Components of Instruction

Toward a Theoretical Tool for Instructional Design

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Abstract

This article defines primary knowledge components for entities, actions, and processes. It also defines primary instructional strategy components. It proposes that a different combination of strategy and knowledge components is required for different kinds of instructional goals. It further proposes that if these fundamental strategy-knowledge component combinations are not present that there will be a decrement in the student's effective and efficient acquisition of the desired knowledge and skill. It further proposes that the underlying architecture of an instructional strategy is a combination of primary strategy components and primary knowledge components appropriate for, and consistent with, a given instructional goal.

Instructional components are a theoretical tool. They are not a method or development procedure. These instructional strategy and knowledge components can be imbedded in a wide variety of different instructional architectures based on a variety of different philosophical orientations. It is hoped that one of the primary benefits of instructional components is to provide a common vocabulary that will enable designers, theorists, and instructional developers to more clearly describe their products and procedures.

Key words

Instructional component, knowledge component, knowledge object, entity, activity, process, property

Introduction

> "The cutting edge of science is reductionism,
> the breaking apart of nature into its natural components." (Wilson, 1998, p. 54)
>
> "In scientific knowledge the purpose is understanding nature; in engineering science the ultimate goal … is the creation of artifacts" (p. 135). Engineering science is … putting together these elements [fundamental scientific laws with design procedures] in an organized and purposeful way" (p.134). The purpose of engineering science is the development of theoretical tools for design. (Vincenti, 1980)

This article is an attempt to define such a theoretical tool for instructional design.

Vincenti (1980) indicates three primary factors that promote the design of theoretical tools in engineering: The first is teaching **--** a search for improved ways to organize the resulting knowledge. A second is economy **--** a search for design processes that are feasible with limited resources of time, money and manpower. The third is accuracy **--** a search for ways to avoid mistakes resulting from human error, lack of imagination, or blind ignorance. These same factors motivate the work described in this article.

Teaching requires an understanding of the phenomena being taught. Understanding is facilitated by an unambiguous vocabulary for describing the phenomena. Teachers of instructional design are engaged to find ways to help novice designers acquire the skills they need to develop effective, efficient and appealing instructional products. Effective teaching of instructional design will be facilitated if there is an agreed vocabulary for describing instructional phenomena. The work described here is an attempt to define such a vocabulary.

A recurring problem in engineering is that there is never enough time and never enough resources to do it right. Business demands training materials yesterday. Many of the current tools for developing technology-based training materials require considerable time to learn and even more time to use. Too often in the search for efficiency there is a corresponding loss of instructional quality. A second goal of instructional science is the search for tools that are significantly more efficient to use while at the same time promoting an improved quality in the product. The use of an agreed vocabulary assists in the development of more efficient instructional design tools.

In formal education the application of knowledge is often far in the future and the consequence of inaccurate knowledge may never be felt. In industry, on the other hand, an inadequately or inappropriately trained employee inevitably results in loss in customer satisfaction, loss in revenue, and sometimes accidents resulting in injury or loss of life. In training situations, effective instruction that enables the trainee to acquire the desired skills is a must. Having a common vocabulary can assist in the development of instructional products that are more effective and efficient in helping learners acquire the necessary knowledge and skill.

Vincenti (1980) identifies four stages in the development of an engineering innovation: (a) The accumulation of ad hoc solutions to individual problems, (b) the development of theoretical tools for analysis and synthesis, (c) the completion and generalization of the theoretical tools, and (d) the diffusion of the theoretical tools.

The field of instructional technology is, for the most part, still involved in the first phase. There are many individual solutions but few general theoretical tools that are widely accepted to facilitate the design process. The purpose of this work is an attempt to move to the second phase of engineering innovation by specifying a theoretical tool that will assist in the analysis and synthesis of instructional solutions.

In any design task, "Designers bring with them fundamental concepts about the device in question. … Designers must first know … the operational principle… how the device works. … A second thing the designer takes for granted is the normal configuration … the general shape and arrangement that are commonly agreed to best embody the operational principle." (Vincenti, 1980, p. 208)

Clark (1998) suggested four instructional architectures (four different operational principles) for instructional products: receptive, directive, guided discovery, and exploratory. "These architectures embody different assumptions [operational principles] about how learning happens, the role of the instructor or instruction, and the final goal of the instruction" (Clark, 1998, p. 4). These four architectures (operational principles) are described as follows:

> "***Receptive***: A good metaphor for this architecture is that the learner is a sponge, and the instruction pours out knowledge that the sponge absorbs. … Learners typically have little control over the information: over its sequence, over its level of detail and, in lectures and most video, over its rate of delivery." (Clark, 1998, p. 4)
>
> "***Directive***: … The instruction sequences and chunks the knowledge and provides frequent opportunities for learners to respond. Their response brings immediate corrective feedback." (Clark, 1998, p. 4)
>
> "***Guided Discovery*****:** … The instruction provides learners with problems … adapted from the actual work setting. …The instructor's role is like that of a coach and facilitator helping learners (…) to obtain the knowledge and skills they need to solve the problems." (Clark, 1998, p. 5)
>
> "***Exploratory***: … There is maximum learner control … learners are provided a rich, networked database of information, examples, demonstrations and exercises. From this database they can select whatever is appropriate to their current needs and mental models." (Clark, 1998, p. 5-6)

In this article components of instruction are defined. Two classes of instructional components are identified: knowledge components and strategy components. These instructional components are an attempt to identify a descriptive theoretical design tool. This theoretical tool is most appropriate instruction based on the operational principles of directive or guided discovery instruction and a normal configuration that includes presentation, practice and learner guidance.

Instructional design is an engineering activity for which the artifact created is some instructional product designed to help a learner acquire some knowledge or skill. An instructional design theory is a set of prescriptions for designing this instructional product. The theoretical tool described in this article defines a vocabulary for identifying the knowledge and strategy components that comprise an instructional theory. This theoretical tool, in and of itself, is not an instructional design theory but defines instructional components that can be used to more precisely define instructional prescriptions. The hope is that these instructional components can be used to build instructional design prescriptions or instructional design theory.

Instructional design requires two major activities: Determine what to teach? Determine how to teach? Determining what to teach requires the process of knowledge[1] analysis. The reference here is not to the broad questions of curriculum but rather to the micro decisions wherein a designer must select from all the knowledge that is available those specific components of knowledge and their sequence that will comprise the instructional materials. Too often instructional designers leave these important what-to-teach decisions to so-called subject-matter-experts (SME). Often a SME knows how to perform the task that is the goal of instruction but is unaware of the knowledge components that are required to acquire this knowledge and skill. A primary role of the instructional designer is to determine these granular knowledge components and their sequence.

Determining how to teach is the instructional strategy that will be used to assist the student in the acquisition of the desired knowledge and skill. Designing an instructional product involves many decisions including a choice of delivery system and the social context (collaborative or individual) of the instruction. However, for this paper the concern is with the underlying presentation, practice, and learner guidance, that is, the micro-strategies that must be present if the instruction is to be maximally efficient, effective, and appealing regardless of the delivery system or social context of the instruction. The intent of this article is that these micro-strategies can be applied in a wide variety of delivery systems and in either collaborative or individual learning environments.

Preliminary to any instructional design theory (prescriptions for designing instructional products) there must be some definition of the components that will be included in these prescriptions. The real world is far too complex to consider everything. A major activity of science or engineering is to determine those components that should be considered in the prescriptions and those that should be ignored. In other words, of all the ways that there may be to analyze knowledge, which knowledge components should be considered and which should be ignored? Of all the various ways to present information to a student or to solicit learning responses from a student (strategy components), which should be considered and which should be ignored?

Components of instruction, as a theoretical tool, specifies those components of knowledge and those components of instructional strategy that are thought to be critical for specifying instructional prescriptions. These knowledge and strategy components can then be used to state a wide variety of instructional propositions that can then be empirically tested. If instructional designers can agree on the components that should be considered, the terms that should be used to identify these components, and the definition of these terms, then it is possible to more precisely state and test instructional prescriptions (instructional theory).

Except for the identification of the operational principles and normal configurations stated above, components of instruction are neutral as to philosophical orientation. The knowledge and strategy components identified are neither behaviorist nor constructivist. The attempt is to be neutral and descriptive. However, instructional prescriptions that are then stated using these components may indeed favor one philosophical orientation over another.

Knowledge Components[2]

Almost all subject matter content can be represented as entities (things), actions (procedures that can be performed by a student on, to, or with entities or their parts, processes (events that occur often as a result of some action), and properties (qualitative or quantitative descriptors for entities, actions, or processes). The knowledge required to learn about entities, actions, or processes can be represented by a collection of knowledge components which we call a knowledge object. In this paper we will define the knowledge components that comprise these knowledge objects. A knowledge object is a framework consisting of containers for different kinds of specific information (the knowledge components). Each knowledge component is a container for a specific kind of information about the subject matter being taught. This knowledge framework is the same for wide variety of different topics within a subject matter or for knowledge in different subject matter domains. The following paragraphs define knowledge components for knowledge objects.

Knowledge objects include knowledge components that: (a) name, describe, or illustrate some entity; (b) name, describe, or illustrate the parts of an entity; (c) identify properties of an entity, part, action, or process; (d) identify actions associated with the entity; (e) identify processes that modify the entity; and (f) identify kinds of entities, actions, or processes. Table 1 identifies each of these knowledge components and the following paragraphs define each knowledge component.

Entity: Name Description Portrayal	**Part**: Name Description Portrayal	**Property**: Name Description Value Value portrayal
Action: Name Description Process trigger	**Process**: Name Description Condition (value of property) Consequence (property value changed) Process trigger	**Kind:** Name Description Definition (list of property values)

Table 1 Major Components of a Knowledge Object[3]

Some name or symbol identifies every entity (thing), action, process, or property. A given knowledge component may have several different names.

The description component is a default category in which the author can put information about an entity, a part of an entity, the property of an entity, an action associated with some entity or set of entities, a process associated with some entity or set of entities, or a class (kind) of entities, actions, or processes. For a given knowledge component there may be several different classes of information available, hence the description category may be subdivided into several sub components.

A portrayal is how the student senses the component. A given portrayal may be symbolic, verbal, graphic, video, animation, audio, olfactory, or kinetic.

A property has a set of legal values that it can assume. These values may be discrete or continuous. Each of these values also has a portrayal that may change the portrayal of the entity, action, or process.

An action usually serves as a trigger for a process, hence one component of an activity is a pointer to the process that it triggers.

A process has one or more conditions. If the conditions are true the process executes, if one or more of the conditions are false then the process will not execute. A condition is defined as a value on some property. If the property has the specified value, then the condition is true and the process executes. If the property has some value other than the specified value, then the condition is false and the process does not execute.

A process always results in some consequence. The consequence is defined as the change in the value of one or more properties. When the property is changed then the portrayal of that property is also changed usually resulting in a change in the entity that on which the process operates.

A process can trigger another process, thus resulting in a chain reaction. One component of a process is a pointer to the next process or processes in the chain.

One of the unique capabilities of human beings is the ability to conceptualize or to place entities, actions, and processes into categories. This capability seems to be part of the neural equipment furnished to human beings. One component of a knowledge object is a list of different category names that may be used to describe the varieties of the primary entity of the knowledge object. In a knowledge object a definition is identified as the name of the super-ordinate category (often the name of the principal entity of the knowledge object), a list of discriminating properties by which an instance in one category is distinguished from another instance in a different category. And the value of each discriminating property that defines a given class.

Knowledge object for the topic sentence

Table 2 is a partial knowledge object for a sentence. The table indicates the components included in the left column, the name for the knowledge being described by the knowledge object in the second column, and either the description of the component or the legal values of the property in the third column.

Component	Name	Description
Name	Sentence	"expresses a complete thought"
$Part_1$	Subject	"tells whom or what the sentence is about"
$Part_2$	Predicate	"tells something about the subject"
		Legal Values
$Property_1$	Purpose	makes a statement asks a question makes request expresses emotion
$Property_2$	Punctuation	Period (.) question mark (?) exclamation point (!)

Insert Table 2 Knowledge Object for the topic Sentence about here

Knowledge base for the topic sentence

A *knowledge base* is the set of portrayals (examples or illustrations) of the content to be taught. A knowledge base includes a number of different instructional objects each of which provides a specific portrayal (representation) or value for each of the components of the knowledge object. Each record in the knowledge base provides another portrayal (example) of the entity of the knowledge object. Table 3 illustrates a partial knowledge base for the knowledge object sentence. In this knowledge base the portrayals are verbal. Portrayals of knowledge components in a knowledge base may also be graphic, video, audio, or any other form of representation.

	Sentence	Subject	Predicate	Purpose	Punctuation
1	The smell of a wood stove makes me think of camping.	The smell of a wood stove	makes me think of camping	statement	(.)
2	What a terrific show we saw!	we	What a terrific show … saw	emotion	(!)
3	On Saturday night will you stay at a friend's house?	you	On Saturday night will … stay at a friend's house	question	(?)
4	Please take the mail when you go.	you	Please take the mail when … go	request	(.)
n	A complete knowledge base would contain many more examples.				

Table 3 Knowledge-base portrayals for the knowledge object sentence

Instructional Strategy Components

Instructional strategies typically involve at least two phases: a presentation/demonstration phase and an application/practice phase. It is generally recognized that there are at least two levels of information: general and specific. General information consists of information about an entity, definitions identifying categories of objects, a list of steps in a procedure, or a list of events in a process. Specific information consists of examples and nonexamples of a concept, a demonstration of how to perform a specific procedure, or a visualization illustrating the execution of a specific process.   Two presentation components are identified -- TELL and SHOW. Merrill (1994) previously used the terms Expository Generality (EG) and Expository Instance (Eeg). TELL and SHOW are less esoteric terms but may suffer from considerable excess meaning. TELL is used to present general information to the student -- to tell information about, tell a definition, to tell the steps in a procedure, or to tell the events in a process. SHOW is used to demonstrate specific information -- to show the instance of a concept, to show a demonstration of a procedure, or to show a visualization of a process.

Everyone knows the axiom "practice makes perfect!" In areas like musical or athletic performance no one would ever expect a student to be proficient without considerable practice. In many areas of the curriculum, however, many designers seem to have forgotten this axiom and seem to believe that SHOW and TELL is sufficient. Research consistently shows that if students are to acquire skill they must have the opportunity to practice this skill. When their performance is not sufficient they must be provided with appropriate guidance or coaching until they have gained sufficient proficiency for the tasks at hand. Two practice components are identified -- ASK and DO. ASK is appropriate when we want the student to recall the general information that was presented -- remember information about, remember a definition, remember the steps in a procedure, or remember the events in a process. DO is appropriate when we want the student to be able to use their knowledge or demonstrate a skill in a specific situation. DO requires the student to analyze an instance to find the properties that determine its class membership (classification), to perform a procedure, to interpret a process by predicting a consequence or by finding faulted, missing, or inadequate conditions. Dijkstra (1997) discusses DO activities as solving problems of categorization, problems of interpretation, or problems of design.

Too much current instruction is TELL & ASK when it would be more effective if it included SHOW & DO. Some recent approaches to instructional design emphasize DO but neglect to include adequate SHOW. Effective instruction almost always involves all four of the primary strategy components.

Primary strategy components do not represent all of the instructional strategy components necessary to design effective and efficient instruction. A complete instructional transaction will also include instructional components for sequence and for learner guidance. In this paper we have concerned ourselves only with knowledge components and the primary instructional strategy components: TELL, SHOW, ASK, and DO.

Sample instructional transactions described using instructional components.

An instructional transaction has been defined as "… all those activities necessary to promote the acquisition of a particular mental model [or all of the knowledge represented by a knowledge object]" (Merrill, et al, 1990, p. 8). The premise of this paper is that an instructional transaction can be more precisely described in terms of the knowledge and strategy components identified in this article. An instructional transaction requires the appropriate combination of knowledge components with strategy components. An instructional transaction is defined by a combination of primary strategy components and knowledge components appropriate for, and consistent with, a given instructional goal. In the remainder of this paper we will illustrate the use of instructional components to describe some simple instructional transactions: a parts-of transaction, a kinds-of transaction, and a how-to/what happens transaction.

The applications of instructional components presented as sample instructional transactions in this paper are based on the assumption of Gagné (1965, 1985) that there are different kinds of learning outcomes (goals) and that each of these different learning outcomes require unique conditions (micro-strategies) for learning. Our purpose here is to demonstrate how instructional components are used to describe particular kinds of instructional prescriptions (transactions). The parts-of transaction and the kinds-of transaction represent a directive architecture (Clark, 1999) and consequently a particular theoretical orientation. The how-to/what-happens transaction represents a guided discovery architecture (Clark, 1999) and consequently a different theoretical orientation. The reader should note that while the prescriptions represented by these sample instructional transactions do represent particular philosophical orientations, the same instructional components are used to describe these transactions and are neutral with respect to that orientation.

Parts-of Instructional Transaction

Knowing the parts of an object is prerequisite for many other instructional tasks such as recognizing an entity, classifying different kinds of an entity, performing a procedure in which the steps are stated in terms of parts, or interpreting a process. In this simple parts-of transaction the goal is for the student to be able to identify the location of a part given its name or description, or given its location recall its name or description.

Table 4 indicates the knowledge and strategy components thought to be required for an effective and efficient directive instructional strategy for teaching parts.

TELL	SHOW	ASK	DO
part name part description	entity portrayal part portrayal	part name part description	point to portrayal

Table 4 Knowledge and strategy components for a parts-of transaction

The reader should be aware of few things that the above table and the tables for the following example are not. They are not a complete set of prescriptions for designing a transaction. They are not an instructional method. They merely identify the primary strategy and knowledge component combinations that should be included in a transaction if it is to enable the student to acquire the ability to acquire the skill taught by the transaction. These components can be combined in a number of different ways to provide an effective transaction. These different approaches may conform to different theoretical positions. Our sample parts-of transaction is based on a directive architecture (Clark, 1998).

In the following examples the numbered items indicate the instructional steps in the transaction. Each of these numbered steps are stated in terms of the strategy and knowledge components defined earlier in this article. The emphasis in this paper is on the primary strategy components. For the purpose of a more complete presentation of these transactions some additional strategy conditions are sometimes stated following the formal transaction step. This is followed by a sample piece of content from a transaction presenting the knowledge object for a sentence.

1. SHOW entity portrayal.

   What a terrific show we saw!

2. SHOW part portrayal and TELL part name and/or description.

   (Note that the name and/or description could be auditory or verbal. An attention focusing device (underline and font style) is used to focus the student's attention on the part under consideration. A guidance condition would suggest that the student should point to the part to continue to insure that the student is attending to the part and associating it with its name and description.)

   What a terrific show <u>**we**</u> saw!
   The <u>**subject**</u> shown <u>**bold and underlined**</u> tells whom or what the sentence is about.

   Repeat for each of the parts to be taught. (The "magic number seven" learner guidance condition would suggest that the number of parts considered together should be limited in number.)

   <u>*What a terrific show*</u> we <u>*saw*</u>!
   The <u>*predicate*</u> shown in <u>*italics and underlined*</u> says something about the subject.

3. SHOW the entity with the part portrayal highlighted. DO direct the student to provide the name and/or description of the highlighted part.

(A guidance condition would suggest the parts be presented in random order. Short answer, multiple choice, or matching format could be used. A guidance condition would suggest that the answers be located to avoid location cues for the student. A guidance condition would suggest correct answer feedback as appropriate immediately after each response during practice.)

The smell of a wood stove makes me think of camping.

Check the name of the underlined part. [ ] subject [x] predicate

4. TELL the student the correct answer (correct answer feedback.)

   The subject is underlined, not the predicate.

5. SHOW a portrayal and the name and/or description of a part and DO direct the student to point to its portrayal.

   Underline the predicate in the sentence.
   On Saturday night will you stay at your friend's house?

   Repeat until the student has named each of the parts in both directions at some criterion level. (A guidance condition would suggest immediate response and 100% criterion. Guidance conditions would also suggest distributed practice and repetition here.)

Exploratory instruction might take a different format.

1. SHOW entity portrayal.
2. DO, allow the student to explore parts by clicking on their portrayal to be told the parts name and/or description.

   (An explore condition would have an advisor function suggest continued exploration if a student had not seen all the parts.)

3. Practice would be as above.

Parts-of instruction could be collaborative, combined with a problem or case, or embedded in transactions teaching some more complex task. A teacher, the instructional system, another student, or some resource can provide the tell-mode of the instruction. A teacher, the system, or another student can also provide correct answer feedback to the student. The emphasis of this article is that regardless of the context or format of the instruction all of the instructional strategy and knowledge components identified in Table 4 must be available to the student some time during the instruction. If some of these strategy or knowledge components are missing then the learning will be less effective.

When designing technology-based instruction, one advantage of representing the content to be taught in a knowledge-base consisting of knowledge components is that an instructional strategy can be written as an algorithm that uses knowledge components as data. A given instructional algorithm can be written once and used over and over. A creative designer could write a parts-of instructional transaction algorithm (transaction shell) that would work with any subject matter. Authoring for such a transaction shell would consist of merely creating the knowledge base. The instructional algorithm could then teach the content without any further design[4].

Kinds of Strategy

Perhaps the basic building block of all knowledge is concept classification -- the ability to recognize a new entity, action, or process as a member of a particular class. Human beings are wired to form concepts. Almost all words in a language (with the exception of proper nouns) are concept words -- they refer to classes of objects rather than to individual objects. One of the most important instructional goals is therefore to learn to classify -- to put a new object into a category that some segment of society has agreed is the kind of object under consideration. The goal of a kinds-of strategy is to be able to assign class membership to a previously unencountered object and to indicate why it belongs to this class by identifying the portrayal of its defining properties.

Table 5 indicates the knowledge and strategy components thought to be required for an effective and efficient instructional strategy for teaching kinds. The sample transaction is based on a directive instructional architecture (Clark, 1998). As with parts, these strategy and knowledge components can occur in a number of different instructional formats including inductive and deductive tutorial instruction and collaborative instruction.

TELL	**SHOW**	**ASK**	**DO**
entity name entity description * kind definition	kind portrayal property portrayal	definition *	identify kind portrayal identify property portrayal

* Often included but not required strategy-knowledge component

Table 5 Knowledge and Strategy Components for a Kinds-of Transaction

A typical directive kinds-of transaction might take the following form.

1. TELL the definition of the kind.

(If a set of coordinate concepts[5] were being taught the definition of each of the coordinate concepts would be presented. A definition is a list of defining properties and the value on each property that defines the kind).

Declarative: purpose = makes statement, punctuation = (.)

Interrogative: purpose = asks question, punctuation = (?)

Imperative: purpose = makes request, punctuation = (.) or (!)

Exclamatory: purpose = expresses emotion, punctuation = (!)

2. SHOW a portrayal of each kind (example) from the coordinate set contrasted with one another. SHOW the portrayal of each of the defining properties so that the student is clear on why a given instance is a member of the class.

(Guidance rules would suggest that instances be matched on properties other than the defining properties, that subsequent instances from a given class should be divergent from one another, and that the instances represent a range of difficulty.)[6]

Click on the following buttons to see examples of different kinds of sentences.

Declarative | Interrogative | Imperative | Exclamatory

The smell of a wood stove makes me think of camping.

Does this sentence make a statement? Does it end in a period?

Students can see several sentences of the same kind or a sentence of each different kind. Students can view as many sentences as necessary until they feel they know each kind of sentence. An effective transaction would arrange the instances to implement the guidance rules for matching, divergence, and range of difficulty.

3. SHOW a portrayal of a kind (an instance not previously seen by students). DO have students identify the instance by giving its name. DO have students identify why it is an instance by identifying the portrayal of the defining property values. Repeat this interaction until each of the coordinate concept classes has been shown several times.

(A guidance rule would suggest that more instances are required when the concept has several defining properties or the portrayal of the defining property values are difficult to discriminate. During practice a guidance principle would suggest that correct answer feedback be provided after students have made their classification and provided a rational.)

What kind of sentence is the following? Click on the appropriate button.

What a terrific show we saw!

Declarative | Imperative | Interrogative | Exclamatory

Click on a reason.

[ ] Tells a fact about the subject.
[ ] Is said with feeling.
[ ] Makes an inquiry.
[ ] Asks the subject to do something.

Examples would be presented until students have correctly classified several sentences of each kind. When students make a classification error, feedback would indicate the correct classification and the correct reason. The reasons are paraphrased statements of the property, *purpose*.

How-to or What-happens Strategy

Recent literature (Jonassen, 1999; Schank, 1999) has emphasized the involvement of students in authentic tasks. This is interpreted as having the student perform in a way that is similar to or identical with those tasks they will be required to do on the job or when they use their newly acquired knowledge or skill. Parts-of and Kinds-of learning goals are enabling goals, knowledge and skill that are required in order to perform the procedure or solve the problem. The last sample instruction is a transaction for doing a simple procedure and for understanding what happens as a consequence. Dijkstra (1997) identifies this as a problem of interpretation. This transaction implements a guided discovery architecture (Clark, 1998).

Table 6 indicates the knowledge and strategy components thought to be required for an effective and efficient instructional strategy for teaching an action or set of actions (a procedure). Table 7 indicates the knowledge and strategy components thought to be required for an effective and efficient instructional strategy for teaching a process or series of events (problem of interpretation).

TELL	SHOW	ASK	DO
action name action description * process trigger process condition process consequence	action portrayal process consequence portrayal	action name action description* order of actions	Action

* Often included but not required for a how-to lesson.

Table 6 Knowledge and Strategy Components for a How-to Transaction

TELL	SHOW	ASK	DO
process name process description * process conditions process consequence	process portrayal process consequence portrayal	process name process description*	predict consequence or find faulted conditions

*Often included but not required for a what-happens lesson.

Table 7 Knowledge and Strategy Components for a What-happens Transaction

Again these tables are not a method, not a set of procedures for designing instruction, but merely an identification of those primary strategy and knowledge combinations that must be present in the instruction if it is to accomplish its instructional goal. The instruction can take many forms and involve individual students or collaboration. All of these many variations will have their impact on the eventual instructional outcome, however, unless these methods involve the primary instructional components identified, students will be less effective and/or efficient in acquiring the desired instructional goals.

Consider the following experiential environment[7]. The goal of this visualization is for students to learn how a canal lock works (a problem of interpretation). The visualization allows students to play with the lock. Students can open and close the gates and valves and move the canal boat through the lock (DO action). The visualization is constructed in such a way that students are not allowed to cause the lock to operate in a way that is inconsistent with the real world lock (e.g. students cannot open the lower gate when the lock is full and flood the boat downstream). When students perform some action they are immediately shown the consequence of this action (SHOW consequence portrayal). For example, clicking on the lower gate opener opens the lower gate if the conditions for this consequence are true.

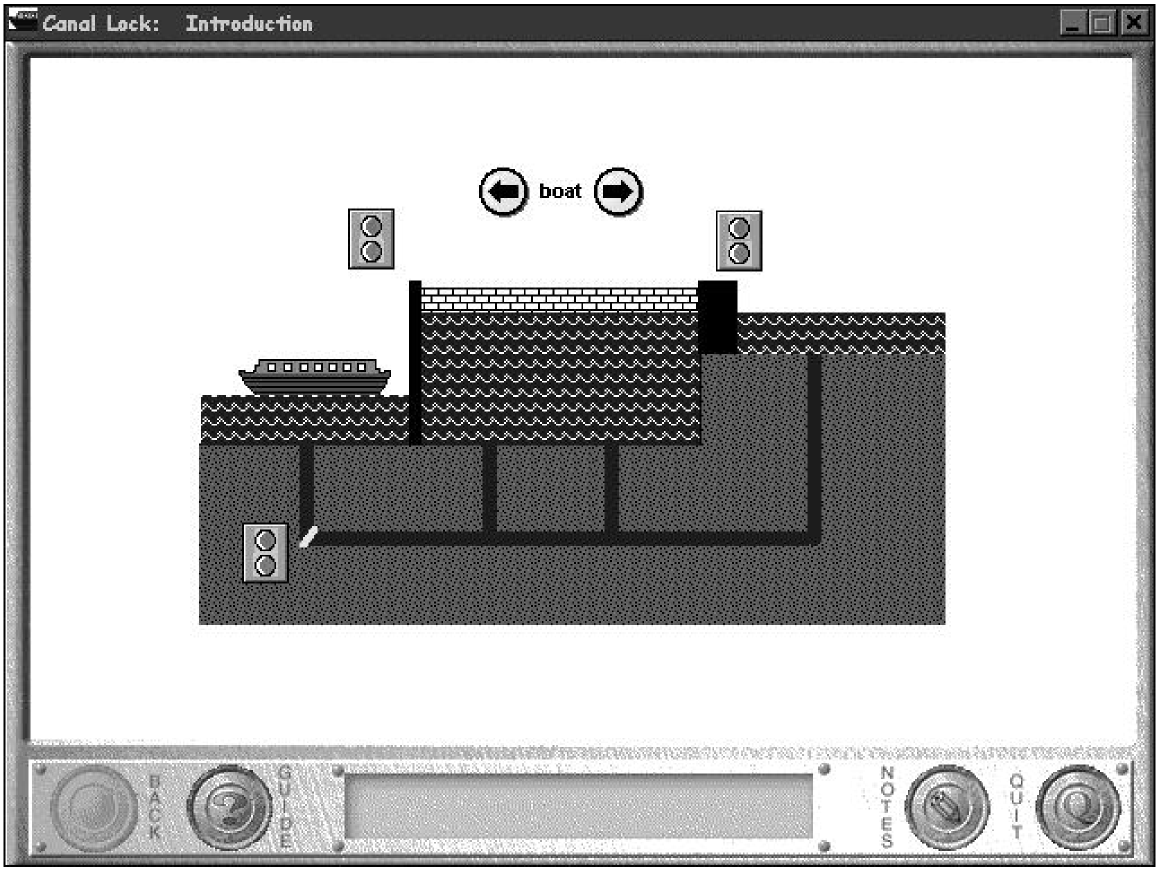

Figure 1 Experiential environment for canal lock

This visualization also contains instruction. When students click on the guide they are offered several options: see a demonstration, guided practice, and unguided practice (or assessment).

The demonstration is a "Simon says" type of activity[8], that is, the visualization provides the name of a step (TELL action), e.g. "Open the lower gate." and waits for the student to DO the step. The system immediately SHOWs the consequence of the action. If the conditions required for the process are not true, then nothing happens. The student has the option of asking for an explanation. An explanation answers two questions: what happened (TELL consequence) and why (TELL conditions). An explanation might say, "When you click the lower gate opener nothing happens (consequence) because the level of the lock water is not low (condition)." If students do an action other than the one they are told, then the system informs them that they did not do the correct step and gives the name of the action again. For example, "That is not the lower gate opener." The student is required to do the step before the demonstration continues.

The guided practice is similar to the demonstration, except that students are not given the name of the step. They are directed to "Do the next step." If students do not do the next correct step, then they are told that this is not the correct action and are given the name of the correct action.

Unguided practice is the same as the free play environment, except that students are given a specific goal to accomplish (e.g. Move the canal boat from below the lock to above the lock with the upper gate closed). Their performance is tracked and compared with the correct path through the task. All legal actions and consequences are allowed. After students have accomplished the goal they indicate that they are finished and their actions are compared with the correct actions.

In an experimental study (Lawless, et al, 1998) three groups of elementary school students were compared. The first group received a hands off demonstration for moving the canal boat up through the lock, the second group received the "Simon Says" demonstration described above, and the third group were allowed free play with the visualization but did not receive any direct instruction. The final task was to move the canal boat down through the lock. The measure was the mean number of steps required to accomplish the final task. There were significant differences among the groups. (Simon-says best at 13.3 steps, hands-off at 20.6 steps, and free-play at 35.1 steps).

The implementation of the canal boat experiential environment emphasized primarily how-to. What-happens, which is the goal of the instruction, was taught indirectly. The SHOW consequence component always followed from a DO action. However, the TELL components were included only if students requested and studied the explanations. The DO components of the what-happens strategy were not included in this implementation. The implementation would be more complete if the following exercise was added to the visualization.

> Prior to doing a step <u>S</u> is asked to predict what will happen.
>
> When you open the outlet valve
> [ ] nothing will happen
> [ ] the lock water will lower
>
> Because
> [ ] all conditions are met
> [ ] the lower gate is not open
> [ ] the upper gate is not closed
> [ ] the lock water is not high

In an experimental study (Drake, et al, 1998) three groups of elementary students were compared. Group 1 received explanation only after an incorrect action, group 2 received an explanation after every action, and group 3 received no explanation. The group that received an explanation after every step performed the final task (move the canal boat down through the lock) in fewer steps than the control group who received only the final task but no instruction. We did not test their ability to make predictions about the consequence of their actions. It is hypothesized that students receiving the explanations would be able to make better predictions because they know what-happens better than students who merely learned how-to-do-it.

Instructional components make the design of experiential environments much more straightforward. The instructional component *properties* play a central role. The consequence of a process is the change of a property value. The condition for a process is a value on a property. When a property value changes its portrayal changes thus making it possible to write a simulation engine that will operate on property values for any situation that can be described via entities, actions, processes and properties[9].

Conclusion

> "The great success of the natural sciences has been achieved substantially by the reduction of each phenomenon to its constituent elements, followed by the use of the elements to reconstitute the holistic properties of the phenomenon." Wilson, 1998

Instructional Components comprise a theoretical tool for facilitating the design of effective, efficient, and appealing tutorial (directive architecture) and experiential (guided discovery architecture) instructional products and environments.

End Notes

1 We have not limited the word knowledge to that which is already available in the brain of a student but rather to that body of accumulated and archived knowledge and skill that we intend the student to acquire.

[2] Knowledge objects have been described in more detail in other papers see Merrill and ID_2 Research Group, 1996; Merrill, 1998; Merrill, 2000.

[3] This table does not show the relationships among knowledge components. The table is merely a list of knowledge components. In Merrill (2000) knowledge structures, the relationships among knowledge components within a knowledge object, are defined and illustrated.

[4] The ID_2 Research Group at USU built such a system. See Merrill & Thompson, 1999.

[5] All coordinate concepts share a super ordinate class (e.g. trees) the coordinate concepts are then kinds of this super ordinate class (e.g. deciduous trees and conifer trees).

[6] See Merrill, Tennyson, & Posey, 1992; Tennyson & Cocchiarella (1986) for prescriptions for teaching concepts.

[7] The transaction described was built using the IDVisualizer™ a simulation authoring system developed by Leston Drake and the ID_2 Research Group at USU. For more details about the operation of this tool see Merrill, 1999. The tool is available as a commercial product from Mindware Creative Inc. see www.mindware1.com.

[8] Many authors call this type of demonstration a simulation. We do not believe that a constrained "Simon Says" activity is simulation but merely a guided demonstration.

[9] For a more complete explanation of PEAnet relationships see Merrill, 1999.

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