencing within a given sub-area as our design process proceeded.

6.2 Rank the theoretical areas.

My primary SME had a tough time trying to rank-order the theoretical areas listed in Figure 8.1. She felt that so few principles were shared among the areas (at least at the elementary levels) that none of the principles in any area were really used much in any of the other areas, with the exception of the process skills, which were used extensively in all areas. So we ranked process skills first, and did not rank any other areas.

6.3 Make any learning episode sequencing decisions that should not be left up to the learners, as determined in Step 6.1.

This was the most time-consuming part of the process. The principles were already arranged in an elaboration sequence, but we decided to rearrange them into elaboration sequences separately within each of the major theo–retical areas. We also found it helpful to state each principle in terms the students would understand or likely state them themselves. This expanded the number of principles. Then, as we got to deeper levels of complexity, we switched to arranging them within each of the sub-areas. An example of the results of this sequence design effort is shown in Figure 8.6.

Level K	
Organizing Content	**Supporting**
Different kinds of solids have different characteristics: size, color, hardness, texture, shape, smell, taste. Different kinds of liquids have different characteristics: size, color, hardness, texture, shape, smell, taste. Air has certain characteristics: you can feel it, see it move things. *How do solids behave? (e.g., a rock)* *Take up space, keep their shape.* *How do liquids behave? (e.g., water)* *Take up space, change their shape, can be poured.* *How do gases behave? (e.g., air)* *Take up space, change their shape (in a baloon), can be felt (blowing).* Matter's (solid, liquid, or gas) location can change. Matter can give off heat. Heat flows from hotter matter to cooler matter. What happens if you put a kettle on a hot stove? - a hot kettle on a table?	Concepts: solid, liquid, air, size, color, hardness, texture, shape, smell, taste Understandings: experiential, coordinate, & subordinate relationships for all the above concepts

Heat is never destroyed, it just moves. Matter can give off light. Light moves in straight lines. Figure out from flashlight beam in smoky air or milky water. Matter can give off sound. Sound moves in all directions. You can hear someone around a corner.	Process Skills: classify objects Attitudes: Enjoy science

Level 1 (elaboration for principles in italics in Level K)	
Organizing Content	**Supporting**
Ice melts into water when heat is added. Water turns to vapor when heated, turns back to water when heat is removed, back to ice when more heat is removed. Some common solids change form (dissolve) in water and others do not. Sugar versus sand. They turn back to solids when you evaporate the water. A crystal is formed. How can you make something dissolve faster? (stir it) Can water hold an endless amount of sugar? Gases can be dissolved as well as solids. (Bubbles in carbonated water.)	Concepts: water, vapor, ice, heat, evaporation, crystal, (saturation) Understandings: ... Process Skills: ... Attitudes: ...

Level 2 (elaboration for principles in italics in Level 1)	
Organizing Content	**Supporting**
Adding heat can cause a change of state of many solids and all liquids. Removing heat can cause a change of state of a liquid or a gas. When matter changes state, some of its properties change: ability to change size, ability to change shape. A solid does not change size or shape. A liquid changes shape but not size. A gas changes shape and size. Conservation of volume: the volume of matter does not change when you change its shape. (water poured, clay kneeded)	Concepts: ... Understandings: ... Process Skills: ... Attitudes: ...

Figure 8.6 Part of an elaborative sequence for one theoretical area

Next, we laid out the sequences beside each other and looked for commonalities. We especially looked for places where the process skills could be demonstrated and repeatedly practiced at the appropriate level. This allowed us to integrate the separate elaboration and SCM sequences into a single sequence. A "birds-eye view" of the result (books, units, and chapter titles) is shown in Figure 8.7.

There are several things worth noting about this sequence. In Grade K because of the heavy focus on the process skill of observing, we decided to make a slightly more spiral than topical sequence by dealing with physical science, biological science, and earth science at three separate times during the year. The first was observing characteristics for all three, in order. The second was observing changes for all three. And the third was observing causes and effects, though the SME felt that causes and effects were quite difficult for kindergarteners to observe in the biological sciences, so we opted to deal with the two major concerns of the physical sciences (matter and energy) in two of these three chapters.

[Put more commont on the blueprints here.]

Grade K

Unit 1: Observing Characteristics
- Chapter 1. Observing Matter
- Chapter 2. Observing Living Things
- Chapter 3. Observing the Sky

Unit 2: Observing Changes
- Chapter 4. Observing Changes in Matter
- Chapter 5. Observing Changes in Living Things
- Chapter 6. Observing Changes Outdoors

Unit 3: Observing Causes and Effects
- Chapter 7. Observing Causes and Effects in Matter
- Chapter 8. Observing Causes and Effects in Heat
- Chapter 9. Observing Causes and Effects Outdoors

Grade 1

Unit 1: The World around Us
- Chapter 1. The Sun and Stars
- Chapter 2. The Earth and Moon
- Chapter 3. Land, Water, and Air
- Chapter 4. Rocks and Soil
- Chapter 5. Ice, Water, and Vapor
- Chapter 6. Solutions and Crystals
- Chapter 7. The Ocean

Unit 2: Cycles
- Chapter 8. Time Cycles
- Chapter 9. The Life Cycles of Animals and People
- Chapter 10. The Water Cycle

Unit 3: Needs of Living Things
- Chapter 11. The Needs of Living Things
- Chapter 12. The Environment Meets Needs

Unit 4: Motion and Energy
- Chapter 13. Pushes and Pulls
- Chapter 14. Work and Machines
- Chapter 15. Light Energy
- Chapter 16. Sound Energy

Grade 2

Unit 1: Adaptations—Differences among Living Things
- Chapter 1. How Plants Meet their Needs
- Chapter 2. Animal Parts that Meet Needs
- Chapter 3. Animal Behaviors that Meet Needs
- Chapter 4. Plants and Animals Together
- Chapter 5. Plants and Animals in the Ocean

Unit 2: How Nonliving Things Move
- Chapter 6. Forces
- Chapter 7. Magnets
- Chapter 8. Energy

Chapter 9. Reflections

Continued

Figure 8.7 The final sequence outline: a birds-eye view

Unit 3: How Nonliving Things Change
- Chapter 10. States of Matter
- Chapter 11. Effects of Heat and Pressure
- Chapter 12. Properties of Matter

Unit 4: Cycles
- Chapter 13. The Rock Cycle
- Chapter 14. What Makes the Water Cycle Work?
- Chapter 15. What causes the Cycle of Day and Night?

Unit 5: Indirect Observations
- Chapter 16. Global Changes in Climate
- Chapter 17. Changes in the Shoreline

Grade 3

Unit 1: Survival
- Chapter 1. Plants and their Babies
- Chapter 2. Animals and their Babies
- Chapter 3. People and their Needs
- Chapter 4. Ecosystems

Unit 2: Matter
- Chapter 5. Motion and Forces
- Chapter 6. Kinds of Forces
- Chapter 7. Work and Machines
- Chapter 8. Seeing and Hearing
- Chapter 9. Changing Matter

Unit 3: Earth Movements
- Chapter 10. The Earth's Air Moves
- Chapter 11. The Earth's Water Moves
- Chapter 12. The Earth's Surface Moves
- Chapter 13. The Planet Earth Moves

Grade 4

Unit 1: Biology—Environmental Science
- Chapter 1. Plants and the Environment
- Chapter 2. Animals and the Environment
- Chapter 3. People and the Environment
- Chapter 4. Ecosystems

Unit 2: Chemistry—Building Models
- Chapter 5. Kinetic Theory
- Chapter 6. Chemical Reactions

Unit 3: Physics—Energy
- Chapter 7. Kinds of Energy
- Chapter 8. How Energy Travels
- Chapter 9. How Energy Changes

Chapter 10. Measuring Energy

Unit 4: Physics—Mechanics
- Chapter 11. Gravity
- Chapter 12. Controlling Forces
- Chapter 13. Machines

Unit 5: Earth Science—Geology
- Chapter 14. What Makes Mountains

Continued

Figure 8.7 *(Continued)*

Unit 6: Earth Science—Oceanography
- Chapter 15. Exploring the Ocean Floor
- Chapter 16. Life in the Ocean

Unit 7: Earth Science—Meteorology
- Chapter 17. What Makes Winds?
- Chapter 18. Measuring the Weather

Unit 8: Earth Science—Astronomy
- Chapter 19: The Solar System

Level 5

Unit 1: Biology—Classifying Life
- Chapter 1. Kinds of Plants
- Chapter 2. Kinds of Animals
- Chapter 3. Parts of People
- Chapter 4. Kinds of Ecosystems

Unit 2: Chemistry—Building Models
- Chapter 5. Phase Changes
- Chapter 6. Chemical Reactions

Unit 3: Physics—Energy
- Chapter 7. Potential Energy
- Chapter 8. Heat
- Chapter 9. Electricity
- Chapter 10. Light
- Chapter 11. Sound

Unit 4: Physics—Mechanics
- Chapter 12. Work and Energy Transfers
- Chapter 13. Attraction and Repulsion

Unit 5: Earth Science: Geology
- Chapter 14. Kinds of Rocks and Minerals
- Chapter 15. Kinds of Landforms

Unit 6: Earth Science—Oceanography
- Chapter 16. Tides

Unit 7: Earth Science—Meteorology
- Chapter 17. Kinds of Air Masses and Weather Patterns

Unit 8: Earth Science—Astronomy
- Chapter 18. Kinds of Stars

Chapter 19. Rockettry

Level 6

Unit 1: Biology—Classifying Life
 Chapter 1. Plant Processes
 Chapter 2. Animal Processes
 Chapter 3. Human Processes
 Chapter 4. Ecosystem Processes
 Chapter 5. Microorganisms

Unit 2: Chemistry—Building Models
 Chapter 6. Atomic Theory
 Chapter 7. Compounds, Mixtures, and Gases

Continued

Figure 8.7 *(Continued)*

Unit 3: Physics—Energy
 Chapter 8. Lenses
 Chapter 9. Electricity
 Chapter 10. Fuels
 Chapter 11. Communications
 Chapter 12. Complex Systems

Unit 4: Physics—Mechanics
 Chapter 13. Forces

Unit 5: Earth Science—Geology
 Chapter 14. Changes in the Earth's Crust
 Chapter 15. Recycling Natural Resources

Unit 6: Earth Science—Meteorology
 Chapter 16. Predicting Hurricanes, Tornados, and Other Storms
 Chapter 17. Oceans and Coastal Climates
 Chapter 18. Climates and Kinds of Life

Unit 7: Earth Science—Astronomy
 Chapter 19. Exploring the Universe

Figure 8.7 *(Continued)*

7. Design the within-episode sequence.

7.1 Identify any additional unmastered learning prerequisites for any of the content in the learning episode. (See Chapter 4.)

Now that we had a much clearer image of what the content would be in each chapter and the order of the chapters, we could double-check through all the chapters to identify any unmastered learning prerequisites we had missed. For the most part, prerequisite skills and understandings were naturally taught before they were needed as a part of the elaboration sequence. However, we did find a few prerequisites that we added to a number of the chapters.

7.2 Decide whether or not the learners will be allowed to make any sequencing decisions within each learning episode, and if so, which decisions.

We found it helpful to do 7.2 and 7.3 simultaneously.

7.3 Identify any within-learning episode sequencing decisions that might be beneficial to make for the learners, and design the corresponding sequences.

The results of steps 7.2 and 7.3 are shown for two chapters in Figures 8.8 and 8.9. It should be apparent from these chapter outlines that most of the within-chapter sequencing really should not be controlled by the students—that there is a natural progression in terms of both thinking skills and principles of biology.

Chapter 8, Grade 1
Time Cycles

Listen to (4.1) and extract from (4.4) a story the important changes that occur during a 24-hour period. [thinking/process skills]

- Each day is a cycle that passes through:
  - the sun rising and setting (daylight and darkness),
  - people and animals waking and going to sleep,
  - flowers opening and closing. [principles]
- Cycle [concept]

Predict (6.2) the important changes that occur during the passing of the seasons in your locality. Then organize and deliver (4.2) a description of them. Students work in groups of four to think up the changes and communicate them to each other. Then each group (separately) explains them to the teacher, who outlines them for each season and assigns one season of changes to each student. Then each student describes his or her changes to the whole class. [thinking/process skills]

- The seasons are a cycle that passes through spring (birth or awakening), summer (growth and life), fall (dying or falling asleep), and winter (death or sleep). [principle]
- Season [concept]

Observe (1.1) a sequence of pictures that shows a plant at its various stages: a seed, a seedling, a mature plant, a flowering plant, and a seed again. [thinking/process skill]

- The life cycle of a flower: A flowering plant goes through changes as it develops from a seed into a mature plant. [principle]
- Predict (6.2) what comes next by placing pictures of the natural events in

order. [thinking/process skill]
- Seed, seedling, mature plant, flower [concepts]

Different kinds of plants have different lifespans. Some die in winter and some "sleep" and reawaken in the spring. [principle]
- Lifespan [concept]

Figure 8.8 A sample of the final within-episode sequence outline: A detailed view of Chapter 8 for Grade 1. (The numbers in parentheses are indicators of new thinking skills introduced in this chapter.)

Chapter 1, Grade 2
Plants

Classify (2.1 or 2.2): Identify the parts that all flowering plants have. [thinking/ process skills]
- All flowering plants have roots, a stem, and leaves. [principle]
- Root, stem, leaf [concepts]

Review the needs of plants (Grade 1, Chapter 11). [principles]

Infer the function that each part serves. [thinking/process skills]
- The parts of a plant help it to live and grow.
  - Roots take in water from the soil and store food.
  - The stem supports the plant.
  - The leaves make food. [principles]

Predict the effects of too little water, too much water, too little heat, too much heat, too little sunlight, too much sunlight, too little space, too much space. [thinking/process skill]
- Plant health, growth, and development are affected by envirnomental conditions such as water, heat, sunlight, and space. [principle]
- Environment, environmental condition [concepts]

Behavioral adaptations: Plant parts may change to get more light or water (to meet its needs). Leaves turn toward light and some close in the dark. Some roots grow faster in moist areas. [principles]
- Moist [concept]

How to care for plants in the classroom. [procedure]

Figure 8.9 Another sample of the final within-episode sequence outline: A detailed view of Chapter 1 for Grade 2. (The numbers in parentheses are indicators of new thinking skills introduced in this chapter.)

Practice Exercises

If you are using this book in a course and you want to use a problem-based learning approach to learning these skills and understandings, you should begin by selecting a problem and scenario that fit the criteria outlined below, and use the relevant prior material in this book on an as-needed basis.

I recommend you choose your own scenario and problem for this exercise, for then it will be more personally relevant and authentic. But if you do so, it is important that the scenario and problem meet certain criteria, or they will not afford you the opportunity to learn to do a conceptual analysis and sequence design. Here are the criteria.

The Problem

- The content domain should be relatively simple. Picking a more complex one will just make your project take longer, without enhancing your learning much.
- The problem should only entail designing the sequence at this point, unless you are using this book in conjunction with other resources that can help you to design additional aspects of the instruction.

The Scenario

- Work on a team of 2 (or at most 3) people to perform this project. You will learn more by sharing ideas and perspectives with each other. You will also further build your teaming skills, which are extremely important for instructional designers. I have found that the more people beyond two on a team, the less active involvement and learning will take place for at least one of the teammates.
- Try to find a real client for whom to do the project, in a school (k-12 or higher education), corporate (profit or nonprofit), or informal setting. If you can't find a real client, then arrange for a classmate or friend to be your client in a role-play type situation. Your client should serve as your subject-matter expert.

A Sample Problem and Scenario

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References

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