Formative Research on Sequencing Instruction with the Elaboration Theory

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The elaboration theory of instruction offers guidelines for several patterns of simple-to-complex sequencing which were developed primarily from cognitive theory, especially schema theory. However, there has been relatively little empirical research on the theory. This study helps fill this void by conducting formative research to identify weaknesses in the theory and possible ways of overcoming those weaknesses. Four chapters in a text on electrical circuit analysis were revised according to the theory. The first phase of the study used interactive data collection for immediate, detailed reactions and suggestions on the sequence. Phase 2 utilized non-interactive data collection to assess the external validity of the results. Qualitative data analysis provided insights into ways to improve the theory. None of the results indicated that elements should be deleted. Weaknesses indicated new methods that should be added to the theory and existing methods that should be modified and/or enhanced.

☐ Bruner (1966) proposed that the sequence of instruction will affect the students' ability to grasp, transform, and transfer what they are learning. "The sequence in which a learner encounters material with(in) a domain of knowledge (will) affect the difficulty he(/she) will have in achieving mastery" (p.49).

Sequencing deals with the order in which elements of subject matter, including information, skills, and cognitive strategies, are taught during instruction. Reigeluth has striven to integrate the knowledge base about sequencing instruction into a comprehensive set of strategies and prescriptions called the elaboration theory of instruction (Reigeluth, 1987, 1992; Reigeluth & Darwazeh, 1982; Reigeluth & Rodgers, 1980; Reigeluth & Stein, 1983). Reigeluth's work is a result of his concern that most of the widely used sequencing strategies were highly fragmented, demotivating, and inconsistent with much knowledge generated recently by cognitive psychologists about how knowledge is best assimilated into schemata (Reigeluth, 1979, p.8). Therefore, Reigeluth pursued the goal of producing guidance for developing more holistic sequences that would enhance understanding, foster motivation, and have the potential to facilitate learner control. M.D. Merrill provided much initial insight and inspiration for the development of the elaboration theory (see e.g., Merrill, 1977; Reigeluth, Merrill, Wilson, & Spiller, 1980).

THE ELABORATION THEORY OF INSTRUCTION

The elaboration theory of instruction (ETI) prescribes different patterns of sequencing for different kinds of learning. It currently deals only with the cognitive and psychomotor domains, and not the affective domain. First a distinction is made between task expertise and content expertise. Task expertise relates to the learner's becoming an expert in a specific task, such as business management, creative writing, or solving algebraic equations. Content expertise relates to the learner's becoming an expert in a body of knowledge not tied to any specific task, such as economics, biology, or history.

For building content expertise, the ETI prescribes one pattern of sequencing if the content is primarily concepts and another if it is primarily principles. The *conceptual elaboration sequence* (Reigeluth & Darwazeh, 1982) was derived primarily from Ausubel's (1968) advance organizers and progressive differentiation but provides greater guidance as to how to design that kind of sequence. The *theoretical elaboration sequence* (Reigeluth, 1987) was derived primarily from Bruner's (1960) spiral curriculum but differs in several important ways and also provides greater guidance as to how to design it. Both types of elaboration sequence can be used simultaneously if there is considerable emphasis on both types of content in a course. This is referred to as multiple-strand sequencing (Beissner & Reigeluth, 1994).

For building task expertise, the ETI prescribes the simplifying conditions method (SCM) for sequencing the instruction. The SCM is a bit different depending on whether the task is primarily a procedural or a heuristic task. A procedural (or algorithmic) task is one for which experts use a set of steps to decide what to do when. A heuristic task (or transfer task or complex cognitive task) is one for which experts use causal models or interrelated sets of guidelines to decide what to do when. The *procedural SCM sequence* (Reigeluth & Rogers, 1980) was derived primarily from work by Scandura (1973) and P. Merrill (1978, 1980) on path analysis of a procedure. The *causal SCM sequence* (Reigeluth, 1989; Reigeluth & Kim, 1991) was derived primarily from the procedural SCM sequence. Both types of SCM sequence can be used simultaneously if the task is a combination of procedural and heuristic elements, and both SCM and elaboration sequences can be used simultaneously as well. Again, this is referred to as multiple-strand sequencing (Beissner & Reigeluth, 1994).

Some limited experimental research has been done on the ETI, mostly on relatively small amounts of instruction (Berg, Daal & Beukhof, 1983; Beukhof, 1986; Carson & Reigeluth, 1983; Chao, Ruiz & Reigeluth, 1983; Frey & Reigeluth, 1981; Reigeluth, 1981). These studies have shown positive effects for elaboration sequences. However, since the ETI is relatively young and is still undergoing considerable growth and development, our concern is less with *proving* the ETI than it is with *improving* it. We are unaware of any large-scale developmental research on the elaboration theory.

The purpose of this study was to help fill this void by conducting developmental research on the ETI. The goals of the course chosen for the developmental research entailed both theory and practice, so we selected a multiple-strand sequence using both the theoretical elaboration sequence (for content expertise) and the procedural SCM sequence (for task expertise). Therefore, each of these two types of sequences is described in greater detail next.

Theoretical Elaboration Sequence

According to Reigeluth (1987), the theoretical 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. . . . [It is] a sequence that progresses from the most basic and observable principles to the most detailed, complex, and restricted principles (p.251).

The first lesson in the sequence is termed the *epitome lesson* and should epitomize the whole subject domain by teaching the one, or at most the few, most fundamental, generalizable, and inclusive (broadly applicable) principles, such as the law of supply and demand in economics or Ohm's law in electricity. The principle(s) should be taught at the concrete application level, where learners learn to apply the principle(s) to a range of real-world situations.

Reigeluth (1987) describes the process for designing a theoretical elaboration sequence as the following:

> After "brainstorming" to list all the principles (usually statements of causes or effects), . . . [you should] "epitomize"; that is, 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 principles 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 [in the historical development of the discipline]. (p.260)

Procedural SCM Sequence

The procedural SCM sequence is based on the notion that complex cognitive tasks (procedural and causal) are performed very differently in different situations, some of which are much simpler than others. Therefore, there exists a wide variety of versions of the task, ranging from simple ones to complex ones. The ETI prescribes that the simplest one that is still fairly representative of the task in general should be taught first to novices, and that the instructional sequence should entail teaching progressively more complex versions of the task until the desired level of competence is reached (or time available for instruction has expired). For example, in teaching someone how to drive a car, you shouldn't start the novice driver out in the middle of New York City during rush hour in a car that has a standard transmission. Start with the simplest real-world conditions, such as a car with automatic transmission in an empty parking lot. Clearly the SCM is not new; it has likely been intuitively used for hundreds of thousands of years. Of central importance to the SCM is that every lesson of the course teaches a complete, real-world version of the task. This is proposed not only to be more motivational for learners, but also to provide a better schema or mental model of the task, for it allows learners to perform as experts from the very beginning of the course, albeit for a very restricted domain of real problems.

The SCM provides considerable guidance as to how to create this kind of sequence (Reigeluth & Kim, 1991). Briefly, one begins by identifying the simplest version of the task that is still fairly representative of the task in general, and identifying the conditions that distinguish when that version of the task should be performed instead of a more complex version. For example, for driving a car, the kind of transmission, the size of the car, the traffic, the weather, the presence of pedestrians, and how wide the road is would all be important conditions that influence the complexity and difficulty of the task (i.e., the level of skill one needs to be able to perform as an expert under those conditions). Then those "simplifying conditions" are rank-ordered based on the complexity, representativeness, importance, expense, and safety of the version of the task that each requires. The simpler, more representative, more important, less expensive, and safer versions are, of course, taught first. That rank-ordering, then, determines the instructional sequence.

Frequently, eliminating a single simplifying condition makes the resulting version of the task so much more complex that it requires a tremendous amount of learning to reach a mastery level. A standard transmission is a case in point. It requires more learning than can be done in a single lesson of a course. In such situations, secondary simplifying conditions should be identified that allow simpler sub-versions of the task to be taught before more complex sub-versions of that version. For example, when first teaching someone how to drive with a standard transmission, you could avoid hills, because hill starts are more complex (require a higher level of skills regarding use of the clutch, gas, and hand brake).

Research Questions

Given that the ETI's sequencing prescriptions (a) have such strong theoretical support, (b) have some empirical support, and (c) are still in the early stages of development, the purpose of this study was to further develop and improve the sequencing prescriptions in terms of their influence on the effectiveness and appeal of instruction. The questions that had to be answered to achieve this goal were What ETI prescriptions work well? and What improvements can be made in the prescriptions? To answer these types of questions, we employed a combination of qualitative and quantitative techniques in this study.

METHODOLOGY

Because the focus of the study was to improve the ETI's sequencing prescriptions, the research methodology chosen for this study was formative research. We relied on predominantly qualitative data with limited use of quantitative data. Reigeluth (1989) has suggested the formative research methodology to improve instructional theories and models, and has supervised the development and use of the methodology to improve other instructional theories and models, including a theory to facilitate understanding (Roma, 1990: Simmons, 1991) and a theory to foster awareness of ethical issues (Clonts, 1993), and to improve instructional systems development (ISD) models, such as procedures for the motivational design of instruction (Farmer, 1989).

Formative research is similar to formative evaluation (Dick & Carey, 1991: Flagg, 1990; Tessmer, 1994), with the primary difference being that its purpose is to improve our generalizable knowledge base about instruction (theories and models), rather than to improve a specific instructional product or system. In formative research some instruction is designed and developed based as purely as possible upon a theory (or model). The instruction is then an instance of that theory, just as treatments in an experimental study are developed as instances of a generic instructional or intervention strategy. The next phase of the formative research process is to submit the instruction to formative evaluation. A series of one-to-one formative evaluations is conducted with learners from the target population to identify the strengths and weaknesses of the instruction and ways of improving it, all of which are measured in terms of the effectiveness and appeal of the instruction. However, the process does not end with the completion of the formative evaluation. Since the instruction is an instance of the theory, weaknesses in the instruction may reflect ways of improving the theory. Issues of reliability and validity play an important role in formative research, as in experimental studies. Naturally, replication with different types of content, learners, and training situations is necessary to assure generalizability of the findings.

There were two phases to this study. The purpose of Phase 1 was to gather rich data about ways to improve the ETI through one-to-one interactions with students, while the purpose of Phase 2 was to enhance the external validity of the study. In the first phase, four chapters in a text (Boylestad, 1990) on electrical circuit analysis were revised according to the sequencing prescriptions of ETI. This phase used interactive data collection and was conducted to collect immediate, detailed reactions to, and suggestions on, the instructional sequence. Phase 2 utilized only non-interactive data collection to enhance the external validity of the results. Qualitative data analysis was performed and included a summary of the data on the effectiveness and appeal of the instruction. The outcome of the qualitative data analysis provided insights into ways to improve the theory. Phase 1 took eight weeks and Phase 2 took two weeks to complete, over two consecutive semesters.

Having two phases allowed multiple methods of collecting data, which is a form of *triangulation* (Lincoln & Guba, 1985). Triangulation combines dissimilar methods, such as debriefings and observations, to study the same unit. The logic behind this tactic is that the flaw of one method is often compensated by the strength of another, and that by combining methods, the researcher can achieve the best of each, while overcoming the intrinsic deficiency of each. Multiple sources of evidence took the form of the investigator's notes, students' comments, interviews with the students, audio tapes from debriefing sessions, the posttests, and the attitude survey.

Subjects

Ten students were asked to volunteer to participate in Phase 1, and three students were asked for Phase 2. All were sophomores from the Electronics and Computer Technology (ECT) program in the School of Technology at Indiana State University. They were enrolled in a circuit analysis course titled ECT 221. The student ages ranged from 18 to 50. Approximately 50% were non-traditional students (most were studying part-time, as well as being older).

Students were selected by the procedures described below to be representative of the student population for the course. Information regarding the students' characteristics was gathered from a data sheet that the students filled out. Three primary factors were used in the selection process: grade point average (GPA), scores on the pretest for content knowledge, and scores on the pretest for prerequisite knowledge (described later). Ten students were asked to volunteer to participate in Phase 1, and three students were asked for Phase 2. Fewer students were selected for Phase 2 because its purpose was to confirm the external validity of the results obtained from the intensive interaction with each student in Phase 1.

The GPA criterion was used because of the desire to have a representative cross section of ability groups that was based on academic performance. This procedure allowed us to determine if certain strategies of the ETI were differentially useful for students of different abilities. For Phase 1, four students were selected from the high-ability group (above 3.3), three from the average group (2.8–3.3), and three from the lower group (below 2.8). For Phase 2, one student was selected from each of the three groups. The pretests ensured that all participants had attained a minimum competency score on a prerequisite knowledge test and did not have prior circuit analysis knowledge.

Materials

The instruction was a revised version of three chapters of Robert L. Boylestad's (1990) text, *Introductory Circuit Analysis.* The specific sections that were revised include Chapter 5, which is about series circuits, Chapter 6, about parallel circuits, and Chapter 7, about series-parallel networks (excluding ammeter, voltmeter, and ohmmeter design). The faculty of the Electronics and Computer Technology (ECT) program recommended this subject matter because it was particularly difficult for students to master. Traditionally, students have had more problems with this course than any other fundamental course. The techniques and problem-solving skills that were learned in this class were prerequisites for higher-level courses.

The first author revised the textbook instruction at the macro level according to multiple-strand sequencing utilizing the ETI's theoretical elaboration sequence and procedural SCM sequence. He also revised it at the micro level according to Merrill's component display theory (Merrill, 1983), which is prescribed by the ETI. The revisions of the three chapters were developed as consistently as possible with the prescriptions of the theories. The materials were reviewed by two subject-matter experts who had considerable expertise in this area. See Tables 1, 2, and 3 for a depiction of the sequence of the theoretical and procedural strands, along with the simplifying conditions for each, for the three chapters (topics).

Table 1, on series circuits, shows that Lesson 1 (the epitome) contains instruction on circuit analysis where the circuits are very simple because they have the following simplifying conditions: no more than one voltage source in series, no opens, no ground references, no single subscript notation, no double subscript notation, no elements with two points in common, and no parallel voltage sources.

In Lesson 2, instruction is provided on circuits that are not quite simple because one of the simplifying conditions has been removed. By removing the condition, the circuits have more than one voltage source in series, which requires additional learning for students to be able to solve problems as an expert would. This simplifying condition was removed first because the subject-matter expert felt that the additional expertise so required was more often fundamental, common, and representative of all versions of the task than would have been the case by relaxing any other of the simplifying conditions. This lesson is on the first

Table 1 ☐ Series Circuits

Lesson	*Level of Elaboration*	*Lesson Elaborated On*	*Simplifying Conditions*
1	Epitome	–	• No more than one voltage source in series • No shorts • No opens • No ground references • No single subscript notation • No double subscript notation • No elements have two points in common • No parallel voltage sources
2	1	1	Remove this: • No more than one voltage source in series
3	1	1	Remove this: • No shorts • No opens
4	1	1	Remove this: • No ground references
5	1	1	Remove this: • No single subscript notation • No double subscript notation

Table 2 ☐ Parallel Circuits

Lesson	*Level of Elaboration*	*Lesson Elaborated On*	*Simplifying Conditions*
6	1 Epitome for Lessons 7–12)	1	Remove this: • No elements have two points in common *Add these: • No more than one voltage source in series • No more than one parallel voltage source
7	2	6	Remove these: • No more than one voltage source in series • No more than one parallel voltage source *Add these: • No shorts in a parallel network • No opens in a parallel network • No series/parallel combinations • No ladder networks • No multiple branch currents
8	3	7	Remove this: • No shorts in a parallel network • No opens in a parallel network

Table 3 ☐ Series-Parallel Circuits

Lesson	*Level of Elaboration*	*Lesson Elaborated On*	*Simplifying Conditions*	
9	3 (Epitome for Lessons 10–12)	7	Remove this:	• No series/parallel combinations
			Add these:	• No more than one voltage source in series or parallel • No shorts in a series/parallel network • No opens in a series/parallel network
10	1	9	Remove this:	• No more than one voltage source in series or parallel
11	2	9	Remove this:	• No shorts in a series/parallel network • No opens in a series/parallel network
12	3	7	Remove this:	• No ladder networks

level of elaboration because it elaborates directly on the epitome.

In Lesson 3, the two next most fundamental, common, and representative simplifying conditions were removed, resulting in instruction on circuits that have shorts and opens. Two conditions were removed because removing only one would have resulted in a lesson that was too short for the amount of class time available. This lesson is on the second level of elaboration because it elaborates on Lesson 2, which in turn elaborates on the epitome. In other words, Lesson 2 is a prerequisite for Lesson 3.

In Lesson 4, the instruction deals with circuits having ground references. This is on the first level of elaboration because it could be learned right after the epitome is mastered. Neither Lesson 2 nor Lesson 3 is a prerequisite for it. The only reason it wasn't presented sooner is that the subject-matter expert deemed its skills to be less fundamental, common, and representative of all versions of the task than were the skills for Lessons 2 and 3.

Finally, in Lesson 5, instruction is provided on circuits with single and double subscript notation.

This same pattern of interpretation applies to Tables 2 and 3.

Table 4 shows a listing of all the content that comprised Lesson 1 (the epitome) for the series circuits "chapter" (module).

The instruction was presented on Macintosh computers using HyperCard and took over 11 megabytes of disk space. It was reviewed for accuracy by two subject-matter experts who had considerable expertise in this area.

Instruments

Six instruments were used to collect data. These included two pretests, a posttest, a set of impromptu questions used during the interactive phase, a set of questions used during debriefing, and an attitude survey.

Of the two *pretests,* the first was to ensure that none of the students had any prior content knowledge in circuit analysis. It dealt with the classification of circuits as either series or parallel; current divider rule; voltage divider rule; Ohm's Law; Kirchhoff's voltage law; Kirchhoff's current law; and so forth. The student was required to calculate voltage, current, and resistance at specific points in a circuit. If students had such prior knowledge, we would not have been able to collect data on ways to improve the elaboration sequence for learners with no prior knowledge. This test was essen-

Table 4 □ A listing

	Procedural Content	Supporting Content Concepts	Principles	Prerequisites	Information
Step 1:	Evaluate the circuit.	Series Circuits			Applied E,
1.1	Assess the circuit as a series circuit circuit with a single voltage source.				Complete Path & Load
1.2	Identify the source voltage, the complete path, and load.				Conventional Current Flow
1.3	Relative to the voltage source assign the direction of conventional current flow.				
1.4	Assign polarities across each element according to conventional current flow as determined in Step 1.3.				
Step 2:	Calculate the parameters of the circuit.			Resistance	
2.1	Determine if values are given so that E, total I & R can be calculated If no, use Ohm's Law or Watt's Law to calculate the unknown value. If yes, go to Step 2.2			Current Voltage	
2.2	Calculate the total resistance of the cirduit by summing the individual resistors.		(Ohm's Law)		$R_T = R_1 + R_2 + R_3$
2.3	Calculate the total current of the circuit by dividing the voltage of the voltage source by the total resistance.		(Watt's Law)		$I_T = \frac{V_s}{R}$
2.4	Calculate the voltage across each element by multiplying the total current by the individual value of resistance of each resistor.				$E_1 = I * R_1$
Step 3:	Verify the parameters of the circuit.				
3.1	Verify the voltage drop across an element (Step 2.4) by calculating the voltage across that same element using VDR. If no go to Step 2.2. If yes go to Step 3.2.		VDR		
3.2	Verify that the sum of voltage drops is equal to the sum of the voltage rises by applying Kirchhoff's Voltage Law (KVL). If no go to Step 2.2. If yes go to Step 4.		KVL		
Step 4.	Power calculations				
4.1	Determine if there is a requirement for power calculations. If no, stop. If yes, go to step 4.2.				$P_S = I_S * V_S$ $P_1 = I^2 * R_1$
4.2	Calculate the power delivered by the voltage source.				$P_T =$
4.3	Calculate the power dissipated by the resistors.				$P_1 + P_2 + P_3$
4.4	Verify that the power delivered by the source is equal to the power dissipated by the resistors.				
4.5	If no, recalculate values from Steps 4.1 and 4.2. If yes, stop.				

tial because of students: (a) transferring into this program from other programs; and (b) retaking the course. We arbitrarily established that students had to score 30% or below to participate in the study. The test took approximately one hour to complete.

The second pretest was to ensure that students possessed adequate prerequisite knowledge in algebra. The class extensively engaged students in solving problems through circuit analysis techniques that required a basic working understanding of algebra (distributive law, associate law, communicative law), and the ability to apply that knowledge to solving problems. The pretest required students to demonstrate their ability to algebraically manipulate an equation. Lack of this prerequisite knowledge would have severely hampered a student's ability to benefit from the instruction and its sequence. We arbitrarily established that students had to score 70% or above to participate in this study. The test took approximately one hour to complete.

A *posttest* was administered after each topic (i.e., series circuits, parallel circuits, and series-parallel circuits). Three posttests were administered in all. Their purpose was to assess achievement and measure the effectiveness of the instruction. A secondary purpose was to have the students reflect upon the instruction. It was hypothesized that a posttest would give students more insight into how effective the instruction was, thereby enabling them to be more critical of the instruction and helping us to find more ways to improve the theory. The overall level of the students' performance was not related to the research questions, since our focus was on improving, not proving, the theory.

Of the two qualitative instruments, the first was some *impromptu questions* that were asked of each student only during the interactive data collection stage (Phase 1). These questions were intended to identify particular aspects of the instruction that helped or hindered the student's comprehension and to identify ways to improve the instruction. Therefore, these questions were not predetermined, but emerged out of the first author's observation of, and interaction with, each student. The nature of the questions depended upon comments by the students, student expressions, and progression through the instruction. For example, students taking an excessive amount of time working through a portion of instruction were questioned so that the problem area could be identified and a solution proposed. Typical questions included What did you *not* like about the sequence of that instruction? and How would you improve that aspect of the instruction?

The second qualitative instrument was a set of 32 *debriefing questions* (see Appendix A) used during the debriefing sessions of Phases 1 and 2. Students were questioned to gain insight on things not directly observed (e.g., feelings, thoughts, and intentions). It is not always possible to observe how students perceive instruction and the meaning they attach to what is going on during instruction, so it is beneficial to question them about those things. The debriefing questions allowed students an opportunity to evaluate the elaboration sequence, to think about specific strengths or weaknesses not previously mentioned, and, for Phase-1 students, to make any suggestions that they had forgotten to make during the interactive data collection. The same set of debriefing questions was administered after each topic was covered. The reliability and consistency of data across students were assessed.

An attitude survey was used to assess (a) the appeal of the instruction, and (b) the student's attitude toward the instruction. Students were asked to rate on a scale from 1 to 5 the degree to which they: liked the instructional unit; liked the sequence of the instructional unit;, liked the overviews of the instructional unit; felt good about what they learned in the unit; and felt the instruction was appropriately related to prior instruction (seven items total). This instrument served as a way of cross-checking the qualitative statements that the student had previously made.

Procedure for Phase One: Interactive Data Collection

Phase 1 was conducted one semester prior to Phase 2. One-to-one formative evaluation, as described by Dick and Carey (1985), provided the direction during this phase. The formative evaluation process was used to obtain data to increase the effectiveness and appeal of the instructional sequence. The interactive data collection was conducted with the investigator sitting at the side of each student while he or she studied the material.

Ten students were involved in Phase 1. Each student was given specific instructions on the use of HyperCard and was allowed to practice before starting the instruction. This procedure allowed the student to become familiar with the characteristics of the computer and software before starting the instruction. The purpose of this practice was to eliminate problems due to the lack of knowledge of the computer program or peripherals (e.g., being able to manipulate the mouse or being able to move from card to card).

It was explained to each student that a new instructional resource had been designed and that his or her reaction to it was desired. The students were informed that any mistakes that they might make would probably not be their fault, but would be due to deficiencies in the instruction. Each student was encouraged to be as critical of the instruction as possible so that the weaknesses could be identified and the instruction could be made as trouble-free as possible. The students were encouraged to be relaxed and to comment freely about problems with the instruction and about methods that worked for them.

During this phase, there was constant communication with each student to determine what methods and tactics were either working or not working. The card number from the HyperCard program was recorded and used to identify the precise location in the instruction at which individual students were having difficulties or where they liked a specific aspect of the instruction. All comments were recorded. Each student was audio taped during this phase as a way of ensuring the accuracy and thoroughness of data collection.

As students used the instruction, they found typographical errors, omissions of information, branching problems, improperly labeled schematics, and other kinds of mechanical difficulties that inevitably happen. This information was used to revise the instruction through the correction of small errors and gross problems.

Once students were finished with the instruction, they were asked if they had any questions. A posttest was given after all the lessons of a topic were presented. Upon completion of the posttest, each student was asked to fill out the attitude survey.

Once each student finished the attitude survey, he or she was debriefed. An outline of the sequence of the material was given to help prompt memory. The debriefing session was audio taped as part of the data collection process. The tape counter was set and the number was recorded so that pertinent comments could be referenced to a tape number. A debriefing log was kept with comments and the associated tape counter number. The debriefing concentrated on such questions as what the strengths and weaknesses of the instruction were, whether students liked or disliked the instruction and why, and what suggestions they had for improving the instruction.

Procedure for Phase Two: Non-Interactive Data Collection

The non-interactive data collection was carried out in a more secluded environment and was used to enhance the external validity of the study. Each student worked through the instruction independently while the researcher unobtrusively observed and wrote notes about student comments and problems with the instruction. Completion time for each unit was logged. During this phase the investigator and the student did not communicate except during the debriefing session.

In Phase 1 the researcher had continually interacted with each student in an attempt to detect ETI methods or tactics that worked or did not work. This action caused students to constantly consider the utility of the instructional methods. We were concerned that the Phase-2 students would not be as cognizant of what tactics worked or did not work well, because they were not continually reminded to consider them (e.g., students would find the instruction appealing, but not know why because they had not been prompted to think as much about the explicit reason the instruction worked). Therefore, in the debriefing session the Phase-2 students were asked about a method if they did not comment about it.

Identical instructions were given concerning the use of the software and practice exercises in both Phases 1 and 2. After each of the three topics was completed, students were asked if they had questions. They were given the posttest and then asked to fill out the attitude survey. After the attitude survey was completed, each student was debriefed again. The same questions were used in all three debriefings.

On the next scheduled class period after each debriefing, students were asked to verify a typed summary of their submitted comments. This practice was used to enhance construct validity as suggested by Yin (1984). The students either approved their comments or suggested or modified them as necessary. The audio tapes were transcribed, and this information was used for data analysis purposes.

RESULTS AND DISCUSSION

The most important results of this study are the qualitative results, which identified ways to improve the ETI. The presentation of those results is followed by some quantitative results, which put the qualitative results into perspective by comparing the performance of students of different ability levels and by comparing the performance of the students in this study with the typical performance of students in the same course.

Qualitative Results

Student comments made while working through the instruction and during the debriefing session were categorized according to emergent categories and were placed on a matrix (e.g., Table 5). Each row of the matrix represents either a category, continuation of a category, or student suggestions for an improvement in a category. A letter is assigned to each row (tactic/flaw/improvement) for easy reference. The matrix reflects the responses categorically within each phase (i.e., Phase 1 or Phase 2) and each ability group (i.e., low, average, and high). Each ability group was represented in Phases 1 and 2. Responses were combined and sub-totaled for each ability group. The combined total response from all three groups is presented in the final column.

Qualitative Comments on the Elaboration Theory

Table 5 presents a tally of the qualitative comments that students made concerning the elaboration theory of instruction, organized into categories that emerged from the data analysis. Many of the comments made were in support of sequencing, and are indicative of the strong influence that sequencing has on learning. There are many areas worth discussing in this category. Most students, in all three ability groups, liked: the organization (+10; row a), the simple-to-complex presentation (+13; row b), and the logical order (+10; row c). Some relevant comments made by students follow:

The material is straight forward, well organized, and easy to follow.

It was easy to follow.

The sequence was very good.

It was progressive, each topic built on the one before, progression was from easy to difficult and variance of problem set up allowed for a challenging lesson.

Each sequence was related to the one before.

I could more easily build on what I had learned.

It seemed I learned something new with every problem.

It seemed to flow together, one section led into another, it builds on itself.

The farther along you got, the more knowledge you had to use to solve problems.

The topics fell right into place. You learn one thing before adding to it.

Similarly, there were many positive comments made in support of the use of the epitome (reflected by rows a-d in Table 5), and this is indicative of its influence on learning. In this category there are many areas worth discussing. The use of an epitome was very effective in terms of: ease of understanding (+10; row d), being focused (+10; row e), identifying critical areas (10; row f), relating previous knowledge (+8, row g), cueing important

Table 5 ☐ Qualitative Data Inventory: Elaboration Theory of Instruction

Ability		Low					Average					High						
Tactics/Strategies Comments:	*Group*	*Phase 1*			*Phase 2*	*Low Sub Total*	*Phase 1*			*Phase 2*	*Avg. Sub Total*	*Phase 1*				*Phase 2*	*High Sub Total*	*Comb. Total*
	N	*1*	*2*	*3*	*1*		*1*	*2*	*3*	*1*		*1*	*2*	*3*	*4*	*1*		
(a) Organization			+	+	+	+3	+		+	⊕	+3	+		+	+	+	+4	+10
(b) Simple-to-complex		+	+	+	+	+4	+	+	+	⊕	+4	+	+	+	+	+	+5	+13
(c) Logical order		+	+		+	+3		+	+	+	+3	+	+		+	⊕	+4	+10
(d) Easy to understand		+	+	+	+	+4	+	+		⊕	+3	+		+		+	+3	+10
(e) Well focused				+	⊕	+2		+	+	+	+3	+	+	+	+	⊕	+5	+10
(f) Identified critical areas		+		+	⊕	+3		+	+	+	+3	+	+		+	⊕	+4	+10
(g) Related previous knowledge				+	+	+2	+	+	+	+	+4			+		+	+2	+8
(h) Cued important relationships			+		⊕	+2	+		+	+	+3					⊕	+1	+6
(i) Motivating kept interest		+		+	⊕	+3			+	+	+2			+		⊕	+2	+7
(j) Built confidence		+	+		⊕	+3	+	+		⊕	+3	+				⊕	+2	+8
(k) Highly visual		+	+		+	+3		+		⊕	+2	+				⊕	+2	+7
(l) Used arrows		+	+		⊕	+3		+	+	⊕	+3	+			+	⊕	+3	+9
(m) Bold face/underlined		+		+	⊕	+3	+	+		⊕	+3	+				⊕	+2	+8
(n) Redundancy of procedural information		–			+	−1, +1		–		0	−1	+	–	–		⊖	−3, +1	−5, +2
(o) Repetition with divergence		+		+	⊕	+3		+		+	+2	+			+	+	+3	+8
(p) Explained theoretical information and then pulled together in procedural information			+		⊕	+2	+		+	⊕	+3		+	+		⊕	+3	+8
(q) Categorized conditions		+		+	⊕	+3		+		⊕	+2		+		+	⊕	+3	+8
(r) Labeled condition		+		+	⊕	+3		+		⊕	+2		+		+	⊕	+3	+8
(s) Pertinent conditions		+		+	⊕	+3		+	+	⊕	+3		+	+		+	+3	+9
(t) Categorize by underlying principles			+	+	⊕	+3	+			⊕	+2	+	+	+		⊕	+4	+9
(u) Interpretation of problem and solution of problem			+		⊕	+2	+		+	+	+3			+		⊕	+2	+7
(v) Easy to calculate numbers			–	–	–	−3		–	–	⊖	−3	–				⊖	−2	−8
(w) Gave impression that you know it all		–			⊕	−1, +1				⊕	+1					⊕	+1	−1, +3
(x) Too simple										–	−1							−1

Where: + = liked, – = disliked, and blank = neutral to a solicited response. Responses enclosed by a ○ were solicited.

relationships (+6; row h), motivating the student (+7; row i), and building confidence (+8; row j). Noteworthy attributes (rows k through m) were high visualization, prominent use of arrows, and use of bold face. Responses were from nearly equal distributions of ability levels.

It is noteworthy that students commented that the simple circuits of the Down to the Basics (epitome) allowed them the opportunity to learn procedural and theoretical information in a focused manner without extraneous detail (row e). These responses came predominantly from the high-ability-level group. Students felt that the categorizations of conditions that started with the Down to the Basics gave them the ability to concentrate (focus) on a low complexity of circuit analysis and become competent within that condition before progressing to more complex circuits.

Of the 13 students, 5 did not like the redundancy of procedural information (row n). These students did not like to read the "same steps" of the different levels of procedural information. However, two students liked it. (The remaining six students made no comments about it.) This issue will be addressed in the improvement table. However, eight students felt that the reiteration process of instruction at the macro-level was important to them for learning to occur (row o). These students commented that going over problems with the same condition, but with divergence within a level of complexity of circuit analysis, helped learning occur (e.g., the voltage divider rule can be used for a simple series circuit and can also be used for series elements in a series/parallel circuit).

Eight students liked that the theoretical information was explained and, then, the prominence and utility of the theory was illuminated by the procedure (row p). These theories are used in every circuit analysis problem (e.g., these theories can be used for more than just problem solving—they are also used in the verification of answers).

Eight students commented that categorization of conditions (e.g., a short in a series circuit with multiple voltage sources, a parallel circuit with an open, etc.), when presented in a simple-to-complex sequence, helped them develop a strategy to determine a solution (row q), particularly in more complex circuitry. The same eight students found the labeling of conditions appealing (row r). The labeling of the conditions was provided for each generality, example, and practice. The labeling of the condition was not deliberately intended, and was not a part of the elaboration theory, but occurred accidentally. The button for the menu for the generality, example, and practice was labeled with the condition. Students would depress the button and a menu would appear, allowing them to pick the strategy component that they desired. However, students also used the button as a label for the condition. The label was on each card of every generality, example, and practice exercise with the name of the condition. Students commented that the labeling of the condition allowed them to relate the condition with the theoretical and procedural information. As the sequence continued and the circuitry became more complex, students could interpret the circuit according to the condition and apply the knowledge previously gathered. They commented that they could then categorize the condition of the circuit and apply the appropriate principles to analyze the circuit.

Nine students commented that the instruction helped them understand principles and the conditions for which these principles could be applied (row s). In certain instances it is not enough to know theoretical information, but it is requisite to understand for which conditions the theoretical information is appropriate. This positive finding is probably a strong influence of multiple-strand sequencing (i.e., sequencing of procedural and theoretical knowledge). In row t, nine students commented that the sequence allowed them to categorize the problem according to underlying principles (i.e., need to understand Kirchhoff's voltage law to determine the unknown voltage, or that a portion of a circuit is series, therefore, the voltage divider rule can be used to find the voltage drop across R_3).

Seven students commented that the macro-level sequencing (row u) helped develop a better interpretation of the problem. In real-world circuit analysis, complex problems have extra-

Table 6 ☐ Qualitative Data Inventory: Improving the Elaboration Theory of Instruction

Ability	Low					Average					High						
Tactics/Strategies Comments: Group N	Phase 1 1	Phase 1 2	Phase 1 3	Phase 2 1	Low Sub Total	Phase 1 1	Phase 1 2	Phase 1 3	Phase 2 1	Avg. Sub Total	Phase 1 1	Phase 1 2	Phase 1 3	Phase 1 4	Phase 2 1	High Sub Total	Comb. Total
Sequencing:																+2	+6
(a) Steps of the procedure that change from previous procedure are underlined.	+			⊕	+2		+		⊕	+2				+	⊕		
Inform students that underlined steps are different from previous steps of procedure.																	
Inform students that non-underlined steps are the same as previous procedure.																+2	+5
(b) Describe why the steps are different from one process to the next.	+			⊕	+2				⊕	+1				+	+	+1	+7
(c) Easy to calculate numbers		+	+	+	+3		+	+	⊕	+3					⊕	−1	+1, −3
(d) Induce uncertainty	+			⊖	+1, −1				⊖	−1					⊖		

Where: + = liked, − = disliked, and blank = neutral to a solicited response. Responses enclosed by a ○ were solicited.

neous information, and part of the task is to learn to differentiate what information and knowledge are needed and what are not needed to solve the particular problem. Simple examples and practice problems did not have extraneous information, while complex examples and practice problems did. The sequence allowed for levels of extraneous information to be presented. This process of slowly adding extraneous information and knowledge to the sequence allowed students to better handle this type of complexity. Therefore, the sequence helped students develop the ability to distinguish the information and knowledge needed to solve a problem from nonessential information and knowledge.

Furthermore, students felt that the simple-to-complex sequence provided insight into the relationship between the interpretation of the problem and the solutions of the problem (row u); it allowed students to interpret the problem at a simple level (the epitome) and then progress to more complexities.

There were certain aspects of the epitome that certain students did not like (rows v and w). As illustrated in row v, eight students, with nearly equal distribution of ability groups, did not like examples that used numbers that complicated the calculations (e.g., 20 volts/4 ohms = 5 amperes rather than 524 millivolts/614 kilo ohms = 853 nanoamps). Also, in row w, one lower-ability student commented that the epitome gave him the impression of being knowledgeable in an area, but as he progressed through the instruction, he discovered he needed to have a richer sense of knowledge (more detailed knowledge base). The epitome gave him a sense that he knew it all when he did not. One average-ability student (row x) commented that two of the epitomes were too simple. As the student progressed through more of the instruction, she commented that learner-control could be used to help facilitate the proper entry level for each student.

Improvements

All of the following suggestions for improving the Elaboration theory of Instruction are offered provisionally, depending on whether or not the findings of this study prove to be valid and generalizable, as revealed by future replications or extensions of this study. Table 6 shows the suggested improvements for the ETI. A plus (+) sign indicates that a student suggested that an improvement should be made in that tactic or strategy. Rows a and b address the dilemma of when a condition is relaxed and the procedure is modified. Some of the steps of the procedure changed to reflect changes in the condition, but other steps of the procedure remained the same from one condition to the next. For those steps that remained the same, the students were forced to repeatedly read those same steps for each new condition. Some students felt that they wasted time determining the differences between the procedure for the new condition and that for the previous condition.

The implications for changes in ETI are that procedural information should be organized so that students can use the method that works best for them, that is, the instruction should be structured so that the student can choose to either read or not read the identical steps for the different conditions. The instruction should compare and contrast the steps between the previous procedure and the current procedure. The instruction should identify the condition and tell what steps were the same and what steps were different, and why.

Seven students suggested that examples and problems in the epitome should use numbers that are easily computed (row c). This approach would allow students to concentrate on the underlying principles and procedures, rather than being burdened with the complexities of the math. This would be a relevant concern for any subject or problem domain that involves computations. The data suggest that epitomes are quite effective in the learning process and should continue to be used within the ETI. Another implication (row c) is that the epitome should be focused on the principles and procedures that are being epitomized. The epitome should allow the student's cognitive processes to be focused on theoretical and procedural knowledge, rather than on the complexities of the computation.

One lower-ability student desired the instruction to induce a sense of uncertainty, but to give a clear indication of how to progress from the epitome with minimal effort (row d). Upon realizing that there was more to learn than the knowledge at the epitome level, the student thought that the epitome allowed the opportunity to build confidence. There seems to be a delicate balance between simplifying the content too much so that the student becomes overconfident, and not simplifying it enough so that the student lacks sufficient self-confidence.

The instruction informed students of the simple-to-complex sequence, but attention-focusing devices were not used to draw the students' attention to this fact. Nor were attention-focusing devices used to prompt the student to use learner-control, as needed, to omit easy material.

The implication for ETI is that the epitome needs to be designed to inform students of the simple-to-complex sequence (by using attention-focusing devices), and students need some way (such as using learner-control) to enter at the most appropriate level.

In summary, the qualitative research results clearly indicate the strengths of the theory, and methods or tactics that should be added and/or modified. None of the information collected reflects that certain elements should be deleted. Weaknesses are composed of two categories of tactics or methods: those that should be added (methods or tactics that should be included in the theory but are not) and those that should be modified and/or enhanced.

Quantitative Results

Quantitative data (i.e., posttest scores, ability, phase participation, sex, GPA, SAT, age) were numerically coded and entered into a system file for analysis using the Statistical Package for the Social Sciences (SPSS).

Each of the 13 students took three tests. The high-ability group achieved a mean of 95.0 (SD = 5.8); the average-ability group achieved a mean of 93.7 (SD = 5.9); while the lower-ability group achieved a mean of 84.1 (SD = 10.0). The overall mean was 91.8.

These scores appeared to be higher than normal for this course, and as a matter of curiosity, we explored how these scores compared to the mean scores of previous students (scores on a similar criterion-referenced test on the same subject matter). The mean score was 77.3% for 189 students who took three similar tests during the previous two years. Although these data do not represent a controlled comparison, it appears that these students did indeed perform better than previous students (91.8% compared to 77.3%). Nevertheless, the intent of this study was not to compare instruction designed according to ETI to instruction designed without ETI, but to gain insights into ways to improve ETI.

The summary data from the attitude survey are presented in Table 7. The table is arranged so that ability groups are separated into phase participation. The number of students who participated in a group and from an ability level is indicated above each column. In general, the attitude results support the qualitative statements made by the students in that they liked the instructional unit (1.62), liked the sequencing (1.46), liked the epitome (1.46), liked the synthesizers (1.62), liked the summary (1.46), felt that it was not too difficult (4.31), felt that it was well-organized (1.46), felt good about the instructional unit (1.62), liked the analogies (1.69), and felt it was appropriately related (1.31). Overall, ETI was reacted to comparably by low, average, and high ability students.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study, we offer conclusions and recommendations about the formative research methodology, ETI's sequencing guidelines, and ETI's epitomes.

The Formative Research Methodology

In general, the formative research methodology seems to have been effective for accomplishing its purpose: finding possible strengths, weaknesses, and ways to improve the ETI. One of its strengths was the wealth of data that were collected about possible ways to improve the theory. The most significant information-gathering techniques were the impromptu questions asked during the interactive phase (Phase 1) and the debriefing questions asked at the end of both the interactive and noninteractive phases. In addition, the qualitative summary tables (Tables 1 and 2) proved to be valuable tools for data analysis and appeared to be an effective method for presenting the data.

Sequencing

The following are tentative conclusions and recommendations for improving the ETI's sequencing guidelines, subject to verification by future replications or extensions of this study.

1. If the instruction is for procedural information, compare and contrast the steps between the previous procedure and the current procedure. The instruction should distinguish what steps are the same and what steps are different, and should inform students of why the steps are different. Allow students the choice to either read or not read the identical steps of procedural information for the different conditions.
2. Provide a label for each condition. This feature would allow students to relate the condition with the theoretical or procedural information and would give them the ability to categorize the problem according to appropriate underlying principles. It would also allow students to use learner control more easily. For example, when a student is working through instruction and needs to refer to an example from a previous condition, the student could use a label to locate that condition.
3. If the instruction involves problem solving, then students need to be able to differentiate information or knowledge that is needed from what is not needed to solve particular problems. Slowly adding extraneous information and knowledge during the sequence allows students to better acquire this capability.
4. The reiteration process at the macro level is important. Going over problems with the same condition, but with divergence within a level of complexity, helps learning to occur.

Apparently, a significant strength of ETI was in sequencing. ETI's multiple strand sequence, comprised of the theoretical elaboration sequence and the procedural SCM sequence, appears to be a very powerful tool in helping students to understand difficult theories and procedures, and it seems to constitute a most appealing element of the instruction. The use of sequencing from simple-to-complex appears to benefit all ability groups.

Table 7 □ Attitude Survey Group Means Summary

	Ability	*Low*		*Average*		*High*		*Total*
Attitude Survey Items	*Group* / *Number of Students*	*Phase 1* $N = 3$	*Phase 2* $N = 1$	*Phase 1* $N = 3$	*Phase 2* $N = 1$	*Phase 1* $N = 4$	*Phase 2* $N = 1$	$N = 13$
1.	Liked the instruction	1.67	2.0	1.67	1.0	1.75	1.0	1.62
2.	Liked the sequencing	1.67	1.0	1.33	1.0	1.75	1.0	1.46
3.	Liked the epitome	1.33	1.0	1.33	1.0	1.75	2.0	1.46
4.	Liked the synthesizers	2.00	2.0	1.33	1.0	1.50	2.0	1.62
5.	Liked the summary	1.67	1.0	1.33	1.0	1.75	2.0	1.46
6.	Too difficult	4.00	4.0	4.33	4.0	4.50	5.0	4.31
7.	Well organized	1.67	1.0	1.67	1.0	1.50	1.0	1.46
8.	Felt good about the instruction	2.00	1.0	1.67	1.0	1.75	1.0	1.62
9.	Liked the analogies	2.00	1.0	1.67	1.0	1.75	2.0	1.69
10.	Appropriately related	1.33	1.0	1.67	1.0	1.25	1.0	1.31

Scale used was: 1 = Strongly Agree; 2 = Agree; 3 = Undecided; 4 = Disagree; 5 = Strongly Disagree

Epitome

Epitomizing involves teaching a small number of skills at the application level. It differs from an advance organizer (Ausubel, 1968) in that it deals with acquiring the ability to use a complex cognitive skill rather than with developing an understanding. Epitomizing also differs in that it entails learning a simple version of the skill itself rather than acquiring or activating an understanding that is at a higher level of generality and inclusiveness than the understandings of interest. The following are tentative conclusions and recommendations for improving this aspect of the ETI.

1. Present an epitome to highlight important relationships and relate previous knowledge. Epitomes should be focused and easy to understand, so all of the student's cognitive processes may be focused on them. Eliminate complexities that do not enhance the student's concentration on the fundamental theoretical or procedural skills. Strip away extraneous factors so that students can focus or concentrate on the underlying principles or procedures, rather than burdening them with extraneous complexities (e.g., performing mathematical computations and segregating essential information from nonessential information).
2. Inform students that the epitome is entry-level, fundamental information and that complexities will be added in layers. Inform students that knowledge at the epitome level is not sufficient to solve problems at the more complex levels. Label the instructional material as the epitome (or some suitable synonym).
3. The epitome should not be so simple as to make students overconfident. The designer might consider directing students to use learner-control if the material is too simple for them, but it is cautioned that low-ability students tend to overestimate their knowledge, and that research on learner control has revealed important problems that must be avoided or overcome for it to be effective (Steinberg, 1989).
4. The epitome appears to be quite effective in the learning process. It allows students to learn highly representative procedural and theoretical material in a focused manner without extraneous detail.

In conclusion, the elaboration sequences were clearly both effective and appealing to the students involved in this study, which provides some evidence that the ETI may be both effective and appealing in its current state of development. But more importantly, some ways were found to improve the sequences that were used in this study, and they may well reflect ways to improve the sequencing prescriptions of the ETI. Further research is needed to corroborate and extend these findings. □

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APPENDIX A ☐ DEBRIEFING QUESTIONS

1. What did you like about the material?
2. What did you not like about the material?

   (Please be very critical so that others can benefit from your experience.)
3. What did you find useful?
4. What did you find that was difficult to understand or follow?
5. What did you like about the lesson introduction?
6. What did you not like about the lesson introduction?
7. Tell me what you thought about the sequencing of the material.
8. What did you find useful about the sequencing of the instruction?
9. What did you not like about sequencing of the instruction?

   (Please be very critical so that others can benefit from your experience.)
10. What did you find specifically useful about the "Down To The Basics" section (the epitome)?
11. What did you not like about the "Down To The Basics" section (the epitome)?
12. What did you find specifically useful about the "Putting it all together" section (the synthesizer)?
13. What did you not like about the "Putting it all together" section (the synthesizer)?
14. What did you find specifically useful about the analogies?
15. What did you not like about the analogies?
16. What did you find specifically useful about learner-control (i.e., ability to bypass simpler examples for more difficult examples, ability to go from practice exercises to examples, etc.)?
17. Was there anything that you did not like about learner-control?
18. What did you find specifically useful about the summaries?
19. What did you not like about the summaries?
20. What did you find that was difficult to understand or follow in the topic?

    Why?
21. How would you improve the instruction?
22. Would you change anything to make it easier for you to understand?
23. Do you feel that you understand the material? Which aspects of it are still confusing?
24. What would you consider to be the strengths of the unit?
25. What are the weaknesses of the unit?
26. What would you consider to be the most appealing aspect of the unit?
27. What would you consider to be the least appealing aspect of the instruction?
28. Was the length appropriate?
29. Was this a tedious exercise for you to do?
30. Did any of the lesson material feel inappropriately sequenced?
31. Did this instruction appear to be more efficient than most instruction?
32. Are there any other suggestions or comments that you would like to make at this time?