Understanding Models for Learning and Instruction
Dirk Ifenthaler
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(Editors)

Understanding Models for Learning and Instruction

Essays in Honor of Norbert M. Seel
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Preface

Layers and Transfers for Learning Theories and Applications

Mental Models continued to be a key subject in different fields of research for almost half a century. For good reason. Foundations from cognitive science, computer science, philosophy and cognitive psychology describe the workings of the human mind in tasks of deductive and inductive reasoning, especially for reasoning under uncertainty. They lead to theories of problem solving and to theories of learning and instruction which are both highly interdependent. Stepping into the design of both computer-based and face to face learning environments is obviously not very far since well founded theories on learning and instruction are ready for transfer into implementation and applications. By following these layers, we will always find two processes of transfer.

The first transfer is to be made from the theoretical foundations and methodology towards the theories of learning, instruction and problem solving, by taking into account the insights about reasoning and mental model building. This transfer is not unique for the field of mental models and should be applied for all theories of learning and instruction. In our case it leads to Model-based Learning and Instruction which is sometimes also referred to as Model-centered or Model-oriented.

Because learning environments are too complex to be described directly by the theories of foundation, the layer of learning theories is necessarily needed in between. In most cases insights on the foundation layer can not directly be translated and properly transferred into applications. Consequently the second transfer aims at the construction of well founded learning environments on the bases of the theories of learning and instruction. This transfer is the integral part of Instructional Design. However it is nearly impossible to conduct the second transfer.
Norbert M. Seel dedicated his lifework to all of the three fields and consequently contributed to them with great reputation on the levels of theory, psychometrics, empirical studies and instructional design. We invite international researchers to participate in an integral work on all the three domains of expertise and the corresponding transfers within the field of mental models. This work will contain the actual state of research, methodology and technology. The three parts for the outline of the work are:

- Foundations and Methodologies of Mental Model Research
- Model-based Theories of Instruction
- Engineering the Model Environment

Foundations and Methodologies of Mental Model Research

The first part of the work will focus on the foundations of mental models and on methodologies which allow to measure constructs of mental models and how to track changes to them over time. Backgrounds and interdisciplinary interdependencies between cognitive science, computer science, philosophy and psychology will be thoroughly presented and discussed.

Model-based Theories of Instruction

The second part will consequently be about the transfers into theories of model-centered learning and instruction on the basis of the foundations and methodologies. It will show how the foundations can be generalized into larger settings of learning and instructions from a perspective of educational science and instructional design. This part will also show how the corresponding findings can be specified again for the referring theories.
Engineering the Model Environment

The third part will lead us to technological theories on applications for instructional design and educational engineering. Selected examples and empirical findings on learning environments based on theories of model-centered learning and instruction will show how state-of-the-art technologies can be build and evaluated.

The Book Project

The editorial committee has selected a wide range of internationally know distinguished researchers who present innovative work in the areas of educational psychology, instructional design, and the learning sciences. The audience for this volume includes professors, students and professional practitioners in the general area of educational psychology and instructional technology. Without the assistance of several specialists the editors would have been unable to prepare this volume for publication. They wish to thank Joost Lowyk and Sanne Dijkstra for their tremendous help with both reviewing the chapters and linguistic editing. Their thanks also go to David Heyde for proofread of several chapters and Andreas Lachner for preparing the chapters to meet the editorial style prescriptions.

Dirk Ifenthaler
Pablo Pirnay-Dummer
J. Michael Spector
Prologue

“Knowledge is no longer an immobile solid; it has been liquefied. It is actively moving in all the currents of society itself”
(John Dewey, The school and society)

The Quest to Understand Mental Life

Norbert M. Seel’s focus on both understanding mental functioning of students and supporting the construction of mental models through instructional design, is highly relevant for the educational field in a knowledge society. No doubt that he has been influenced by his German roots in philosophy and more specifically in epistemology. It is an interesting issue to look back in history and to appreciate early efforts to gain insight in psychological phenomena. A shallow look at the work of Herbart (1776-1841) already reveals a systematic approach of scrutinizing mental life. In Herbart’s view, initially chaotic presentations (‘ideas’) in the human mind can be modelled through the conscious process of apperception that links new ideas to former experiences. Herbart postulates that interactions between ideas can be expressed in mathematical formulas, which is perfectly in line with the scientific ambitions of his time. In this way, psychology is conceived of as a real ‘science’ with a specific object and a strict methodology. Education, then, aims at systematically directing the process of apperception using predefined, sequenced materials as sources to trigger expected experiences of children. Since the mind is filled with ideas, the kind of ideas and their sequence are important design components, which gave rise to the so-called ‘formal steps’ in Herbart’s didactics.

Though times drastically changed, away from a mechanical view of the mind, there remains some similarity with Herbart regarding the ambitions of modern cognitive psychology. It is a premium merit of Norbert M. Seel to have undertaken a systematic search to understand mental models from an interdisciplinary angle. This is not evident given the Zeitgeist of behaviourism at times he started his academic career. Indeed, after a period of almost exclusive attention to behavioural aspects of human functioning in education and training during the sixties and seventies of the former century, renewed interest in what happens in the human mind became predominant in successive waves of cognitivism, constructivism and socio-constructivism. Norbert M. Seel acknowledged already in an early stage the importance of mental representations and mental models as parts of student’s individual knowledge. Indeed, a central issue for education in a knowledge-
intensive society is how humans represent information in order to use it in interaction with the world they are living in. Therefore, ‘mental model’ is a key construct to search for the way knowledge is organised, developed, and changed under pressure of a steadily developing self and world.

The Need for Strong Research

Once a research topic has more or less been stabilized - which is the case with ‘mental models’- effort is invested in further clarification of the concept, development of valid and reliable tools, design, and implementation strategies. As has been acknowledged by the research community in educational psychology, a theoretical concept is only valid if open to observation and testing. Indeed, sciences develop along with the quality of the instrumentation. A recent example is the multi-level statistical approach that allows for measuring and interpreting complex, layered phenomena. In this book, vantage points for strong interdisciplinary research on mental models are presented. At first, the interrelationship between different knowledge domains needs clarification of the conceptual framework and the methodological toolset of each discipline in order to link that domains. Pirnay-Dummer reflects on the interdisciplinary links between research in cognitive psychology and theories of learning and instruction. He thoroughly analyzes methodological and logical traps in this complex interrelationship between domains. Spector rightly considers any interdisciplinary domain as a puzzle with missing pieces, pieces that often do not fit together or pieces from different puzzles that are quickly thrown together. More specifically, incompleteness of knowledge on learning brings about uncertainty in instructional design. In his opinion, Seel’s research endeavours are important steps toward a more comprehensive theory of instruction.

Mental models are not so much viewed as static entities but they refer to knowledge development in individuals. Consequently, knowledge diagnostics of mental models are vital endeavours that call for the use and construction of standardized tests (Al-Diban). Since ‘mental model’ is not a ‘static’ but a dynamic construct, changes in mental model construction can only be captured through valid methods and techniques to measure these progressing mental models of change (Ifenthaler). In a similar vein, a possible powerful tool for measuring mental model construction and change is the use of eye-tracking methodology (Mikkilä-Erdman, Penttinen, Anto & Olkinuora). Mental models are complex, multi-faceted and multi-layered, and no single form of assessment can represent all different kinds of knowledge. This is exemplified with Mindtools as a cognitive tool for externalization of mental models (Jonassen & Hoan Cho). Many authors contend that mental models are not an aim but a means that contributes to the quality of cognitive performance. A question in this regard is how measurement of knowledge can be related to measures of cognitive ability in order to identify individual’s level of proficiency (Shute & Zapara-Rivera).
Designing Powerful Learning Environments

If one knows better than before the basic aspects and structure of mental models, this knowledge-base needs transformation into design principles for learning environments that are suited to help learners build knowledge or learn to know. This is an intensive and complex endeavour since descriptive knowledge (‘knowing that’) needs to be transformed into prescriptive knowledge (‘knowing how’). This transformation is not an automatic or routine process given the many epistemological and empirical differences between descriptive and prescriptive knowledge. Consequently, there is a huge need for so-called transformation knowledge and skills. In terms of Podolskij, an utmost important aspect of scientific knowledge is its practical application. More specifically, this author refers to the Planned Stage-by-Stage Formation of Mental Actions (PSFMA) elaborated by Galperin in order to bridge the gulf between knowing that and knowing how.

One of the outcomes from a vast amount of research on mental models is that construction of mental models is a developmental activity. This clearly refers to learning processes that need explicit guidance through instruction. Instructional design with a focus on mental models necessarily has to adapt a model-centred perspective. Essential elements of that model are the learner’s conditions, the domain-specific knowledge and the reflexive nature of constructing mental models. This calls for flexible and adaptive designs at the micro-, meso- and macro-level (Blumschein). Hanke links the constructive nature of schema building with instructional design. A mental model passes through several steps before it is learnt. She depicts different learning sub-processes that can be supported by five specific teaching interventions. Whereas some instructional designers clearly emphasize instructional design in terms of the representation and organisation of subject-matter content to enhance learning others opt for (complex) problem solving at the core of instructional design. This problem solving activity in designing mental models is multi-layered and depends on the mental model of the instructor, the experience used to communicate the mental model, and the evolving mental model of the learner in order to connect teaching and learning. In this multi-layered architecture, the content layer, being the form in which subject-matter is stored, plays an important role (Gibbons).

Powerful learning environments obviously also encompass rich technologies to support the construction of mental models. More specifically the relationship between theories of cognition and learning on the one hand and the design of instruction on the other can be furthered through the use of information and communication technologies, like simulations and games (Dijkstra & Leemkuil). Technology, however, is not limited to educational software products but, in line with the intelligent tutoring systems (ITS), adaptive web-based learning environments show
how user modelling is apt to facilitate learning (Weber). However, building mental models is not restricted to regular educational settings. The use of games can be conceived of as model-centred learning environments that not only serve traditional education, but the workforce as well in supporting complex skill development (Johnson & Huang).

**In Honour of Norbert M. Seel**

It may wonder that a topic like ‘mental models’ is well and alive despite its long history, its often different meaning, and the fact that it is a construct and not a reality. It stems from research that needs to define and confine possibly relevant aspects of human cognitive functioning in real settings. The reason for its success could be that this concept is basic to knowledge building and understanding how people construct knowledge in a complex society. Even a quick scan on Google reveals the existence of many specific websites that illustrate the penetration of the concept in research, consultancy, and daily life contexts.

In this book, different topics were passed in review. They mostly are at the spearhead of evolutions in this domain, contributing to a better conceptual understanding of the interdisciplinary phenomenon at hand, constructing new but valid research tools, and refining principles for advanced instructional design. An interesting reading activity could consist of scrutinizing the list of references after each chapter in order to grasp the real impact of Norbert Seel on researching mental models and designing suitable (technological) environments. The reader will recognize Seel’s leading role in building a valid knowledge-base and will value as well the many research projects on mental models he launched in Germany and abroad. It is nice to observe how the different authors of the chapters are tackling each another topic and by doing so, produce a clear portrait of Norbert M. Seel.

Joost Lowyck
Strong theoretical foundations and precise methodology are always the one and only starting point for good research. Without sound foundations nothing follows, and thus a deep understanding of the theory of mental models and the methodology involved is mandatory for research on cognition and learning as well as for instructional design. This part contains contributions from J. Michael Spector, Val Shute & Diego Zapata-Rivera, Dirk Ifenthaler, M. Mikkilä-Erdmann, M. Penttinen, E. Anto & E. Olkinuora, and Sabine Al-Diban.

Spector begins with an overview of the field of learning sciences and instructional design from the critical and constructive perspective of the philosophy of science. This leads the focus directly to the inner relations between research questions and topic areas, between interest and methodology. After discussing the difficulties of the interaction, Spector presents Bob Dylan’s Dream and other songs as a parable for the workings of theory and research, of design and application. He carefully shows possible ways out of the many possible illusions which can be created by fast plausibility and early consensus in the domain of cognition and learning and its applications, taking the reader to a path from pattern recognition all the way up to a profound revision of constructivism.

A new approach for tracking the flexible belief networks in mental models is shown by Shute and Zapata-Rivera. Following the understanding of mental models and their different forms of external representations, the authors show the differences between summative and formative assessment and between knowledge and belief. In addition to discussing concrete research, Shute and Zapata-Rivera show examples of how the differences apply to mental model assessment.

On the basis of classical model assessment, Ifenthaler shows new approaches which enable researchers to track change over time within individuals and groups. This is of particular interest in the field of learning and instruction because learning always evokes systematic change. Therefore, learning progress has to be evaluated through observation of the functions of change. For a complete understanding of the tasks involved, a methodological synopsis is also provided.
Ifenthaler shows and systematically compares selected measures from graph theory and analyses how they can be applied to the measurement of change. He also shows that these procedures can be implemented within fully automated computer programs which serve as assessment and analysis tools.

Mikkilä-Ermann, Penttinen, Anto, and Olkinoura focus on conceptual change within tasks of text understanding, thus building a bridge to the theories of learning and instruction. New methods which use eye-tracking within studies of immediate text understanding are mapped to cognitive conflicts to gain knowledge about the processes involved in conceptual change and understanding.

Al-Diban gives an overview of the classical approaches to mental model assessment. Consequently, she discusses several of the methodological problems of morphism. With an emphasis on causal models, Al-Diban shows best practice examples from research on mental models and discusses and evaluates the common strategies of data analysis and testing.
1. The Fragmented Nature of Learning and Instruction

Remarks on the Philosophy of Science, the Psychology of Learning and the Design of Instruction

Michael J. Spector

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Abstract:  This chapter falls roughly into the intersection formed by the philosophy of science, cognitive psychology, and instructional design. I have drawn heavily on notes written for my students that have been read and commented on by Professor Seel in their earlier incarnations. Seel’s work on the progressive development of mental models and the implications for the design of instruction have inspired many of my remarks. I regard this general domain of discourse as somewhat like a puzzle with missing pieces and pieces that should fit together well but often do not. It is almost as if the building blocks of instructional systems research were pieces from different puzzles thrown together hastily. The general thrust of my argument is that we do not yet have comprehensive and completely coherent accounts of how people learn and, as a consequence, we lack a complete theory of how best to design instruction and assess its effectiveness. Seel’s research over the years represents important steps towards such a comprehensive theory of instruction.

Keywords: Constructionism; instructional design; instructional science; learning theory; mental model.

Remarks on Scientific Inquiry and Instructional Design Research

In a recent doctoral seminar in the Instructional Systems program at Florida State University, Professor Seel asked participants to indicate what each regarded as the single most important research question to be addressed in the next five
years in the domain of instructional systems, broadly and loosely defined to include instructional analysis, design, development, evaluation, management and technology. Answers reflected topic areas rather than research questions. He then asked each student to indicate an appropriate research methodology to address [part or all of] the indicated question. This second request turned out to be problematic since topic areas rather than research questions had been provided by students.

I was struck by two things. First, the notions of science and research seemed to vary considerably from one person to another. Second, specific responses indicated a strong tendency to only consider those aspects of instructional systems with which a particular individual was engaged, with the implicit assumption being that what each was doing represented the most critical research issue in instructional systems.

What is science? What is the nature of scientific inquiry? What distinguishes scientific research from other forms of research? What do scientists do? There are many answers to such questions. They can be found in books on the philosophy of science and in nearly every introductory text to a particular scientific discipline. I found myself generating such questions during Professor Seel’s seminar as various doctoral students provided their responses. I settled on a rough and ready representation of inquiry in physics as a starting point. For centuries, physicists have been asking such questions as these: (a) what kinds of things are there in the universe? and, (b) how do these different kinds of things affect each other? My first thought was that the basic questions within that discipline had remained fairly stable over the years; what have changed are the instruments and tools used to investigate various phenomena, which have led to new answers to basic questions and to improved understanding of the phenomena being investigated. Of course research methods and perspectives have also evolved, partly based on new answers to the basic questions. The basic research questions are basically unchanging. What changes are the tools used to investigate possible answers and the answers themselves. Moreover, interpretations of the basic questions may change considerably over the years; new interpretations of the basic questions might be regarded as representing a new approach, or possibly even a paradigm shift.

For example, Empedocles, (a pre-Socratic physicist who lived circa 492-432 BCE) believed that there were only four basic things – earth, air, fire and water – and that the physical world and our experiences could be completely accounted for in terms of these four elements. Aristotle further elaborated this view of matter and argued that all earthly substances contained mixtures of these four elements, with the particular distribution of the basic elements determining the nature and appearance of a particular object. For example, a rock contained much more earth than air, fire or water, according to Aristotle, which is presumably why rocks are hard, not readily combustible, and not easily transformed into liquid or gaseous forms. Aristotle then identified four kinds of causes: (a) material cause – the basic composition of an object; (b) formal cause – the inherent or underlying structure
of a thing; (c) efficient cause – how the thing came to be in its current state; and (d) final cause – the purpose of an object.

We do not think about the world in the same way as did Empedocles or Aristotle. Physicists no longer accept their accounts of the physical world. In spite of dramatic advances in physics in the last two thousand years, much has not changed. What has not changed are the basic questions: What kinds of things exist and how do they interact? Scientists are still attempting to elaborate adequate answers to these basic questions. Modern answers are that there are some 118 or so elements – a few more than four – and these elements are comprised of more basic building blocks – with leptons, quarks, and bosons being the basic categories for these sub-atomic building blocks. Furthermore, a small number of forces have been proposed to explain interactions among these basic building blocks of the universe – gravity, electromagnetism, weak nuclear force and strong nuclear force.

Okay – I did not recall all of those details late at night after the seminar. I had to look up a few things. My basic line of thought, however, was that this framework might be applicable to Seel’s questions. Imagine a door that has this question posted outside: What do instructional design researchers regard as the basic elements and what do they propose as the critical interactions among these elements? Shall I open this door? What might I find inside?

There is someone pulling on my elbow telling me not to waste my time opening that door. This person says that such an account applies only to the hard sciences – the physical sciences, such as astronomy, biology, chemistry, and physics. This person says that the soft sciences, which include the social sciences and what Herbert Simon (1996) called the sciences of the artificial, are fundamentally different. I understand those distinctions, I think, but there are some common concerns across all the sciences. Basically, what nearly all scientists want to know and understand is what exists – the building blocks – and how these things interact to bring about the things we observe, want to observe or would like to create. While causal interactions might be more difficult to establish in the social sciences, there is still strong interest in understanding, explaining, and predicting critical interactions. While the things that social scientists investigate might not be as precisely defined as those investigated by physical scientists, there is still strong interest in identifying the basic elements that explain what we have observed and are likely to observe in the future.

Perhaps this is a biased or naïve interpretation of science. Perhaps not. Nonetheless, I am going to push that door open and go looking for the basic elements and their interactions in the domain of instructional systems. What will I find?

What are the basic building blocks of an instructional system? What comes to mind immediately are students, instructors, things to be learned, and instructional resources. This might be an earth-air-fire-and-water kind of answer, though. Each of these elements might be further elaborated in terms of more discrete components which are more informative with regard to explaining interactions that are observed or desired.
What are the essential interactions or causal influences in an instructional system? Outcomes common to most instructional systems include improved understanding and performance with regard to some body of knowledge or set of skills. This implies that there should be reliable ways to assess relative levels of understanding and performance (relative to past performance or understanding or relative to a desired standard or goal). Other outcomes might be identified, and these might be further elaborated in terms of types of outcomes (e.g., affective, cognitive, psycho-motor or … there are many ways to cluster outcomes) and their relationship to other knowledge and skills.

Regardless of the sophistication and granularity of the components and interactions, we want to understand the various things that comprise an instructional system and how they are related, especially with regard to efficacy in achieving desired outcomes. Maybe. Well, I seem to recall Robert Gagné saying that our job as instructional designers was to help people learn better. What can we do at a systems level to fulfill that responsibility? How can we measure success? These and related questions represent the overarching areas of inquiry and scholarship in the general domain of instructional design and technology.

Lastly, there is the notion of research issues central to progress in a domain. The students who responded to Professor Seel each had a favorite area of inquiry. Why believe that one’s favorite area of inquiry is critical to progress in instructional systems research, however? What evidence can one bring to bear to defend such a view? How might one identify critical areas of research inquiry?

One might think beyond oneself and beyond one’s own training and set of predispositions. One might look at what distinguished researchers have said. The Book of Problems (see the 2002 events archive at www.learndev.org) would be a good starting point, I would think. That collection includes the contributions of 22 scholars and researchers who were asked by Jan Visser to describe what we do not know about human learning and to identify key unresolved problems. Contributors included a nobel prize winning physicist, a renowned biochemist, a neuroscientist, several sociologists and psychologists, an anthropologist, a number of educational researchers, and the odd philosopher. This collection is well worth a visit – what do such distinguished scholars believe is lacking in our knowledge of human learning? I leave the answer to this question as an exercise for the reader – an eminently worthwhile exercise, I believe.

I recall the advice I was given when searching for a dissertation topic by Professor Ed Allaire: Pick the central domain of inquiry within a discipline and then pick a central unresolved issue within that domain of inquiry that can sustain your interest. Of course there is much subjectivity in this – there will be different views about the centrality of domains and issues. I suspect, however, that a small number of alternatives can be identified. What might these alternatives be for instructional systems?

Addressing that last question is where I thought the discussion might have gone in Professor Seel’s seminar; at least that is where it was going in my mind. What are the central research issues in instructional design? I will suggest a few such issues later in this chapter.
What values are at the core of scientific inquiry? Are values relevant in our work? Of course they are. The starting point of scientific research is a desire to understand a phenomenon or situation or sequence of events. This implies that one admits to a state of relative ignorance: “I do not understand this.” One might then say that humility (“I know that I do not know”) is the starting point of every scientific inquiry or investigation. Humility would then be one of those core values in scientific inquiry. What do leading instructional systems researchers admit to not knowing or not understanding? That was the focus of Visser’s *Book of Problems*. It would be interesting and revealing to find out to what extent academics and practitioners agreed with the things identified in the *Book of Problems*. I have not conducted a survey and am not positioned to answer, but I would propose such an exploratory investigation as relevant for our discipline.

By way of encouragement for others to explore this question, I shall provide a small sampling of contributions to the *Book of Problems*. John Shotter asked this in his contribution:

“To what extent is our living involvement in a whole situation necessary for us to get an *evaluative* grasp of the meaning for action of a small part of it – as when a music teacher points out a subtle matter of timing, or a painter a subtle change of hew, or a philosopher a subtle conceptual distinction, such as that between, say, a *mistake* and an *accident*?”

Vera John-Steiner asked: “How would our understanding of learning be transformed if its purpose were joint discovery and shared knowledge rather than competition and achievement?” Gavriel Salomon noted that “what we’d need to study is what makes socialization and acculturation so effective and how their ‘active ingredients’ could be incorporated into instruction.” Leon Lederman suggested that we should figure out “how to construct a dossier of misconceptions, of ‘natural’ assumptions that must be viewed with suspicion.”

Basarab Nicolescue posed this question: “If we distinguish three types of learning, the mental (cognitive), the feeling (affective) and the body (instinctive), how important are, for a given type of learning, the other two types?” Federico Mayor observed that we do not know much about “learning to be, to transform information into personal knowledge” even though we know a lot about learning to know and learning to do.

David Perkins posed four general questions about learning:

1. The Question of Mechanism - When we learn, in what form is that learning captured in us and our physical, social, and symbolic surround? – in the form of mental representations, the weightings of neural networks, conditioned reflexes, runnable mental models, priming or expectancy and different degrees of primability, distributed cognition, etc.? …

2. The Question of Difficulty - When learning is hard, what makes it hard? When learning is easy, what makes it easy? Answers would have to deal with the match between mechanism and the things to be learned. …
3. The Question of Design - What can we do to make learning something easier? This is the problem of instructional design taken broadly, not just for schools but for groups, teams, families, societies, even for immune systems and genetic codes. 

4. The Question of Worth - What’s worth learning, for whom, for what purposes practical or ideological, at what cost? Do we find the guide to what’s worth learning … in Adler’s great books, in Dewey’s pragmatism, in Socrates’ insistence that we know our own ignorance, in more humble crafts and skills of the kitchen, the tailor’s shop, the chemist’s laboratory, the accountant’s spreadsheet, in the ancient human modes of love, parenting, friendship, ownership, command, peace, war? … “

In order to conduct sustained scientific investigation, one must be open to alternative explanations – this (what I or someone else has proposed) is one possible explanation; perhaps there are other explanations. Open-mindedness is then a second important value. The inability to imagine alternative explanations does not mean that alternative explanations do not exist. It would be a remarkable coincidence if the limits of reality happened to coincide with the limits of one’s imagination. Alternative explanations always exist (this is a remark about the logic of scientific explanations). Humility is the starting point, and openness to alternative explanations is required for sustained inquiry.

Perhaps none of Seel’s doctoral students mentioned such things because they are so obvious. I find myself requiring such reminders, though. In answer to Seel’s question about important research questions in instructional systems for the near future, I offer this: How can we reliably determine which interventions intended to help improve understanding of complex and dynamic systems are effective, to what extent they are effective, with whom they are effective and why? By way of clarification, I offer a few additional remarks. Complex and dynamic systems, be they natural or artificial, create challenging problem-solving and decision-making situations for humans. In such systems, many problems arise that are not especially well-structured; there may be incomplete information about critical aspects or goals, there may not be one standard or correct solution, there might be multiple approaches to the problem, and there might even be alternative interpretations of the problem situation itself. Complex and dynamic systems are pervasive. Examples include economic policy development, engineering design, environmental planning, instructional design, medical diagnosis, and many more. There are university curricula built around such problem solving areas. How might one go about determining whether and to what extent various curricula that support development of knowledge and skill in solving complex problems are effective? How might the findings of such an investigation be used to improve human understanding and performance in complex problem solving domains? I admit to not knowing the answers to these questions, but I am engaged in trying to find reasonable answers, as are Professor Seel and others.
The Fragmentary Nature of Psychology

From Bob Dylan’s Dream:

As easy it was to tell black from white
It was all that easy to tell wrong from right
An’ our choices they was few so the thoughts never hit
That the one road we traveled would ever shatter or split.

One of my graduate students asked about the fragmentary nature of psychology. This question implies that psychology is incomplete or disconnected. Perhaps the request is for an explanation why psychology is incomplete or disconnected. I am not sure. Perhaps I am incomplete and disconnected; I am sure this is often the case.

Suppose we agree for the sake of this discussion that psychology is the disciplined investigation of human thought and behavior. The aim of psychology is to provide a general account of the processes that underlie observable behavior and reported thought processes. As is true in other scientific enterprises, the desired general account will consist of causal factors and underlying mechanisms that explain what has been observed and reported and that predict what is likely to be observed and reported.

Where shall we start? Perhaps we should begin with a familiar phenomenon, such as confusing the names of two people. Suppose this phenomenon is common to nearly everyone – it represents the one road we are now all traveling together. Suppose further that we are all able to easily recognize this phenomenon and know when we have in fact confused one person’s name with that of another person – it is easy to tell black from white – at least at the outset. Someone said that in the beginning there was chaos and confusion. Or was it chaos and the void? In any event, this beginning is not like that other one that happened a long time ago.

Now, we are underway. The journey has begun. Let us begin by collecting explanations for this phenomenon. One person says that he confuses X’s name with that of Y because X resembles Y. Another person says that she confuses the names of X and Y because she met them both at the same time. Still another claims that the cause for mixing up the names is that the situations in which each person was first encountered were remarkably similar, although X and Y were met separately at different times and in different parts of the world by that person.

We already have three different accounts and we have barely begun. One explanation focuses on physical resemblance and implies a recall mechanism that assumes a search for an association between two kinds of mental representations – one textual (the name) and one visual (the person). Another explanation focuses on storage and retrieval cues, implying that the circumstances in which a person’s name is first learned are stored along with that person’s name and then used at least sometimes in recalling that person’s name. The third explanation also focuses on storage and retrieval mechanisms and also implies links between a retrieval cue (one kind of mental object) and a name (another kind of mental object).
Just as these three different explanations were beginning to coalesce, along comes another person who says that he confuses two people because he likes them both a lot and both remind him of another person. Emotions may also play a role in cognition, at least on some occasions for some people – namely those with emotions. I am heartless and unable to understand this person, so I continue on my way.

Just as I realized that fact about myself, along came yet another person who said that she confuses X and Y because their names are syntactically similar. Let us not overlook the mediating influences of language. Language pervades so much of what we do and learn. How can we properly account for the role that language plays in learning? What tales these twisted tongues will tell. One might even sense a change of language use and tone within this very chapter – even our use of language is fragmented. Back to our investigation of a simple phenomenon.

Then a person driving a convertible drove up, stopped and told me that the reason that I confused those two names was that I was in love with them both. Or perhaps I was in love with my deceased mother. Or perhaps with someone else’s deceased father. Or just lusting after them for no particular reason. Beware people driving convertibles.

Next there came along a large truck – a moving van, in fact. The driver stopped next to me, unloaded a couch, and invited me to sit down and tell her my troubles. I began to cry realizing that there were just too many possible explanations for this apparently simple phenomenon. She consoled me and gave me a lollipop.

What a strange beginning, I thought. When I looked around after the convertible and truck had driven off, I found myself all alone. Those with whom I had begun this quest were no longer in sight. I suppose they had followed a different bend in the road. Perhaps they escaped to Canada. Then I began to think about that other beginning, the one involving chaos and confusion. I concluded that not much had changed in all the intervening years.

Is it no wonder that psychology is incomplete and disconnected? Humans are complex creatures. Consciousness is especially complex. In the *Tractatus Logico-Philosophicus* Wittgenstein said that we picture facts to ourselves. Is it not remarkable that we are able to do that and then to talk about those pictures with others? We picture facts to ourselves. We are also able to picture to ourselves things that are not facts. Misperceptions, misconceptions, and misinformation account for many of these misleading internal pictures. We picture facts to ourselves. We cannot stop picturing facts to ourselves. This is a natural and ongoing process. Some are apparently able to improve the quality of these internal pictures, but such improvements are difficult to assess because these internal pictures are not directly available for public scrutiny; we cannot even examine our own internal pictures – mental models and schema, if you like. We construct internal representations to make sense of our experiences; these internal representations are hidden from view but affect what we come to believe and how effective and efficient we are able to learn. Is not a critical issue for instructional research the investigation of these internal representations and their role in learning? What interactions might exist between external representations provided by an instructor or a co-learner or oneself and these internal representations? What kinds of internal representations
Recognizing Patterns

One of the most remarkable statements I have encountered is also one of the simplest. It is this: “Wir machen uns Bilder der Tatsachen,” which has been translated from the German as “We picture facts to ourselves” (Wittgenstein, 1961). I mentioned this in the previous section and implied that these internal pictures are one of the basic building blocks of learning and instruction. Is this not a remarkable statement – we picture facts to ourselves? Is it not a remarkable ability? To highlight why this is so remarkable, perhaps a short philosophical sojourn is in order. Such a sojourn is consistent with my conception of philosophy as thought in slow motion.

We picture facts to ourselves. Or, more literally, we make for ourselves pictures of actualities. Making such internal pictures is not at all like drawing a sketch of something. We can observe a person making a sketch. Many people have drawn sketches while sitting in philosophy classes listening to boring lectures on epistemology. Some sketches are made more or less thoughtlessly, but many are constructed intentionally to represent something. Sketches are typically created on flat surfaces in one or more colors. They may or may not bear some resemblance to an object in the surroundings of the person making the sketch. So, we make sketches – that is not so remarkable, although drawing is a skill that can take years to master. This other ability, though, is something else. We make pictures to ourselves. How long did it take to learn to draw internal pictures? No time at all, although perhaps one can improve with practice – a serious matter well worth investigating, this last claim. Where is the hand that draws the picture? Oh, no hand is involved with internal pictures. Where is the flat surface on which the image is drawn? Oh, there is no such surface. Where is the crowd that gathers to watch the image being drawn? Oh, no one can observe this process, not even the person making the internal picture. Oh.

Is this statement – we picture facts to ourselves – a metaphorical remark, then? What can it mean? It seems to be a critical claim in Wittgenstein’s Tractatus Logico-Philosophicus, and it is closely related to concepts fundamental to cognitive science. It does seem worth exploring a bit more, especially since most people seem to accept it as obvious and non-problematic. Only the odd beast – the philosopher – draws attention to such apparently simple claims. Somehow or other we seem to build up an understanding of our surroundings, including other people and unusual phenomena we encounter. Moreover, we have a nearly irresistible urge to talk about our experiences and our surroundings, especially odd people and unusual phenomena. How is this possible?
Apparently, humans excel at recognizing particular images and patterns. Infants seem to naturally realize the significance of faces and quickly learn to recognize the faces of their mothers, for example. Applying a simple pattern matching algorithm to this ability only makes the ability seem more mysterious. The appearance of a face changes often and for many reasons, including changes in mood, hair styling, lighting and more. Moreover, the person may be moving, and the angle at which a face is viewed is rarely the same. How does an infant come to recognize a particular face as the same one viewed on previous occasions? Indeed, how do we come to recognize things at all? Something more than a physical perceptual mechanism must be involved. Memory is surely involved. There must also be something – some kind of process – that fills in missing parts of an image or suggests that an image is sufficiently similar to one that is recalled to regard it as representing the same thing. This process suggests a kind of pattern matching logic.

We picture facts to ourselves. Babies create internal representations of their mothers. The logic of this process can quickly escape our control. We start with one external reality (a mother’s face) and one internal reality (a baby’s internally constructed image of that face). When considering how the infant recognizes that face as its mother, a third reality intrudes – a recalled image. When making the judgment that this external reality is one’s mother, one produces an internal image, recalls prior images one associates with one’s mother, decides that the internally constructed image is sufficiently similar to the accepted mother-images to be part of that collection, and finally concludes that the external reality is indeed one’s mother – presumably it is also sufficiently similar to the internally constructed image. Whew. All that pattern matching is enough to make one cry.

It is a good thing that babies are not logical – they would never recognize their mothers if they were. Consider this. For X (the internally constructed image of mother) to be judged as truly representative of Y (the mother), there must exist a third thing Z (a previously constructed and stored internal representation of mother) that is truly representative of Y. But how did the infant come to the conclusion that Z was truly representative of mother? Hmmm. Presumably, on a prior encounter with the mother Y (which we are allowing to be the same Y for the sake of simplicity), the infant constructed an internal image Z (which we are allowing to be the same as the one recalled earlier for the sake of simplicity), compared it with another stored image (let’s call it W – why ever not?) of mother that had been previously accepted as truly representative, realized that this one was sufficiently similar to belong to that collection, and thereby concluded that it was also truly representative of mother. Well, this third mother regress cannot be infinite since the baby was born at some point and only then started constructing internal pictures and collecting images.

Infinite regress arguments seem to lead nowhere, which is where we were headed with that analysis. It is somewhat reminiscent of Aristotle’s unmoved mover problem. The problem with infinite causal sequences is getting them started (or stopped, depending on your point of view). That problem. All events have causes. Event Z is caused by Y which was caused by X which was caused by … and so on back to a much prior event situation and on to an endless sequence of
prior events and causes. The imagination handles that logic about as well as the pattern matching regress and usually concludes that there was a big bang or some other bursting out party to get things going. Happy birthday.

So, how does the baby come to recognize mother? The ability to recognize faces takes some reflection – or at least may at one time have taken some time for reflection and comparison and recall. In any case, understanding how we recognize faces requires some serious reflection on various human abilities, characteristics and tendencies. To emphasize the significance of reflection, I pause for this moment of reflection:

And indeed there will be time
For the yellow smoke that slides along the street,
Rubbing its back upon the window-panes;
There will be time, there will be time
To prepare a face to meet the faces that you meet;
There will be time to murder and create,
And time for all the works and days of hands
That lift and drop a question on your plate;
Time for you and time for me,
And time yet for a hundred indecisions,
And for a hundred visions and revisions,
Before the taking of a toast and tea.

From T. S. Eliot’s “The Love Song of J. Alfred Prufrock”

What was that question dropped on our plate? What was it that we were trying to understand? How we are able to recognize faces. Well, visual cues typically come bundled with other perceptual cues. Perhaps babies also smell their mothers; the reverse is certainly the case. There is the famous biblical story of Jacob and Rebecca deceiving the blind Isaac using the smell of Esau’s clothes and the feeling of an arm disguised using goat skin to feel hairy and rough, like Esau’s. While we might use several senses together to identify objects, we can nonetheless be misled. Descartes makes much of this possibility in his Meditations on First Philosophy – never trust a source that has misled you even once. If we followed such advice, we would suffer the same fate as those babies who never learn to recognize their mothers due to the third mother regress. Perhaps fewer politicians would get re-elected, though, if we decided not to trust a source that had even once misled us. There is almost always a silver lining to inquiry and investigation.

Well, it seems there is a need for some kind of explanation with regard to how we manage to build up an understanding of our surroundings and experiences out of these internal representations we construct. We picture facts to ourselves. Is it not remarkable that we are able to make sense of these pictures? Even more remarkable is how quickly an infant is able to automatically recognize a face, even one of those early-morning-after-a-very-late-night faces. Perhaps it takes an infant two or three times to develop an association of a face, and perhaps also a smell, a
sound and a touch, with mother, milk and such. Quickly the recognition process becomes highly automated and only a momentary glimpse is required. Once the pattern recognition process is established, it is highly resilient. What might this suggest about human reasoning?

The notion that we create internal representations to make sense of our experiences and surroundings is a fundamental tenet of a naturalistic epistemology that has roots in the philosophical works of David Hume and Immanuel Kant. In the 20th century, naturalistic epistemology became the basis for socio-constructivist approaches to education, although there is much confused discourse pertaining to constructivism in learning and instruction. As a tenet within naturalistic epistemology, the claim that we picture facts to ourselves is not a prescriptive claim – it does not tell the baby that it should create an internal picture of that face to see if it is mother and likely to bring comfort. We simply do, it seems, create internal representations of things. We do so naturally and without any prompting or guidance. We cannot stop creating these internal representations, and many will argue that the process continues even while we are sleeping. Ah, “to sleep, perchance to dream” … pass the rubbing alcohol … all this talk about epistemology is making my brain muscles ache.

Half of the people can be part right all of the time,
Some of the people can be all right part of the time.
But all the people can’t be all right all the time
I think Abraham Lincoln said that.
“I’ll let you be in my dreams if I can be in yours,”
I said that.

From Bob Dylan’s “Talking World War III Blues”

We create internal representations to make sense of our experiences, and then we use these representations to guide our actions and to structure our discussions with others. We realize that on occasion others may be viewing the same situation and engaging in a similar process of creating representations and sense making. What about these others? Might some of them be constructing internal representations that are sufficiently similar to mine to guide them to similar actions and conclusions? Half of them might say and do things similar to those that I would say or do. Hmmm. I suppose we need another distinction – that between internal and external representations, to which I have alluded already on several occasions. We picture facts to ourselves. These internal pictures are private and cannot be directly inspected or shared. We also create external representations of these internal pictures that are public and can be shared. These artifacts become part of the observable world and might also be worthy of investigation and consideration.

Ouch. Occam’s razor just got stuck in my beard. Am I multiplying entities beyond necessity? We began with external realities (mothers) and internal representations (constructed internal images of mothers). We added more internal things – things stored in and recalled from memory. Now we are adding more external