A Theory-Based Alternative for the 
Design of Instruction: Functional Design

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ABSTRACT
An approach to instructional design is described which avoids some of the problems traditionally associated with process design models, sometimes referred to as waterfall models. The new approach is based on the functional decomposition of a generic instructional artifact and the use of the functions as entry points to the design. A theory of design architecture is described that relates artifact functions to the “layers” of a design, similar to Schön’s architectural domains. By viewing the instructional artifact functionally, the designer takes advantage of the correspondence of instructional design layers and their associated theories. Thus, instructional theory can be applied more directly to designs. A design order that is adaptive to the individual design project is obtained as the process order restraints of the waterfall model are traded for ordering on the basis of a set of decision priority rules.

Categories and Subject Descriptors
D.2.2 [Design tools and techniques]

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Design.

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1. INTRODUCTION
Herbert Simon [1] proposed that “description of an artifice in terms of its organization and functioning...is a major objective of invention and design activity” (p. 9), and yet during the early development of a new area of technology, practice often gravitates toward process models that are devised to guide the activities of the designer step-by-step. This has been the case in the practice of instructional design, which has been dominated by various versions of a general process model over the last several decades [2]. This paper stresses the importance of an alternative approach: deriving instructional design practices and theories from a generic functional description of the instructional artifact. The value of this approach is that it is grounded in a more appropriate concept of theory as it applies to instructional design.

For this argument, I assume that Simon’s distinction between science and the sciences of the artificial is valid. As Simon observed, “the contingency of artificial phenomena has always created doubts as to whether they fall properly within the compass of science. Sometimes these doubts refer to the goal-directed character of the artificial systems and the consequent difficulty of disentangling prescription from description” (p. xi).

The theory appealed to in this paper is not scientific but technological in nature. The importance of this distinction is described by Gibbons [3]. In Simon’s view there are technological theories of synthesis just as there are analytic scientific ones. This difference is particularly important in the framing of the practices of the instructional designer because the general (but mistaken) belief is that scientific learning theories can be applied directly to the creation of designs without an intermediate step that translates descriptive theories into prescriptive ones.

I argue that two kinds of technological theory are of special importance during the design of instructional artifacts: theories of instruction, and theories of instructional design [4]. I will try to show that by considering these kinds of theory separately and by performing a generic functional analysis of the instructional artifact as a class, a new approach to generating instructional designs is possible that circumvents many of the problems created when only process models are used to guide designer activity.

2. TWO KINDS OF THEORY
Vincenti [5] describes several domains of design knowledge, each of them a venue within which design theory should be anticipated to guide the designer. Two of Vincenti’s domains are of particular interest to this discussion: fundamental design concepts—which includes operational principles—and design instrumentalities. The primary difference between these two areas of theory is that one describes the content of designs while the other describes the architecture of designs and of the designing processes.

Fundamental design concepts—especially that subcategory of them called operational principles—are abstractions that serve as building blocks for specific designs. They are ephemeral patterns that describe energy transfer and transmutation mechanisms to which designers assign specific material, properties, and dimensions as they design [6]. As a class they represent theoretical constructs for design composition—the design content.
Operational principles were first described by Polanyi [7], and their utility has been recognized in the literature of architecture [8] [9], business [10], marketing and product strategy [11], and aviation [7]. Operational principles are, in effect, mini-theories of structure that can be applied to designs. Operational principles supply the terms of the design languages [12] used to compose designs within a particular field. Thus, electrical system designers for a new building speak of circuits and trunks, while the structural engineers of the same building are concerned with load-bearing members and foundations. During design the abstract principle of circuit serves as a pattern for designing specific circuits that operate according to the circuit principle.

In contrast, design instrumentalities, are abstractions about designing itself. Theories about designing are to some extent, though not completely, portable across disciplines of design. They are theories about how something can come to be structured rather than describing the elements of a structure. This is an important distinction in the field of instructional design, which confines the two types of theory, making it hard to talk independently about the content of a design and the process of designing.

Simon (p. 134) lists multiple kinds of theories pertaining to designing, including theories of evaluation, theories of computation, theories of design logic, theories of search, theories of resource allocation, theories of structure and design organization, and theories of problem representation. None of these bodies of theory is exclusive to a particular design discipline (such as automotive design: all of them contain at least some principles applicable to designing in any field.

3. FUNCTIONAL DESIGN

The value of these typologies of design-related theory is that they provide the terms for a more pragmatic discussion of how theory operates in the creation of designs. I propose that a functional analysis of a generic instructional artifact provides a set of sub-categories for the organization of instructional theory at a more detailed level. These, in turn, provide the framework for a new approach to instructional design. I will illustrate this by defining a generic functional architecture for an instructional artifact and then using it to derive a novel approach to instructional design.

As a preliminary step, it is important to define the concept of instruction used as the context for this discussion. Instruction takes place when two or more agents (human or automated) engage in cooperative conversation with the goal to promote the learning of at least one of the agents. For human instructors the metaphor of conversation is traditional, despite the fact that in actuality many of our instructional conversations are mostly one-sided. Winograd and Flores [13] also describe interactions with interactive technologies such as the computer in conversational terms. An instructional artifact by this definition is anything deliberately designed to promote or support learning-motivated conversations in either formal and informal settings.

This definition is subtly different from the one many designers have in mind when they create instructional designs. Different designers have different ideas about what it is they are designing. For example, Gibbons [14] describes four different structural perspectives that a designer might take while originating a design:

- Media-centric—In this perspective the designer allows the structures supplied by the instructional medium to dominate the design. This may include the structures inherent in a Web page (terms: site, page, resource, xml tag, etc.) or a book (terms: chapter, page, paragraph, headings). A media-centric designer believes that the object being designed is a media product.
- Message-centric—In this perspective the design concentrates on the properties of the message presentation that are felt to have the most value to learning. This designer believes that the object of design is a message that communicates. A message-centric designer might therefore think of the design in terms of explanations, diagrams, questions, and exercises and ways to make them more effective. Considerations of the media form are secondary for this designer to the intelligibility of the communication.
- Strategy-centric—In this perspective the designer’s plans are dominated by strategic plans and moves that are expected will be the most effective ones, given the nature of the subject-matter and the desired outcome of instruction. Considerations of media and message structure are important to this designer but are secondary to concerns about the nature and sequencing of instructional events at a higher level.
- Model-centric—In this perspective the designer places content concerns at the forefront of the design and makes other parts of the design to conform to the demands of the content structures—in this case, content that exists in the form of a dynamic model of some kind with which the learner might interact. Other commitments to content structuring are possible, and perhaps a better name of this group of designers would be “content-centric”.

These centrism represent different priorities being placed on particular architectural aspects of the design. They represent a particular bias toward certain building block structural features in preference to others. In a sense, they represent priority given to particular functions carried out by the instructional artifact. They therefore also represent constraints on the order of design. This is the key principle underlying the alternative approach to instructional design described in this paper.

Simon talks about the “factorization” of a design—the decomposition of a design problem according to functionality: “To design...a complex structure, one powerful technique is to discover ways of decomposing it into semi-independent components corresponding to its many functional parts. The design of each component can then be carried out with some degree of independence of the design of the others, since each will affect the others largely through its function and independently of the details of the mechanisms that accomplish the function” (p. 128).

Instructional conversations require as a minimum the following functions:

- A representation function capable of producing information-bearing sensory experiences for the learner.
- A messaging function capable of driving the representations according to a conversational pattern.
• A control function that allows the learner to make responses and form inquiries.
• A content function capable of defining the learning matter in appropriate-sized parcels of the right composition.
• A strategic function capable of driving the conversational interaction with the learner according to a larger plan or of assisting the learner to form such a plan.
• A data management function capable of recording information from the instructional interaction for use by the learner and by the strategic function.
• A media-logic function capable of executing any of the above functions that are automated, and of directing human functions within role descriptions.

These functions may be implemented in many different ways, some of them technology-based, and some of them performed by humans. Most artifacts blend technology and human execution of the functions. Instructional designers do not typically decompose design problems in terms of the functions named above. A process approach has been widely taught and regulated, so it is by far the most commonly used.

Functional decomposition as it is described here refers neither to the packaging of the artifact nor to its intended human/technology footprint. In functional design, as the functions are implemented, they are most often undetectable. That is, the layers of design created by the functions are invisible to the user, despite the fact that they can be very important to the designer. Early conceptions of technology-based instruction favored the creation of self-contained “modular” and “teacher-proof” products, an idea that was shown by experience to produce artifacts poorly fitted to their context. The experience of that period was sufficiently negative that the concept of “modularization” and functional isolation still carries an unpleasant connotation for many designers. This early use of the term “modular” should not be confused with the concept of design modularization by layers that is presented here.

4. DESIGN LAYERS
Simon’s factorization principle for decomposing designs applies especially to complex designs. One possible reason that instructional designers have not found it important to see their artifacts in functional terms may be that technology-based instructional designs have tended in the past to be dictated by media, message, and strategy structures almost exclusively, as previously described. In current practice one functional area of a design can easily dominate the rest of the design to the exclusion of adequate consideration of the potential within the remaining functions.

However, the design of more sophisticated types of instructional artifacts (e.g., games, simulations, highly-interactive educational Web sites) is more demanding, and the expectation of users is rising. Increasingly, the range of talents and the depth of theory required to design is diversifying. So the time is approaching when instructional designers will not be able to design by paying attention to one dominant design function to the exclusion of others. For this reason, a balanced approach to design that gives consideration to all layer functions will become more important in the future. Being aware of the many layers of a design is a first step in this direction.

This balanced approach must view the multiple functionalities of a design as layers of the design that are evolved in a semi-independent manner, in parallel. A slow transition toward this type of thinking has been underway for many years. More sophisticated designs require the skills of more than one person and draw on the diverse skills of a creative team representing different design disciplines. As the technologies in each subdiscipline continue to mature and evolve, specialties form along the fault lines of the layer structure just described:

- Skills for the analysis of complex and multi-faceted subject-matters (content layer skills)
- Skills for the design of conversational exchange protocols (message layer skills)
- Skills for the design of broader strategic plans that drive conversational messaging (strategy layer skills)
- Skills for the design of control and response-gathering systems (control layer skills)
- Skills for the design of art, photographic, video, audio, and tactile elements (representation layer skills)
- Skills for the design of data recording, reporting, and utilization systems (data management layer skills)
- Skills for the design and creation of the software and human execution protocols for all of the above (media-logic layer skills).

Design of complex instructional products often takes place through a process of rapid-cycle planning, implementation, testing, and revision that requires the concerted efforts of this team and the ability to discuss the evolving design in abstract terms. Making such designs demands that the team members share with each other the design languages they use within their own specialty (layer) and eventually form a “pidgin”—a language consisting of combined terms from all of the individual languages that allows the team to, as a group, argue the design. The value of the design layer concept is that it provides a framework within which individual languages can be described and catalogued and also a framework for describing how the individual languages come together to describe a whole design. Having awareness of design languages allows the team to discuss the properties of a design separately from the specific content of a particular design.

5. IMPACT ON DESIGN APPROACH
Process models work in an assembly line fashion, each process step accepting raw material from a previous step, transforming it in some way, and then passing it along as input for a subsequent step. In a process model, what is created at each step is an intermediate artifact slightly more organized, detailed, and concrete than its predecessor. The generic instructional design process model in general use today works in this way. An early stage of analysis produces data on learner characteristics, the problem context, and learning targets. These are passed to a stage in which the learning targets are matched—using data from the other analyses—with teaching strategies, event patterns, and media plans. This recipe is in turn passed to a production assembly line, and products in various stages of integration are tested and revised as needed.
Similar process models of design are common in the early history of most developing technologies and are usually complemented later by alternative design approaches as the technology matures. In order for this to happen, there must be a separation in the designer’s mind of the design process from the manufacturing or production process. Design processes must be recognized for what they are: distinctly different thought processes with a logic of their own [1].

This transition has been difficult for instructional designers to achieve, though there have been objections to the continuing emphasis on waterfall models and the lack of a strong alternative. This paper proposes a viable alternative that complements the process model without discarding it—at the same time freeing the designer from the order constraints of a process model and providing the means for adapting design and development processes to individual projects. A tailorable model of this type is desirable because the quirky eccentricities of individual projects frequently challenge inflexible process models.

I propose a design model based on a functional description of the generic instructional artifact previously described. This choice of base has three implications:

1. Layer definitions have a rough correspondence with processes from the traditional instructional design process model, suggesting that valuable elements of that model need not be discarded.
2. Layer definitions correspond closely with practical aspects of the design, including the classes of initial constraint that exist for virtually every project.
3. Layer definitions correspond with subdivisions of instructional theory, making the application of theory to different parts of the design more straightforward.

Typical constraints on instructional design problem fall naturally into categories aligned with one or more layer definitions. These may consist of constraints on instructional medium, on the nature of the content, or on instructional method. In addition, constraints on time (both development and delivery time), resources, and skills correspond with varying depths of sophistication achievable within different layers of the design.

The approach I define in the remainder of the paper is based on the principle of progressive imposition of constraints within and across the layers of a specific design. The initial activities of the designer in this approach include:

1. Registration of the initial problem constraints imposed upon each of the layers individually and on the integrated design as a whole
2. Acceptance or negotiation of the constraints. Accepted constraints become the equivalent of design decisions, just as if the designer had made them.

From this point, the following activities are performed in a pattern of repetitive cycles:

1. The implications of constraints within each layer are traced. Design trajectories that are no longer relevant (because they are precluded by a constraint) are eliminated from the design, and new trajectories are added. These trajectories create sub-layers within the design.
2. Following the tracing of implications, the remaining design space with its new configuration of sub-layers is examined to identify the layer or layers in which the next most critical design decision is to be made.

The next most critical design decision is indicated by one or more of the following:

1. The decision most constrained by the latest previous decision.
2. The decision most constrained by external factors, such as skill availability, infrastructure, resources, etc.
3. The decision that best takes advantage of an opportunity afforded by the latest previous decision.
4. The decision that creates the most options for later decisions.
5. The decision for which there is the most supporting data from the analyses of the target population and of the instructional context.
6. The decision that represents the next highest quality priority.
7. The decision that most directly addresses a major client criterion or desired feature.
8. The decision that best leads to the satisfaction of an innovation goal.
9. The decision that is most necessary to the implementation of a chosen theoretical position.
10. The decision that responds to the latest prior decisions in other layers of the design.

This list of selection criteria is not exhaustive. However, it illustrates a range of priorities that become dominant at different points in the design process. As design proceeds, attention is spread across all layers, and new priorities rise as different decisions within individual layers are made firm. A designer may also proceed forward with multiple design configurations—design hypotheses—as a way of testing the effects of different orderings of the priorities.

Rather than making firm decisions one at a time, a designer using this approach will most likely advance the design within many layers at once through interdependent decisions spread across two or more. Once one such a set of proposed decisions is selected, the entire set can be confirmed at the same time. In this way, individual decisions within separate layers of the design can be integrated into a harmonious whole. This method of proposing hypothetical designs and testing them is described by Schön [7] as a design “conversation”. Just as Schön’s domains of an architectural design define the loci of individual design decisions, the layers and sub-layers of an instructional design localize the attention of the instructional designer without obscuring the integrity of the whole.

6. CONCLUSION

The design approach outlined in this paper combines the strengths of a design process model with a model that relies on a functional description of the designed artifact to supply the order of design decision making. The functional design approach has the benefit...
of tailoring the design process in detail to the givens—the constraints and criteria—of the specific project, and it allows the designer to adapt designing to shifting priorities occasioned by design decisions in the order they are made.

Most importantly, this approach to design capitalizes on a technological theory of design layers that are aligned with functions of the artifact and at the same time correspond with bodies of local theory related to these functions. As the complexity of instructional designs continues to increase, as new instructional design concepts emerge, and as instructional theory continues to advance, designers are sure to find design processes that adapt to change increasingly useful.

7. REFERENCES