The Science of Learning

A Systems Theory Approach

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Preface

Many people are talking about the "science of learning" and "scientifically-based" education research. For example, the "No Child Left Behind" legislation (U.S. Congress, 2001) mentions "scientifically-based research" over 100 times (Richardson, 2002; Slavin, 2002). To effectively apply science to the study of learning, persons in the instructional field need to understand science and how the scientific method is used in the study of learning and the development of instructional applications. The goal of this book is not to make every reader a scientist. It is rather to help each reader appreciate and more fully understand science and how it is applied to the study of learning and the development of instruction. Above all, it is intended to help readers to think more "scientifically" about learning and instruction.

What is the Science of Learning?

The *Science of Learning* is the body of knowledge derived through scientific research about the way that people learn, the factors that affect learning, and the ways in which instructional methods and technology can be used to facilitate learning. The Science of Learning helps us plan, develop, and deliver effective and affordable instruction. The Science of Learning also provides the methods to evaluate whether the instruction meets its learning objectives.

The Purpose of This Book

The purpose of this book is three-fold. It will help the reader understand the role of science in the study of learning processes and the development and evaluation of various approaches used to enhance learning. It also will help the reader think more scientifically, whether he or she is a scientist, an instructional developer, or an instructional program manager. It will help any of these instructional practitioners understand how science and the scientific method are used to generate data that support specific instructional practices. Second, it provides an introduction to systems theory and introduces two system-based models: a systems model of the learner and a systems-based model of instruction. Third, these models are used to organize summaries of learning research and the use of instructional media to help the reader integrate these data and transform them into a "body of knowledge." The book is not intended to provide specific prescriptions for classroom practices or instructional designs, although some of these will be discussed to help explain various learning theories and concepts. Other books (e.g., Mayer, 2002; Clark, R. C., 2003; and Clark, R. C. & Mayer, 2003) provide ample guidance on specific instructional approaches such as classroom management techniques or instructional methods.

Data, Information, and Knowledge

When discussing research results, an important distinction should be made between the terms *data*, *information*, and *knowledge*. Davenport and Prusak (1998) provide a useful discussion about the relationship among these concepts. Acknowledging that the word data is plural, but choosing to use the more popular singular form, they define data as, "a set of discrete, objective facts about events" (p. 2). These facts include the results of many different experiments and research efforts on learning and the effects of instruction. However these results alone are insufficient to build the knowledge base for the science of learning. "There is no inherent meaning in data" (p. 3). Data can be considered as raw material, which provides "no judgment or interpretation and no sustainable basis of action" (p. 3). To do this, we need to understand the meaning of the data. We need information.

Information is derived from data, but goes beyond facts to: 1) change the way someone perceives something and 2) to have an impact on his or her judgment and behavior. "Information is meant to shape the person who gets it, to make some difference in his outlook or insight" (p. 3). Davenport and Prusak (1998) suggest that data can be transformed into information by adding meaning to the facts through several methods:

- *Contextualizing*: knowing for what purpose the data were gathered
- *Categorizing*: knowing the units of analysis or key components of the data

- *Calculating*: analyzing the data mathematically or statistically
- *Correcting*: removing errors from the data
- *Condensing*: summarizing the data into a more concise form

Researchers and theorists have used the data on learning to develop a variety of theories and models of processes that contribute to learning. Many of these theories and models are discussed in the following chapters. Information on learning effects is still not sufficient for our purposes. The science of learning requires a knowledge base.

"Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information" (Davenport & Prusak, 1998, p. 5). Knowledge derives from information through another level of transformation. This transformation happens through methods like the following:

- *Comparison*: relating the information about one situation to other situations
- *Consequences*: determining the implications of the information for decisions and actions
- *Connections*: relating bits of knowledge to each other
- *Conversation*: determining what various people think about the information

Media, such as this book help humans communicate information to help each other develop knowledge.

Knowledge is still not the highest level we can hope to achieve. If we cogently use our knowledge, we may reach the level of wisdom. This book uses systems theory to organize discussions of the important data on learning, instructional media, and instructional design. It is hoped that these discussions help the reader to transform and synthesize these data into information. The book also suggests methods and recommendations for applying this science of learning knowledge base in a wise manner. Our wisdom will be judged by whether our efforts help learners achieve their learning goals.

Organization of the Book

The book is organized into four major sections. The first section, *Using Science to Study Learning and Develop Instruction*, includes three chapters. Chapter 1, *The Process of Science*, is a discussion of the purpose and process of science and how the scientific method helps us learn more about the world. Chapter 2, *A Scientific Approach to Instructional Development*, focuses on how the scientific method is applied to the study of learning and presents an introduction to systems theory and a systems model of the learner. This model is used in Section II as a way to organize and integrate summaries and discussions of learning research and instructional approaches. The third chapter, *Learning and Education Research and Myths about Learning and Instruction*, is a discussion of the similarities and differences between learning and education research and includes a presentation of some prevalent, yet erroneous beliefs about learning and instruction.

Section II, *Empirical Research on Learning*, includes five chapters that summarize the data generated from major learning research efforts and theoretical approaches. Chapter 4 is titled *Research on Physiological and Simple Learning*. It summarizes what we know about the physiological basis of learning and memory and how simple learning mechanisms seem to work. Chapter 5, *Research on Complex Learning: The Cognitive Domain*, is a discussion and summary of research on complex learning in the cognitive domain. It includes discussions of information processing models of learning and summaries of recent research on metacognition. Chapter 6, *Research on Complex Learning: The Motor and Affective Domains,* includes discussions and summaries of data that have been generated from studying the learning of complex motor tasks and the use of techniques to alter the learner's emotional reactions to instruction (affect). Chapter 7, *The Learning System*, provides an overview of the research results presented in the previous chapters. The systems model of the learner is used to organize this overview and to help the reader integrate and better understand the data. Following the overview of learning data, a model instruction as a communication process is presented as a way to discuss how our knowledge of learning can help us facilitate instruction and make it more effective. Chapter 8, *Conditions of Learning Outcomes,* *Instructional Events, and Instructional Objectives*, introduces the reader to Gagné's theory of instructional design and the important events that must occur in effective instruction. It then provides summaries of taxonomies of instructional objectives and instructional techniques in each of the three domains of complex learning: cognitive, motor, and affective.

Section III, *Research and Issues on the Use of Instructional Media*, includes three chapters on methods and approaches used to aid instructional communication. Chapter 9, *Instructional Media: Issues and Approaches*, opens this section. It provides an explanation of the debate on the use of instructional media that has been ongoing for over twenty years. It also includes a summary of some of the research data on the effectiveness of instructional media. These summaries include data from laboratory, classroom, and field research on the use of a variety of instructional media (e.g., computer-based instruction, instructional simulations, and instructional games). Chapter 10, *Research on Instructional Simulations*, provides definitions of important terms in the field of instructional simulations, a historical review of the use of instructional simulations, and summaries of research on the effectiveness of these approaches. It also includes a discussion of the concept of simulation fidelity as a method to determine the characteristics of an instructional simulation. Chapter 11, *Research on the Effectiveness of Instructional Games*, concludes this section. It provides summaries and discussions of research to determine if instructional games are effective instructional aids and when to choose a game over other instructional methods.

Section IV, *The Science of Learning and the Art of Instruction*, is the final section of the book. It includes two chapters. Chapter 12, *Evaluation of Learning Outcomes*, is a discussion of the important methodological decisions that must be made if one wishes to evaluate the outcomes of instruction to determine if learning has occurred. It provides methodological recommendations about how to scientifically determine the effectiveness of instruction in terms of improved learner performance. The final chapter, *Applying the Science of Learning*, summarizes recommendations that can help readers apply the science of learning to design effective instruction. It illustrates some of these recommendations by discussing a successful instructional development project, the first virtual environment training system fielded by the U.S. Navy. Finally, the chapter closes with a few concluding remarks that highlight important recommendations discussed in the body of the book.

Section I
Using Science to Study Learning and Develop Instruction

During the last several centuries, science has helped humans to gain a great degree of understanding about and control over their environment. The main tool of science is the scientific method, a controlled process used to accumulate knowledge and test its accuracy. This section includes three chapters that examine the scientific method and how science is used to help us understand learning and develop effective instruction. The first chapter focuses on the methods and processes of science and how people can think more scientifically. Chapter 2 discusses how the scientific method is applied to the study of learning and the development of instruction. It also presents an introduction to systems theories and a systems model of the learner that will be used to help organize and integrate subsequent summaries of learning research. Chapter 3 examines the similarities and differences in research on learning and research on education. It also includes a discussion of pervasive, yet incorrect assumptions about learning and instruction (myths). The chapter concludes with an introduction to methods to evaluate the scientific quality of learning and education research. More detailed discussions and recommendation on the evaluation of instructional outcomes are provided in Section IV, Chapter 12.

Chapter 1
The Process of Science

The *Science of Learning* is the body of knowledge derived through scientific research about the way that people learn, the factors that affect learning, and the ways in which instructional methods and technology can be used to facilitate learning. There are three parts to this definition. First, the science of learning is a body of knowledge. Second, it is not just any knowledge. Rather, it is knowledge about how people learn and how to enhance the learning process. Finally, this knowledge is derived from scientific research data. The quality and utility of empirical data depend on the scientific quality of the research from which they were derived. These data are transformed into knowledge by integrating them using learning theories and models. This book uses systems theory as the integrative perspective.

The Science of Learning is used to plan, develop, and deliver effective and affordable instruction. It also is used to evaluate whether the instruction meets its learning objectives. However, to effectively apply the science of learning, one must develop the worldview that allows one to think "scientifically." Some basic rules of scientific thinking are presented next. Then, we will examine how science and the scientific method help us in our search for "truth" in the realms of learning and instruction.

Basic Rules of Scientific Thinking

Science is more than methods and the data they generate. These are important and are discussed below. However, science is also a way of thinking and of making decisions. Here are a few basic rules (Beveridge, 1957) that anyone can use to think more "scientifically."

1. *Maintain a healthy level of skepticism*. Don't believe everything you hear. Demand evidence that demonstrates the effectiveness of instructional approaches and require demonstrations of instructional products that will justify their claims.
2. *Consult original sources (e.g., publications) whenever possible*. Don't trust someone else's summary,

interpretation, or explanation of a research effort (p. 14). Read it yourself and make your own interpretations.

3. *Don't jump to conclusions* on the basis of opinions or insufficient data (p. 74). If it sounds too good to be true, it probably is.
4. *Always be ready "to abandon or modify our hypothesis* as soon as it is shown to be inconsistent with the facts" (p. 66).
5. *Do not draw general conclusions from one experiment*. "Experimental results are, strictly speaking, only valid for the precise conditions under which the experiments were conducted" (p. 35).
6. *Apply Occam's Razor*. This is the maxim of parsimony (first stated by William of Occam in the 14th century): given alternative explanations for some phenomenon, the simplest explanation is usually to be preferred.

Science and the Scientific Method

Humans have always wondered about their place in the universe. They have sought to understand themselves and the world around them by applying various approaches to the examination of the environment and their internal states. Science is the most successful of these approaches. We have made incredible progress in our understanding and control of our environment because science works. As Francis Bacon, widely regarded as one of the earliest proponents of the scientific method, put it, "The lame in the path outstrip the swift who wander from it" (quoted in Beverage, 1957, p. 3). The "path" of science is very narrow—it requires the use of precise vocabularies, carefully developed definitions, reproducible measurement techniques, and open communication among scientists. To stay on the path, we must carefully apply the techniques of science and use these methods to identify and correct our errors. We need to remain on the path of science because we need to build and expand our body of knowledge of how people learn and how to apply instructional techniques to make learning more efficient. If we do not follow the path of science, we are left with speculation, biases, and fads—not the most efficient way to ensure improved performance.

Science Defined

Science (from the Latin *scire*, to know) deals with knowledge. Science is defined (Webster's New Collegiate Dictionary, 1977) as:

1. Possession of knowledge as distinguished from ignorance or misunderstanding.
2. Knowledge covering general truths or the operation of general laws especially as obtained and tested through scientific method.

It is only since the seventeenth century that the scientific method, as we know it today, has played a major role in the search for knowledge. In earlier times, other methods were used to test the truth of our conceptions of reality. "*Scientia* in the classical world meant reasoned disclosure of something for the sake of the disclosure itself. Up to the seventeenth century such disclosure consisted largely of classifications of things that were qualitatively different, but after Galileo it became the search for nature's quantitative laws" (Smith, 1982/1989, p. 83). The goal of the science of learning is to apply the scientific method to the factors that influence learning to help us use these results to design more effective instruction.

Four Ways to Search for Truth

Wallace (1971), based on W. P. Motague's (1925) *The Ways of Knowing*, stated that there are four major ways of generating and testing the truth of empirical statements: authoritarian, mystical, logico-rational, and scientific. The *authoritarian mode* seeks and tests knowledge by referring to those who are socially defined as qualified producers of knowledge (for example, oracles, elders, archbishops, kings, presidents, or professors). By relying on these authority figures, one does not have to worry about testing the truth of statements about reality. It is assumed that, because of their social status, authority figures have special knowledge in their area or expertise and will communicate that knowledge to others.

The *mystical mode* is partly related to the authoritarian. However, the authoritarian depends essentially on the social position of the knowledge-producer. On the other hand, the