KNOWLEDGE AND INTERACTION

A Synthetic Agenda for the Learning Sciences

Andrea A. diSessa,
Mariana Levin,
and Nathaniel J. S. Brown

ROUTLEDGE

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Decades of research in the cognitive and learning sciences have led to a growing recognition of the incredibly multifaceted nature of human knowing and learning. Up to now, this multifaceted nature has been visible mostly in distinct and often competing communities of researchers. From a purely scientific perspective, "siloed" science – where different traditions refuse to speak with one another, or merely ignore one another – is unacceptable. This ambitious volume attempts to kick-start a serious, new line of work that merges, or properly articulates, two different traditions with their divergent historical, theoretical, and methodological commitments that, nonetheless, both focus on the highly detailed analysis of processes of knowing and learning as they unfold in interactional contexts in real time.

Knowledge and Interaction puts two traditions in dialogue with one another: Knowledge Analysis (KA), which draws on intellectual roots in developmental psychology and cognitive modeling and focuses on the nature and form of individual knowledge systems, and Interaction Analysis (IA), which has been prominent in approaches that seek to understand and explain learning as a sequence of real-time moves by individuals as they interact with interlocutors, learning environments, and the world around them. The volume's four-part organization opens up space for both substantive contributions on areas of conceptual and empirical work as well as opportunities for reflection, integration, and coordination.

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Routledge
Taylor & Francis Group
NEW YORK AND LONDON

First published 2016
by Routledge
711 Third Avenue, New York, NY 10017

and by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

Routledge is an imprint of the Taylor & Francis Group, an informa business

Library of Congress Cataloging in Publication Data
Names: DiSessa, Andrea A., editor. | Levin, Mariana, editor. |
Brown, Nathaniel J. S., editor.
Title: Knowledge and interaction : a synthetic agenda for the learning sciences / edited by Andrea A. DiSessa, Mariana Levin, Nathaniel J. S. Brown.
Description: New York ; London : Routledge, [2016] |
Includes bibliographical references and index.
Identifiers: LCCN 2015023242 | ISBN 9781138797130 (hardback) |
ISBN 9781138998292 (pbk.) | ISBN 9781315757360 (ebook)
Subjects: LCSH: Learning, Psychology of. | Knowledge, Theory of. |
Interaction analysis in educationClassification: LCC LB1060 .K625 2016 |
DDC 370.15/23–dc23
LC record available at http://lccn.loc.gov/2015023242

ISBN: 978-1-138-79713-0 (hbk)
ISBN: 978-1-138-99829-2 (pbk)
ISBN: 978-1-315-75736-0 (ebk)

Typeset in Bembo
by Out of House Publishing

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PREFACE

In the late 1980s and through the 1990s, the Berkeley/Palo Alto axis was a swirling cauldron of intellectual activity that laid important groundwork for the Knowledge Analysis/Interaction Analysis (KAIA) project, out of which this volume grew. In 1985, the Education in Mathematics, Science, and Technology unit (EMST) at the University of California at Berkeley declared itself the first Ph.D. and research program focusing on cognitive science in the service of learning. Jim Greeno, Alan Schoenfeld, and Andy diSessa were principles of the new unit. The next year, the Institute for Research on Learning (IRL) started up in Palo Alto, initially associated with the innovative Xerox Palo Alto Research Center. John Seely Brown and Jim Greeno were co-directors and intellectual leaders of that institution; diSessa and Schoenfeld were senior consultants. IRL was instrumental in advancing the visibility of "situated cognition," which aimed to either extend or supplant, depending on the author, purely cognitive approaches to learning with anthropological, social, and interactional approaches. On the anthropological side, Jean Lave's ideas were influential, particularly in her critique of cognitive developmental approaches to understanding learning and in her promoting apprenticeship as an attractive alternative to schooling as a model for learning. IRL developed the idea of "cognitive apprenticeship," combining Lave's ideas within the larger frame of situated cognition, but also building on revised conceptions of learning and knowing, such as those advanced by Schoenfeld and diSessa. Lave worked for a time at IRL, and then moved to Berkeley (reversing Jim Greeno's move from Berkeley to Palo Alto). Brigitte Jordan ran the Interaction Lab at the hub of IRL activity, and her article on Interaction Analysis with Austin Henderson in the *Journal of Learning Sciences* (Jordan & Henderson, 1995) arguably cemented the modern version of Interaction Analysis into the core of the learning sciences.

Many contributors to KAIA, as younger students and faculty, continued the dance between traditions and institutions. Rogers Hall worked as a post-doc at IRL, and then became an assistant professor (later, associate professor) at Berkeley. Randi Engle worked as a graduate student with Jim Greeno at Stanford before becoming an assistant professor (later, associate professor) at Berkeley. A number of the next two generations of researchers that are involved with the KAIA project worked with both the interaction and knowledge perspectives at Berkeley, including Reed Stevens, Noel Enyedy, and Nathaniel Brown. Other participants in this project (David Hammer, Andrew Elby) began complementary studies – expanding from KA-inspired work to include focus on interactional elements – after they left the West Coast.

During this middle period (1990s), the public face of cross-perspective work included two American Educational Research Association (AERA) symposia (one organized as a debate between situative and cognitive perspectives, one on p-prims in everyday conversation) involving diSessa, Greeno, Sherin, Stevens, and others.

It's easily arguable that the split between traditions was much more external to the Berkeley/Palo Alto axis than internal to it. Certainly almost all these actors were more familiar with both traditions than most researchers outside these circles. In addition, collegial friendships crossed boundaries willy-nilly. Thus, intellectually and socially, the Berkeley/Palo Alto axis set the stage for this current work, even if the two ends of the frequently traveled road became better known as advocates of interaction (and "situated cognition") and knowledge ("cognitive approaches") separately. Almost all the other authors in this volume worked with one of the researchers named above, or with their students.

By the mid-2000s, Knowledge Analysis and Interaction Analysis had become more established, and articulation of perspectives was becoming a more prominent and explicit concern. In 2006–2007, diSessa organized a faculty seminar on "dialectical approaches to cognition" at Berkeley. Attendees included Abrahamson and Engle. The following year, during sabbaticals, Andy diSessa and Rogers Hall jointly organized a "dialectical" seminar at the Center for the Advanced Study of the Behavioral Sciences in Palo Alto, an institution with a long and strong tradition in hosting and fostering cross-disciplinary and cross-perspective research. In 2010, diSessa organized an AERA symposium on "dialectical approaches to cognition."

Meanwhile, Orit Parnafes, and Mariana Levin, who had both been graduate students at Berkeley, spearheaded a 2009 effort to get funding from the AERA to host a mini-conference on bridging Knowledge Analysis and Interaction Analysis approaches to studying knowing and learning (together with Andy diSessa, David Hammer, Bruce Sherin, Nathaniel Brown, Rogers Hall, Reed Stevens, and Victor Lee). The idea was that real progress on articulation of perspectives would have the best chance if it happened in cross-paradigm research projects, working out ideas collaboratively on concrete data sets.

The work of this volume grew directly out of the resulting AERA-funded workshop held in June 2011 in Marin County, California. The Marin meeting gathered 29 researchers from the Knowledge Analysis and Interaction Analysis communities, spanning methodological expertise and career stages. Charles Goodwin, aluminary in Interaction Analysis (one of few attendees not within the geography of the social history described above – but certainly in it intellectually), also participated in the workshop. At the workshop, four teams of researchers worked up analyses using tools from both KA and IA and presented these analyses. Following the workshop, additional teams and individuals began working on their own attempts at integrated analyses. Two additional workshops (Vancouver, 2012, and San Francisco, 2013) furthered development of the agenda and community. The work of the KAIA project was disseminated through conference symposia at AERA (2012: "Integrating Issues of Knowledge and Interaction in Analyses of Cognition and Learning" with Bruce Sherin and Reed Stevens, discussants) and ICLS (2014: "Is the Sum Greater than its Parts? Reflections on the Agenda of Integrating Analyses of Cognition and Learning" with Timothy Koschmann, discussant).

ACKNOWLEDGMENTS

The efforts of many individuals and organizations helped move a research volume on the contributions of the KAIA project from a dream to a reality. We gratefully acknowledge the AERA Educational Conferences Program for funding the initial mini-conference "Integrating Knowledge Analysis and Interaction Analysis Approaches to Studying Learning and Conceptual Change," which took place June 5–7, 2011, in Marin County, CA. The following individuals, along with the editors of this volume, collaborated in writing the initial proposal to fund the workshop and also gave input in planning the meeting: Ann Edwards, Victor Lee, Jim Greeno, Rogers Hall, David Hammer, Orit Parnafes, Bruce Sherin, and Reed Stevens. Orit Parnafes and Mariana Levin were the primary organizers of the workshop, a conceptual and practical task that was accomplished skillfully and with foresight. Janet Koster van Groos videotaped and provided other logistical support.

We also thank Felice Levine and AERA for partial support for two follow-up meetings in Vancouver and San Francisco. The Evelyn Lois Corey Chair at Berkeley (A. diSessa, chair holder) provided additional support for follow-up meetings.

Alex Masulis and Dan Schwartz of Taylor & Francis provided intellectual and invaluable practical support in moving our work toward publication. Melinda diSessa provided critical and editorial feedback on several chapters. We thank the Knowledge Analysis and Patterns research groups at UC Berkeley for generative conversations as the general integrative agenda and specific analyses took shape. Leigh Kupersmith copy-edited the final volume.

Lastly, we especially owe thanks to our families and partners, Melinda diSessa, Aaron Levin, and Eve Brown.

In Memoriam

Randi Engle: 1967–2012. She is and will be greatly missed.

FIGURE 0.1 The participants of the KAIA workshop in Marin, CA. June 2011. Pictured in the photo: (back row, left to right) Chandra Turpen, Luke Conlin, Andy diSessa, Rogers Hall, Joshua Danish, Andy Elby, Victor Lee, Jim Greeno, David DeLiema, Ricardo Nemirovsky, Noel Enyedy; (middle row, left to right) Lama Jaber, Ann Edwards, Sarah Michaels, Ayush Gupta, Bruce Sherin, Reed Stevens, Molly Kelton, Siri Mehus, Shuly Kapon, David Hammer; (front row, left to right) Janet Koster van Groos, Mari Levin, Orit Parnafes, Jessica Umphress, Jasmine Ma, Flávio Azevedo, Randi Engle. Not pictured: Chuck Goodwin.

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INTRODUCTION

Decades of research in the cognitive and learning sciences have led to a growing recognition of the incredibly multifaceted nature of human knowing and learning. It is immensely sensible that different communities develop in a "divide and conquer" approach to understanding different aspects of human cognition. Still, at some point, sometimes fractious debate between diverse communities with the same overarching goal (an emblematic example is the cognitive–situative debate; see Anderson, Reder, & Simon, 1996; Greeno, 1997) must be replaced by sensible interactions among perspectives and mutual accountability.

This volume is ambitious, attempting to kick-start a serious new line of work that merges – or properly articulates – different traditions along with their divergent historical, theoretical, and methodological commitments. At the same time, we believe we are being realistic in not proposing to try to take on the task of putting all possible perspectives on knowing and learning in relation to each other at once. Rather, our approach is to focus on two lines that, while representing clearly different traditions (broadly, one socio-interactionist and one individual/cognitive), still have a great deal in common. The two traditions we put in dialogue both deal with details of knowledge in development, typical of the cognitive perspective, but they also deal with learning in interaction, typical of sociocultural or situated perspectives. Perhaps most important in terms of aligning or merging is that both lines of research focus on the intricate analysis of processes of knowing and learning as they unfold in real time. The two perspectives are Knowledge Analysis (KA) and Interaction Analysis (IA).

Knowledge Analysis draws on intellectual roots in developmental psychology and computational modeling, and it focuses on the nature and form of individual knowledge systems: what they are comprised of, how they are organized, and how this organization changes over time in interactions with the physical,

social, and material world. KA has been prominent in approaches to conceptual change that – unlike most approaches to that topic – include real-time learning analysis. Interaction Analysis draws on foundational work in linguistic anthropology, ethnomethodology, and conversation analysis, and it seeks to understand and explain learning as a fine-grained and interwoven sequence of real-time moves by individuals as they interact with interlocutors, learning environments, and the world around them. Of particular interest are the social and embodied practices of communities of learners and the interactional means by which participants display and interpret meaning.

Despite this volume's agenda to join perspectives, it also recognizes deep debates and differences in points of view between KA and IA, which will not recede quickly. For example, one of the broader controversial issues is methodological: How is it sensible to model knowledge "in the head" given that we have no direct access to the inner workings of minds, and we thus construct models of knowledge only by observing actions and interactions? IA proposes a more direct approach to observation, eschewing complex inferences to underlying mechanisms. Another issue that is very much a part of conversations between KA and IA researchers concerns how and whether cognition can be studied in the lab, separately from the broader material and social context in which it is generally situated. Thus, not only progress and agreement, but also difficulties and disagreements, are reported in chapters and commentaries.

Several previous volumes, handbook chapters, and special issues have noted the diversity of perspectives on cognition and learning that exist, and they have observed that different lenses can illuminate different educational issues in a "compare and contrast" mode. However, the current volume makes the further effort to articulate perspectives and bridge across them through original and collaborative analyses. That is, this volume does not merely showcase the diversity of perspectives that could be illuminating of a particular piece of data or an issue, but rather, it involves researchers of differing perspectives working together to create a new analysis, or even in some cases a new kind of analysis.

From a purely scientific perspective, "siloed" science – where different traditions refuse to speak with one another, or merely ignore one another – is unsatisfactory. Competing accounts of the same thing, say, learning in a classroom, need to have their differences and contradictions resolved. In some cases, one or another tradition may be wrong about some particular issue. More likely, proper articulation will produce an encompassing and more powerful account. What follows is a list of progressively more intimate models of how IA and KA may come to relate to one another.

To begin, two models – global competition and complementarity – are quite common in the existing educational research literature, but they are not emphasized in this book. We aim to engage more synthetic approaches. The next three models – micro-complementarity, influencing paradigms, and deep synergy – are well represented in this book. While each chapter has a unique perspective on

the relationship between KA and IA and we do not wish to pigeon-hole, we think these three models serve as a useful advance organizer for Part II: Synthetic Analyses. The final model – fusion – represents a possible far-future outcome of the present work. Fusion is clearly speculative and beyond our current grasp, but it is addressed in bits and pieces in a few empirical chapters, in some of the essays and synthetic chapters in Part III (Theoretical, Methodological, and Meta-scientific Issues), and, tangentially, in Part IV (Reflections and Prospects).

Global Competition

In principle, one might frame IA and KA as competing perspectives between which one must choose. One perspective might be right and the other wrong. "Choice" is a common trope at the "cognitive" vs. "sociocultural" level; many researchers still act as if one must choose between them. However, we think this attitude is antiquated. Minimally, both views deserve respect and continued attention for their accomplishments and promise.

Complementarity

One might take the view that IA and KA perspectives are complementary. They concern different phenomena. In this view, there need not be any conflict. A common way of thinking about this is that one has a variety of issues and problems to investigate concerning learning, and, depending on the problem, one or the other perspective might be more productive – "live and let live." One might frame this issue as incommensurability (and some authors have done so). Both perspectives are useful, but they have nothing to say to one another. We think this might be or has been an appropriate attitude in the historical development of IA and KA, but it is too weak a connection to support the main efforts of this volume.

Micro-complementarity

Suppose IA and KA are not just complementary at the level of choice of problem or phenomenology to investigate, but each has a perhaps critical role in understanding particular and important issues in learning. To take an example that is developed at some length later in the volume, it might be that KA researchers, trying to identify knowledge in a clinical interview, might need the help of IA to understand optimal conditions for – and possible threats to – their enterprise of "reading out knowledge." Here, KA and IA researchers probably have to read and listen to each other, but they might still conduct their investigations within a paradigm.

KA and IA researchers already both investigate processes of knowing and learning in clinical and other "artificial" settings, but also in the real world of

classrooms, workplaces, museums, gardens, and rocketry clubs. All such settings intimately involve both interaction and knowledge, hence they can serve as loci for micro-complementary analyses. But different contexts likely involve different issues and different relations of micro-complementarity, some of which might be easier to approach, at present, than others. The great diversity of contexts investigated in empirical chapters in this volume provides similarly diverse views of micro-complementarity, which are sometimes enhanced by companion commentaries.

Putting KA and IA in micro-complementary relationships also provides good grounds for investigating methodological issues. We already mentioned managing interactional optimizations or threats to Knowledge Analysis in clinical interactions. Similarly, comparative study across different contexts can enlighten the different affordances of "natural" vs. "artificial" contexts or small vs. large groups for studying thinking and learning. These and similar methodological issues are broached in many empirical chapters, and they are developed later in meta-scientific ones.

Micro-complementary analyses put IA and KA in intimate contact with one another, especially if one team of researchers does both. Such studies are also fertile ground for deeper synergy, which we take up immediately below.

Mutually Influencing Paradigms

Different intellectual traditions identify their own families of phenomenology worthy of investigation, and they also develop methods of investigation and theorizing appropriate to their focal phenomena. Once identified and developed, however, there is no strong reason to suppose that foci of investigation or methods of investigation and theorizing need remain with the tradition in which they originated. For example, IA – having staked a claim in phenomenology that, as a matter of fact, was largely ignored by historical approaches to knowledge – might convince KA researchers to bring their methods to bear on the same focal phenomena. In a similar way, KA has methods of theorizing and model building that one doesn't see in IA, but we know of no convincing arguments that they cannot be insightful, once one begins to try to use them on different-than-traditional phenomena.

Several chapters involve very particular versions of the dialectical agenda that we would put under the rubric of "mutually influencing paradigms." Some seek to demonstrate the additional insight that complementary analyses may provide *even concerning exactly the same issues*. For example, data previously analyzed from a KA or IA point of view may be subjected to complementary analysis, resulting in reaffirmations of results, corrections, additions, or, most importantly, extensions and refinement of avenues of research originally developed only from one (KA or IA) perspective. Some chapters seek to re-situate central constructs developed in one perspective in the other perspective, resulting in changed or expanded

meanings of theoretical terms, or changes in the range of applicability or the form of empirical results.

Deep Synergy

This is the level of articulation at which things pass beyond being "interesting" to being "fundamental for the field." One can identify two grades or levels of deep synergy. First – valuable also as a working principle, rather than only as a level of accomplishment – the perspective might undertake systematic *mutual accountability*. Whatever result one obtains within one perspective, it should also be examined and found sensible in the other perspective. As mutual accountability progresses, one may expect the next substage, *deep synergy* (proper), where the intellectual support for at least some of the most important ideas comes from both perspectives. This is the regime where retaining the identity of the two perspectives begins to become questionable. Genuinely new intellectual territory has been reached that is not construable from within only one perspective.

Several chapters aim explicitly at "deep integration," articulating KA and IA at a grain size that makes it difficult or impossible to distinguish "separate perspectives."

We briefly consider two different versions of deep synergy that appear in existing literature.

Reduction means that one has discovered that one level of explanation seems to account for most or all phenomena at "higher" levels. For example, all of chemistry is based on the basic principles of quantum mechanics. In this case, reduction is at best "in principle," since chemistry is a very particular context for doing quantum mechanics, and puts basic quantum mechanical principles in forms (the periodic chart of elements) and with attention specificities (e.g., binding energies of particular atoms) that are relevant to certain kind of phenomena (chemistry) and not others (nuclear reactions, plasma physics).

Reduction is not division by status. It is, minimally, unclear in this modern world whether chemists (biochemists among them) are doing more to enhance civilization than physicists, or vice versa. There is no point denying the value of each. Where fields have come to equilibrium with respect to one another, physicists (for example) do not dismiss the work of chemists (for example), nor do chemists believe that physicists are arrogantly encroaching on and doing violence to their territory. Reduction is not the bugaboo that it seems popular to assume.

Reduction puts a certain kind of emphasis on the "lower" of two levels. *Subsumption* puts the same emphasis on a "higher" level. Again, physics also provides a clear example. Electromagnetism and nuclear physics were eventually subsumed by "particle exchange" and quantum field theory, where the "sciences" that are subsumed turn out to be special cases.

In the learning sciences, whether subsumption or reduction is possible is, speaking minimally, unclear. At the cognitive vs. sociocultural level, however, one can certainly find claims or hopes that border on subsumption or reduction.

Socioculturalists often give voice to the concern that cognitivists have an unproductive (imperialist) reductionist program; historically, some cognitivists have at least bordered on claiming that culture might be an unproblematic extension of cognitive principles (Newell and Simon, more so by omission rather than commission). In terms of subsumption, Lave gives the impression that social perspectives (e.g., participation) will subsume phenomena such as "knowing and learning," and Greeno projected interaction to enfold (rather than to obliterate) cognition. Even if one of these eventualities is realized, whether the lower level of reduction or the upper level of subsumption can be seen to emerge unproblematically from one of the (definitively incomplete) existing paradigms of study, or whether such levels will emerge mutually or independently, is impossible to know.

Meta-scientific chapters engage some of these issues, particularly concerning levels.

Fusion

Finally, one might imagine a future stage of *fusion*, where distinct perspectives have become completely merged into an overarching one. We are a long way from that, so speculating about when, how, and even if, is not worth much effort.

These models represent potential outcomes of our work bringing together researchers from the KA and IA traditions, but they are equally applicable to an attempt to bring together any competing scientific paradigms. Our aim is that the analyses in this volume will illuminate how current theories and methods for studying learning and interaction, across different scholarly traditions, can be better articulated and coordinated. In this sense, by articulating KA and IA approaches, we hope to explore foundational issues emblematic of the larger cognitive–situative debate (and other such debates) in educational research, starting with a potential synergy that seems particularly likely to be immediately profitable.

Organization of the Volume

The volume is organized into four parts, with different intentions and somewhat different styles.

I. Foundations

The first part of the book provides a foundation for the rest. The first chapter lays out the "big-picture" background and intentions of this work, including the case for the compatibility between KA and IA with respect to theoretical focus, methodology, and analysis. The chapter also describes historical and current differences between the approaches, reasons for believing a joint analytical effort would be productive, and a description of the forms that such a joint effort might entail.

The two following chapters provide introductions to each of the main orientations that are articulated in this volume, Knowledge Analysis and Interaction Analysis. DiSessa, Sherin, and Levin situate KA with respect to historical and recent trends, give a description of theoretical and methodological foundations of KA, and then close by surveying the landscape of work done from a KA perspective and commenting on near-future pursuits of KA research. Hall and Stevens discuss some lines of work drawing upon IA methods, taking stock of almost 20 years of research since the publication of the fundamental IA reference by Jordan and Henderson (1995). At the same time, they identify new opportunities and problems in developing methods for Interaction Analysis that have a bearing on what counts as knowledge.

II. Synthetic Analyses

This part may be regarded as the main set of results that have emerged from the multi-year efforts of the larger KAIA project. Empirical chapters in this section draw from two main sources: (1) research that was explicitly initiated in conjunction with the Marin conference and follow-up meetings, and (2) research conducted by individuals who have been part of the ongoing conversations in this community and which explores issues related to the conference and volume. Most empirical chapters engage the task of repositioning phenomena typically understood from either a KA or IA perspective by creating a new, joint cognitive-interactional lens on the phenomena.

III. Theoretical, Methodological, and Meta-scientific Issues

This part aims to rise above (although sometimes enfolding) empirical work to directly reach important theoretical, methodological, and meta-scientific perspectives on a potential KAIA synthesis. Some of this effort aims to expose the essentially interactive and dialectical work (in the literal sense of people speaking directly back and forth at the original workshop or in subsequent meeting) that was done while working toward this volume. Other contributions are broader explorations of such issues, mostly occasioned by our interactive work. In several cases, the larger contributions spurred further critical, extending, or complementary commentary, which is also presented here.

IV. Reflections and Prospects

The final part of the volume includes reflections by the editors and chapters by Jim Greeno and Timothy Koschmann on the current state of the KAIA project and where the best future possibilities may lie.

Finally, readers can find thumbnail descriptions of all the chapters (save Part I and Part IV itself) in the editors' reflections chapter. These can interpolate between the aggregated introduction here and the chapters themselves.

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PART I

Foundations

1

COMPETENCE RECONCEIVED

The Shared Enterprise of Knowledge Analysis and Interaction Analysis

Nathaniel J. S. Brown, Joshua A. Danish, Mariana Levin, and Andrea A. diSessa

Knowledge Analysis (KA) and Interaction Analysis (IA)[1] are two approaches within the learning sciences that trace their primary lineage to opposite sides of the cognitive–situative divide. On the one hand, KA is deeply committed to the study of intra-mental phenomena, focused on understanding systems of knowledge. On the other hand, IA is deeply committed to the study of situated practice involving individuals, artifacts, and culture, focused on understanding systems of interaction. However, despite the apparent incompatibility implied by this history, there is much in common in their theoretical perspectives on knowing and learning and their suite of methodological and analytical tools. Over the last decade, a growing number of researchers have come to believe that these approaches are in fact deeply compatible and that a joint effort between KA and IA would represent a powerful synergy, a possible way to bridge the cognitive–situative divide and leverage the strengths of both approaches to improve education.

This volume is the result of a concerted attempt at capitalizing on synergy, bringing together researchers from both traditions to analyze data on knowing and learning while drawing on both approaches. This chapter lays out the case for the similarities between KA and IA with respect to goals, methodology, and theoretical orientation. Despite similarities, we also describe differences and points of contention between the approaches. The chapter concludes with a brief discussion of why we believe a joint effort would be particularly productive for the design of learning environments.

Competence Reconceived: Knowing and Learning as Performance in Context

Although they emerged as independent research traditions within different paradigms, Knowledge Analysis and Interaction Analysis can both be viewed as efforts

to rethink how we analyze an individual's observable performances. We use the word *performance* to capture the broad range of activities in which people engage; in the learning sciences, these performances are the observable cognitive and physical actions of learners or experts in a variety of settings, including schools, workplaces, research sites, and everyday life. Both KA and IA treat such actions as performances in the sense that they recognize their nature as dynamic and responsive to activity as it unfolds. That is, both approaches recognize that a performance is never a simple public display of a static mental state, but rather a highly contingent and continually adaptive response that is shaped by many aspects of the individual's history and by the context of action.

For the learning sciences, one crucial result of focusing on dynamic and contingent performances as a means of understanding knowing and learning is that researchers in these traditions have fundamentally transformed our conceptions of competence. Competence and its opposite – incompetence, deficiency, or naiveté – are treated not as static traits but as interpretations of performances that are situated in the immediate context, allowing the possibility for each action to be viewed (by both participants and researchers) as more or less competent based on both the physical and social context. The most poignant and likely most important cases of this reframing concern KA and IA researchers' challenging conventional characterizations of learners as systematically deficient. For example, KA researchers have challenged descriptions of students as holding fundamental and entrenched misconceptions of scientific phenomena, discovering that such students demonstrate a highly contextualized understanding, giving both normative and non-normative explanations for the same phenomenon in response to shifts in attention. As another example, IA researchers have challenged descriptions of students as being academically or behaviorally deficient, discovering that such students demonstrate a highly contextualized ability, giving both competent and deficient performances of the same academic skill in response to shifts in the interactional environment.

The root of revised conceptions of competence and incompetence lies in equally dramatic shifts away from orthodox conceptions of knowing and learning. Instead of assuming that knowledge and ability to learn are stable, KA and IA researchers began to focus on when and where (in which contexts and interactions) students are either viewed or treated as competent, and how novice competency evolves very gradually into expert competency. For both perspectives, *contextuality* became a central concern, and the term acquired a very different and deeper meaning than the ways in which it had been previously construed. Rather than expecting differences in competence depending only on broad strokes of context – such as in school vs. out of school, or English Language Arts vs. Mathematics – these perspectives came to understand contextuality as operating on a moment-by-moment basis, highly sensitive to the changing details of the situation as participants interact with the environment and people around them. Striking differences in competence can manifest within the same setting or

domain as a result of subtle differences in participants' focus of attention, the social arrangement, or the materials at hand.

Reconceiving competence and accounting for the contextuality of knowing and learning was not the only impetus behind the development of KA and IA, nor even necessarily the most important. However, it represents a fundamental commitment of both approaches, deeply connecting with their theoretical perspectives, preferred methodologies, and recommendations for educational reform. Relevant to the purpose of this volume, this joint commitment is a wellspring of the convergent evolution that makes it seem possible and desirable to search for common ground between KA and IA, and to look for ways to work together.

Parallel Examples from Knowledge Analysis and Interaction Analysis

To highlight the KA and IA convergence concerning contextuality, we review two chapters from edited volumes that were published in the mid-1990s, each describing the important role of this deeper sense of contextuality in understanding and explaining the competence of a student. We associate the first chapter with the cognitive tradition and argue that it is, despite appearing many years before the term Knowledge Analysis came into use, an example of the KA approach. We associate the second chapter with the situative tradition and argue that it is, despite appearing several years before the term Interaction Analysis came into common use, an example of the IA approach. The first, "What do 'just plain folk' know about physics?" was written by Andrea diSessa in 1996 and published in *The Handbook of Education and Human Development: New Models of Learning, Teaching and Schooling*, edited by Olson and Torrance. It describes apparent changes in the conceptual understanding of an undergraduate student, J, in subtly different contexts. The second, "The acquisition of a child by a learning disability," was written by Ray McDermott in 1993 and published in *Understanding Practice: Perspectives on Activity and Context*, edited by Chaiklin and Lave. It describes apparent changes in the reading ability of an elementary school student, Adam, in subtly different contexts.

Although both were and remain influential, neither of these chapters represents the first application of their respective approaches. The data underlying the argument in each chapter were collected many years prior (in the late 1970s and early 1980s), and had been previously analyzed in other published reports. Moreover, as described in the chapters in this volume on Knowledge Analysis (diSessa, Sherin, & Levin, this volume) and Interaction Analysis (Hall & Stevens, this volume), both of these traditions trace their roots even further back. Nor are these two chapters the most famous or highly cited examples of their respective approaches. Arguably, these might be the theoretical and methodological overviews provided by diSessa (1993) and Jordan and Henderson (1995). However,

this pair of case studies provides a striking parallel, illustrating a common awareness of the importance of moment-by-moment contextuality, and arguing forcefully for a reimagining of the notion of competence.

J and "What do 'just plain folk' know about physics?"

J was a female university freshman enrolled in introductory physics, participating in a series of seven one-hour clinical interviews intended to probe her understanding of physics. She enjoyed and had obtained good grades in physics classes. In the excerpts below, J exhibits an apparent inconsistency in her understanding of what happens when a ball is tossed into the air. First, she provides a normative physics account of the toss, emphasizing by asserting twice that the only force acting on the ball during the toss is gravity:

> J: Not including your hand, like if you just let it go up and come down, *the only force on that is gravity*. And so it starts off with the most speed when it leaves your hand, and the higher it goes, it slows down to the point where it stops. And then comes back down. And so, but *the whole time, the only force on that is the force of gravity*, except the force of your hand when you catch it. And, um, it … when it starts off it has its highest speed, which is all kinetic energy, and when it stops, it has all potential energy – no kinetic energy. And then it comes back down, and it speeds up again.
>
> *(diSessa, 1996, p. 720; emphasis added)*

Then, after being asked what happens at the peak of the toss, J gives an incorrect but common account (after waffling about the role of air resistance) in which a second force acting on the ball is in competition with gravity, initially stronger, then fading away:

> J: Um, well air resistance, when you throw the ball up, the air … It's not against air because air is going every way, but the air force gets stronger and stronger to the point where when it stops. *The gravity pulling down and the force pulling up are equal*, so it's like in equilibrium for a second, so it's not going anywhere. And then gravity pulls it back down. But *when you throw it, you're giving it a force upward, but the force can only last so long* against air and against gravity – actually probably more against gravity than against air. But *so you give this initial force*, and it's going up just fine, slower and slower because gravity is pulling on it and pulling on it. And it gets to the point to the top, and then it's not getting any more energy to go up. You're not giving any more forces, so the only force it has on it is gravity and it comes right back down.
>
> *(p. 720; emphasis added)*

Before the follow-up question about the peak of the toss, J appeared to be a competent physics student, giving a normative account of this phenomenon. Her subsequent account, however, appears to be deficient, invoking a common misconception, which was, in fact, previously documented and described as a (stable and pervasive) naive theory of mechanics (McCloskey, 1983). diSessa's (1996) analysis of J illustrates one of the central phenomena uncovered by conceptual change researchers working in the KA tradition: students can produce both normative and non-normative explanations in response to what is ostensibly the same line of questioning, in response to subtle shifts in attention to different aspects of the phenomenon. The interviewer's intervention, merely asking J to consider the top of the toss, was, in fact, designed to probe for the stability of her apparently normative model of a toss by subtly highlighting different aspects of the situation, leading to a reconfiguration of her model.

Adam and "Acquisition of a Child by a Learning Disability"

Adam was a male nine-year-old elementary school student, participating in a multi-year study in which he was videotaped in various settings, including classroom lessons and testing sessions, an after-school cooking club, and everyday life, to record naturally occurring examples of mental activities like attending, remembering, and problem solving. He was an officially designated Learning Disabled (LD) child. In the excerpts below, Adam exhibits what appears to be an inconsistency in his level of reading competence as he prepares bread in Cooking Club. First, Adam brushes off a mistake in which he and a friend, working together, add some ingredients in the wrong order and produce green cranberry bread, a behavior that is ultimately treated as a normal level of competence for these students:

> When the others gathered around to laugh, he simply said, "So I made a goddamn mistake, so what." The issue passed.
>
> *(McDermott, 1993, p. 287)*

On a different day, when working alone, Adam once again adds some ingredients in the wrong order, giving the impression to a fellow student that he is farther along than she in preparing banana bread, a context in which she participates actively in positioning Adam as needing more than a normal level of assistance, perhaps deliberately "putting him in his place":

> The girls are screaming and Adam whimpering. The double vowels in Lucy's talk are chosen to show that she is reading to Adam as one would read to a child in a phonics lesson. The scene opens with Adam returning from the adult with the sense that he knows what to do next.

Adam: Finally!
Where's the yogurt. Oh.
Nadine: You're *up* to yogurt already.
Adam: Yeah.
Nadine: Where's the bananas.
Adam: We, uhm, they didn't give us bananas yet.
Nadine: Well, go get 'em.
Adult: The bananas are here on the shelf.
Adam: But this is our second page.
Lucy: That is a teaspoon. That is a tablespoon.
Adam: This is a teaspoon, and it says
Lucy: It says tablespoons, twoo taablespooons.
Adam: We're right here, Lawana. Lawana, we're right here.
Lucy: That's
Nadine: That's the ingredients, not the instructions.
Lucy: That's baakiing powowder.
Adam: What do you mean, baking powder?
Nadine: You go in this order.
Adam: (Oh my God). What do you mean, in what order?
Nadine: Look! This is the instructions. That's what you need to do all this.
Adam: Ai yai yai.
One … Cup … Mashed … Fresh

Everyone looks away, and Adam returns to the adult for more advice.

(pp. 288–289)

When making cranberry bread incorrectly, Adam appeared to be a typical elementary school student, someone who makes the occasional mistake in reading but who is not marked by himself or his peers as incompetent. However, when making banana bread incorrectly, Adam appeared to be a typical LD student, someone who is expected to make mistakes in reading comprehension and who is publicly marked as incompetent. Note that both his peers ("That's baakiing powowder.") and Adam ("Ai yai yai. One … Cup … Mashed … Fresh") participate in this marking. Ironically, it seems likely that his difficulty might not be his self-mocked reading, per se, but rather his missing the cultural template that separates "ingredients" and "instructions." McDermott's (1993) analysis of Adam's experiences illustrates one of the central phenomena uncovered by educational anthropologists working in the IA tradition: students can be construed to be both competent and incompetent at what is ostensibly the same task, in response to subtle shifts in the social environment and the attention of others.

Reconceiving J's and Adam's Competence as Performance in Context

Both J and Adam look like a competent student in some contexts but like a deficient student in other, very similar contexts. Indeed, for an analyst not expecting

performance to be sensitive to subtle shifts in context, it may be tempting to search for a description of their behavior that identifies their "true" level of competence, dismissing inconsistencies as the result of unusual circumstances. For example, such an analyst might hypothesize that J doesn't really understand these physical phenomena, and is only able to say the right words that she learned in physics class until her understanding is probed more deeply. Or they might hypothesize that J does understand these phenomena well enough, but is momentarily tricked by a particularly complex or misleading question. Likewise, they might hypothesize that Adam isn't really able to read as well as he should be, and that he is only able to get by when the task is simple or he has enough external support from his friends. Or they might hypothesize that Adam's reading difficulties aren't deserving of particular note, but that he is being targeted and maligned by his peers when it suits their needs.

In contrast, and in their own ways, both diSessa and McDermott reject the notion that J and Adam have a "true" and stable (mis)understanding or (in)ability that is masked or revealed under certain conditions. Instead, they offer alternative descriptions in which competency is highly situated, and in which the observable differences in J's and Adam's performance are understandably tied to subtle differences in context.

In the case of J, diSessa (1996) argues that different knowledge elements[2] are activated in response to a focus on different aspects of the ball toss. When focused on the hand pushing the ball up, J describes an upward force as existing only while the hand is in contact with the ball, having activated the *force as mover* knowledge element. When focused on the apparent stopping of the ball at the peak of the toss, J describes two forces as being in balance, having activated the *dynamic balance* knowledge element. These knowledge elements are cognitive resources that J and others deploy to their advantage in different situations. *Force as mover* allows J to explain why the ball starts moving and to predict what will happen next. *Dynamic balance* allows J to explain why the ball appears to be stationary at the peak, despite the continuing action of gravity. Shifts in focus make one knowledge element more likely than the other. What J needs to succeed in school is to learn which knowledge elements are appropriate to use in which situations. *Dynamic balance* is not useless. But it just doesn't apply at the top of a toss. One would want to deliberately restructure the learning environment so that J can face her own complex contextuality: She needs to rethink how to construe a variety of contexts; she does not need to reject dynamic balance or think more abstractly.

In the case of Adam, McDermott (1993) argues that different social positionings[3] of Adam – alternatively as unremarkable or as an LD student – emerge in response to differing forms of attention to his performance. When other students have no need to pay close attention to his performance, Adam is able to pass off mistakes without lingering consideration. When others do have need to pay close attention to his performance, such as when Nadine feels threatened that he is farther along than her, Adam is caught up in a public display

of incompetence. These positionings are interactive resources that Adam and others deploy to their advantage in different situations. Positioning mistakes as no big deal allows Adam to navigate difficult tasks efficiently while maintaining dignity. Positioning Adam as LD allows Adam, his peers, and his teacher to explain away his poor performance. Shifts in the consequentiality of Adam's performance make one positioning more likely than the other. What Adam needs to succeed in school is to be positioned as unremarkable – as making mistakes that are no big deal – in more situations. That would require a deliberate restructuring of his learning environment to minimize the contexts in which he is positioned as being LD.

In both of these cases, we see how competence has been reconceived as performance in context. J and Adam are not described as having a static, inherent competence or constant relationship with others, but they are instead described as acting in ways that are sensitive to moment-by-moment shifts in systems of knowledge and/or interaction. This shared need to characterize and understand performance in context has led researchers in both KA and IA to gravitate toward similar methodologies and theoretical orientations. These are described in the following section.

The Shared Enterprise of Knowledge Analysis and Interaction Analysis

Reconceiving competence as performance in context, and the consequent need for analysts to carefully attend to and account for moment-by-moment shifts in systems of knowledge and/or interaction, has led to a number of similarities in the preferred methodology and theoretical orientation of KA and IA.

Methodology

As the brief transcripts above illustrate, both KA and IA attend closely to the details of talk on a moment-by-moment basis. To record these details, both J and Adam were videotaped. Video recordings have become common data in the learning sciences, for a variety of reasons (Derry et al., 2010; Goldman, Pea, Barron, & Derry, 2007). For one, video provides a stable, reviewable record of what occurs in educational settings. Moreover, video cameras have the potential to capture much more than human observers in terms of both quantity and quality.

These features make video recordings attractive to many researchers. However, what sets KA and IA apart from most other research in the learning sciences is an attention not only to *what* occurs in educational settings, but to *how* it occurs. Researchers working in these traditions want to know not only what a student says or does, but also why it was said or done in that particular way at that particular time. This presents an added methodological challenge, as the ways that

participants attend to context on a moment-by-moment basis – how they signal their understanding of what is happening and attempt to influence what happens next – are particularly difficult for a human observer to record, for several reasons.

First, people have multiple, simultaneous, and overlapping channels by which they can interact and communicate meaning, including speech, prosody (e.g., tone and emphasis), gesture, kinesics (e.g., gaze and body positioning), the manipulation of artifacts, and the creation and use of inscriptions and representations. As participants interact with each other and their environment, it would be impossible to monitor all of the ways they attend to context without the use of video recordings.

Second, meaning is generally construed through a combination and coordination of some or all of these channels, rather than a single channel in isolation (C. Goodwin, 2000, 2013). People often rely on coordinations of speech and gesture to communicate understanding (Goldin-Meadow, 2003, 2004). Coordinations of speech, prosody, and kinesics can communicate confusion, displeasure, or sarcasm (Goffman, 1983; C. Goodwin, 2007; M. H. Goodwin, 1990; Kendon, 1990). Manipulation and creation of artifacts, inscriptions, and representations involve gesture and kinesics, and are often coordinated with speech and prosody (Danish & Enyedy, 2007; C. Goodwin, 1994; Hall, 1996). Without video recordings, which can be slowed down and repeatedly viewed, it would be impossible to analyze how participants precisely time and coordinate their actions from one moment to the next.

Third, although humans are highly sensitive and responsive to subtle shifts in context, this sensitivity is largely intuitive and often not available for conscious reflection. People often don't explicitly realize what cues they are responding to and what cues they are sending to others, and their explanations of their behavior are often inconsistent with how they are observed to behave (Garfinkel, 1967). Video recordings allow researchers to avoid relying on intuitive and potentially inaccurate explanations of participants' behavior, instead allowing them to produce analyses supported by evidence that can be shared with and critiqued by other researchers.

The multifaceted, precisely coordinated, and largely unconscious nature of interaction presents an enormous challenge to human observers in the field. Video recordings, however, are uniquely positioned to document and support the analysis of performance in context, allowing researchers to identify and describe subtle shifts in context, why such shifts occur, and what effect they have on the participants.

While this methodological interest in video data is shared by both KA and IA, it is important to note that analysts in the two traditions often make different choices in what and how to record, and how to display this information in transcripts and research reports. As a later section argues, while these differences are theory-laden and consequential for both analysis and conclusions, and while they have historically marked points of contrast between KA and IA, we do not believe they represent an irreconcilable difference between the two approaches.

Theoretical Orientation

In order to account for moment-by-moment shifts in systems of knowledge and interaction, researchers in both the KA and IA traditions typically rely upon a complex-systems approach and develop theories with a smaller grain size than other traditions. Such theories propose a relatively large number of theoretical entities and processes, with the goal of explaining how and why observed behavior unfolds from one moment to the next.

KA researchers sometimes refer to their theoretical orientation as involving a process account (diSessa & Sherin, 1998) or a humble theory (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). In a typical KA analysis, descriptions of observed behavior are accompanied by an account of which elements of an individual's complex knowledge system are likely to have been activated and how those elements shape and are shaped by the evolving context. IA researchers sometimes refer to their theoretical orientation as involving a simplest systematics (Sacks, Schegloff, & Jefferson, 1974), an ethnographically adequate account (McDermott, Gospodinoff, & Aron, 1978), or a sequential organization (Schegloff, 1968, 2007). In a typical IA analysis, descriptions of observed behavior are accompanied by an account of which aspects of the complex system of social interaction are relevant and procedurally consequential (Schegloff, 1972) and how those aspects shape and are shaped by the evolving context.

The theoretical orientations of KA and IA, involving a complex-systems approach and proposing a relatively large number of theoretical entities and processes to account for the contextuality of performance as it evolves moment to moment, stand in contrast to theories that attempt to identify a relatively small number of underlying causes that govern wide swaths of human behavior. Indeed, recognizing the differences between their theoretical orientation and that of most other researchers in their respective fields, KA and IA researchers often explicitly contrast their work against such alternative theories.

Researchers in the KA tradition have often positioned their work in contrast to alternative theories of conceptual change in developmental and cognitive psychology. As an example of such an alternative theory, Gopnik & Wellman (1994) proposed a Theory Theory that seeks to explain young children's intuitive psychology and their understanding of mind. This theory identifies a small number of concepts, such as desire, perception, and belief, and posits that all children transition from one theory involving these concepts to a more normative theory between the ages of 2 and 5, passing through one intermediate stage along the way. As another example, Carey (1991, 1999) proposed a theory of conceptual change in science involving a small number of processes, such as differentiation and coalescence, positing that children's understanding of matter, life, and other domains develops via these pathways.

Similarly, researchers in the IA tradition have often positioned their work in contrast to alternative theories of human behavior in sociology and anthropology.

As an example of such an alternative theory, Parsons (1949) proposed a Social Action Theory that seeks to explain human social action within a culture. This theory identifies a small number of motivational factors, such as ends, purposes, and ideals, and posits that a society's culture is the product of such factors. As another example, Searle (1970) proposed a Speech Act Theory that seeks to explain the function of different utterances. This theory identifies a small number of speech acts, such as assertives, directives, commissives, expressives, and declarations, and posits that these different forms of speech indicate different intentions on the part of the speaker.

The alternative theories mentioned above have several features against which the theoretical orientations of KA and IA can be contrasted. First, these alternative theories assume that human behavior can be compactly described, invoking a relatively small number of theoretical entities and processes to explain a large domain such as conceptual change in science or the culture of a society. In contrast, researchers in KA and IA assume that human behavior is much more complex, involving – and requiring a description of – many theoretical entities and processes. Second, these alternative theories presume that the behavior of an individual is relatively consistent, given their current state. Even if theories or goals are not available for conscious reflection, they are nonetheless stable cognitive structures that will produce similar behavior across multiple contexts. In contrast, researchers in KA and IA assume that human behavior is highly sensitive to context, producing differences in behavior that can appear inconsistent and unstable. Third, these alternative theories often rely upon theoretical entities that are poorly differentiated from everyday ideas used by laypeople to describe why people act the way they do, such as concepts, beliefs, theories, goals, and intentions. In contrast, researchers in KA and IA believe it is necessary to propose novel, technically precise theoretical entities that require more analytic effort to apply to data.

Together, these contrasts highlight the fundamental differences between the theoretical orientations of KA and IA and those that are more common in related fields. When analyzed on a moment-by-moment basis, knowing and learning are revealed to be complex, constantly shifting in response to subtle contextual clues, and resistant to being described using common-sense language. A proper account of performance in context demands a relatively large number of technically precise theoretical entities and processes as well as careful analytic attention to the details of interaction.

Of course, this endeavor comes with its own set of challenges, challenges that are shared by researchers in both KA and IA. One particularly notable set of challenges arises from our shared commitment to doing detailed, moment-by-moment analyses of performance in context, while retaining a commitment to understanding and impacting education more generally, which involves much longer timescales. Minimally, KA and IA researchers must attempt to relate moments of knowing and learning that occur over seconds and minutes with longer-term changes in student and teacher practices that occur over the length

of a unit, course, educational career, or lifetime (e.g., Hall & Rubin, 1998). Saxe (1999) would call this coordination between microgenetic and ontogenetic processes. Moreover, some researchers (e.g., diSessa, 2000; Hall, Lehrer, Lucas, & Schauble, 2004) are also interested in long-term cultural changes, such as those brought about by changes in representational infrastructure and practices around that infrastructure, that operate on an even longer timescale and require further coordination with sociogenetic processes (Saxe, 1999).

Coordinating timescales of knowing and learning presents both practical and theoretical challenges. On the practical side, capturing learning over ontogenetic timescales produces an enormous corpus of video data for analysis. Studies of classroom learning frequently generate hundreds of hours of video data, which must be reviewed, content logged, and at least partially transcribed. Since not all the hours of data can be given equal attention, a sampling problem arises, and analysts must be wary of the extent to which moments that stand out are representative of the overall process. Transcribed examples in published reports often focus on interesting moments of insight or conflict, which suggests they may be relatively unusual. On the theoretical side, sociocultural researchers have pointed out how inextricably linked these levels of analysis are, arguing that they cannot be conveniently separated but must instead be understood and analyzed in relation to each other (Cole, 1996; Lemke, 2000; Rogoff, 1995; Saxe, 1999).[4]

The preceding sections have made the argument that KA and IA share much in terms of methodology and theoretical orientation, both in their commitments and in the challenges they face. However, a larger historical difference in theoretical paradigm represents a hurdle that must be overcome. This historical difference arises from the traditional association of KA and IA researchers with opposing sides of the cognitive–situative debate that emerged in the 1990s. This historical legacy, and the residual but very real points of contention between the KA and IA approaches, are described in the following section.

Uneasy Bedfellows: Tensions Between Knowledge Analysis and Interaction Analysis

As has been often noted (e.g., Anderson, Greeno, Reder, & Simon, 2000; Sfard, 1998), the cognitive and situative paradigms define learning in different ways. For cognitivists, learning is best understood as involving knowledge, with a focus on the nature of how knowledge is represented in the mind and how mental representations are acquired and modified. For situativists, learning is best understood as changes in practices, with a focus on the similarities and differences between practices in different human pursuits and how practices are adopted and adapted.

Commitments to knowledge and practice are still hallmarks, respectively, of the KA and IA approaches. Knowledge analysts hold an explicit commitment to the existence and central importance of knowledge, studying its nature as a complex

system or ecology of many types of mental representation of various forms and functions. Interaction analysts, on the other hand, hold an explicit commitment to the existence and central importance of human social interaction, studying how individuals and communities adopt and adapt social, cultural, and historical practices.

For some researchers in the heydays of the cognitive–situative debate, mental representations and practices were treated as incompatible perspectives on knowing and learning, with the competing perspective at best dismissed as irrelevant or at worst decried as undermining education. While the tone of this debate has softened considerably since the 1990s, the contentious history of the cognitive and situative paradigms has an enduring influence on the relationship between KA and IA. Despite the similarities in methodology and theoretical orientation described previously, consequential differences do exist in terms of the analytic approaches and research questions that researchers pursue in practice. These differences, which have historically been a source of tension between knowledge and interaction analysts, will need to be addressed in dialogue between the two perspectives. Indeed, fostering this dialogue is one of the explicit purposes of this volume, and many of these issues are discussed in later chapters. In the following sections, two particularly salient tensions are highlighted as they pertain to the analysis of performance in context: which aspects of performance are given central focus, and which settings are selected in which to observe performance.

Selective Focus

As previously discussed, people have multiple, simultaneous, and overlapping channels through which they can interact, communicate meaning and intention, signal their understanding of the current context, and attempt to influence how that context evolves. For this reason, researchers from both the KA and IA perspectives rely upon video recordings to capture as much of this complexity as possible. However, not all of this complexity can be focused on simultaneously during an analysis, nor can all of it be described or represented in reports of research. Consequently, at any given time, analysts must selectively focus on certain aspects of performance while backgrounding others.

It is problematic to associate either KA or IA with a stereotypical selective focus, given that each field contains a wide variety of approaches. Moreover, individual researchers focus on different aspects of performance in different reports (for example, contrast diSessa [2007] with diSessa [1996], and McDermott, Gospodinoff, & Aron [1978] with McDermott [1993]). However, despite this within-perspective variety, published KA analyses have tended to look different from published IA analyses for a variety of historical, theoretical, and analytical reasons. For example, in comparing the transcript excerpts at the beginning of this chapter, it is apparent that McDermott (1993) has chosen to represent more detail about prosody (i.e., tone and intonation) than diSessa (1996).

Differences like these have been a source of tension between KA and IA because of the relationship between how performance is represented and the researcher's theoretical and analytical commitments (Bucholtz, 2000; Hall, 2000; Jordan & Henderson, 1995; Ochs, 1979). On the one hand, if a researcher represents a particular aspect of performance in a transcript, it is straightforward to assume that they focused on that aspect in their analysis and found it to be relevant and consequential. For example, McDermott (1993) provided prosodic detail in his transcripts because key to his analysis is the claim that the participants in Cooking Club are using prosody to establish and maintain social positioning. On the other hand, if a researcher does not represent a particular aspect of performance in a transcript, it is not at all straightforward to interpret the reason. For example, diSessa (1996) did not represent prosody in his transcripts and McDermott (1993) did not represent kinesics or gesture in his transcripts, and these aspects of performance may have been omitted for any number of reasons. Perhaps they were analyzed in detail but backgrounded as not being consequential for these participants at this time. Perhaps they were attended to in broad strokes but not considered deserving of a closer analysis. Perhaps they were assumed a priori to be irrelevant for the current analysis. Perhaps they were attended to intuitively but without particular and systematic reflection. Perhaps their consideration was entirely absent, as might be the case if the video recordings were transcribed before analysis. Without a dialogue with the researcher, it is impossible to know why a particular aspect of performance may have been backgrounded.

The issue of selective focus is not unique to KA and IA. Because of the complexity of knowing and learning in context, it is unlikely that a universal, one-size-fits-all approach to analysis would ever be useful, even if it were possible. Different aspects of performance must be focused on in different settings and in service of different research questions.

Within a community with a shared history, researchers are often more willing to accept the selective focus of their colleagues, believing, perhaps too complacently, that choices were made in good faith and that a widening of focus is unlikely to undermine the researcher's conclusions. In contrast, researchers are often less willing to accept the selective focus of researchers in a different community, believing, perhaps unfairly, that choices may have been made out of ignorance and that a widening of focus may undermine or even contradict the researcher's conclusions.

Given the contentious history of the cognitive and situative paradigms, it is understandable that researchers in KA and IA might interpret salient differences in selective focus as emblematic of deep and perhaps insurmountable divisions. We, however, disagree. We believe that researchers working in both perspectives are likely to benefit from a study of how the other side operates. By challenging each other to revisit basic assumptions about analyzing and representing performance in context, we expect a dialogue between KA and IA will lead to increased sensitivity to the aspects of performance to which analysts can and should attend

in order to better understand learners' activities. Indeed, we believe this is one of the great benefits of working together: learning about and leveraging the ontological and analytical innovations of both perspectives to understand more about how performance is sensitive to systems of knowledge and interaction.

Research Settings

One of the guiding principles of both KA and IA is that, since performance is highly sensitive to context, conducting research in multiple settings is both productive and necessary for understanding processes of knowing and learning. However, because the possible range of settings that could be studied is so vast, researchers must necessarily select particular settings to observe, thereby excluding, at least temporarily, others.

Just as it was for selective focus, it is problematic to associate either KA or IA with a stereotypical research setting, given that each field has conducted research in a wide variety of settings. Moreover, there is considerable overlap, with researchers in both traditions having studied classrooms, both "as they are" and those in which the researchers have intervened. However, despite this variety and overlap, KA and IA researchers have tended to supplement classroom studies with different research settings in which knowing and learning can be seen. For example, to return to the case studies at the beginning of this chapter, diSessa (1996) studied J in a series of clinical interviews, while McDermott (1993) studied Adam in an after-school club and in other "everyday life" settings.

Differences like these have been a source of tension between KA and IA because of concerns about ecological validity. Underlying the choice of research setting is the assumption that it will reveal important and useful information about processes of knowing and learning that will be relevant to other settings, including learning environments. Non-classroom-based KA studies often involve clinical or semi-structured interviews that probe how students think about unusual phenomena or how they respond to questions they may never have considered. The benefit of these settings is that the researcher can obtain focused, nuanced information about knowledge resources that might otherwise be difficult or time-consuming to observe. Non-classroom-based IA studies often involve students in after-school programs, experts engaged in professional practice, or individuals interacting with friends or family. The benefit of these settings is that the researcher can obtain information about highly routinized patterns of interaction and how different patterns affect knowledgeable performance. What all of these studies have in common is the assumption that these knowledge resources or patterns of interaction will be relevant in other settings.

Issues of ecological validity and generalization across research settings are not unique to KA and IA. Because of the complexity, contextuality, and adaptability of human behavior, it is unlikely that researchers could ever fully plumb the depths of human performance. Particular settings must be chosen because of

what they can reveal, and despite what they can obscure, about knowing and learning.

Within a community with a shared history, researchers are often more willing to accept the research settings of their colleagues, believing, perhaps too complacently, that findings will translate to other environments. In contrast, researchers are often less willing to accept the research settings of researchers in a different community, believing, perhaps unfairly, that findings will be limited to that narrow context.

Given the contentious history of the cognitive and situative paradigms, it is understandable that researchers in KA and IA might interpret salient differences in research settings as emblematic of deep and perhaps insurmountable divisions. Once again, however, we disagree. We believe that researchers working in both perspectives are likely to benefit from expanding the settings in which they conduct research. By actively comparing and contrasting performance in a wider range of settings, we expect a dialogue between KA and IA researchers will lead to increased understanding of the contextuality and adaptability of processes of knowing and learning. Indeed, we believe this is one of the great benefits of working together: learning about and leveraging what both perspectives know about the relationship between performance and setting to guide the design of novel and more effective learning environments that draw on systems of both knowledge and interaction.

The Time for Synthesis Is Now

While it may have been unavoidable, and even prudent, for KA and IA to have evolved independently, we believe the time has come for researchers to actively investigate how these perspectives could be synthesized. No longer should we be content to set aside considerations of individual learning (as proposed by McDermott, 1993) or cognition (as proposed by Latour, 1988). Likewise, it is time to move beyond views of cognitive processes as timeless, a-cultural, and immune to deep influence by real-time social and material interaction (as implied by, e.g., Anderson, Reder, & Simon, 1997; Newell, 1980, 1990). The synthetic agenda we have set for ourselves in this volume is to tackle head-on both knowledge and interaction as they contribute to performances of knowing and learning in context.

There is every reason to believe that this agenda will be complex, that the sum of KA and IA will be greater than its parts. In fact, complexity is everywhere evident. KA has established that systems of knowledge are complex, and IA has established that systems of interaction are complex; accounting for the relations between these two complex systems will add yet another layer of complexity. Competing claims will have to be reconciled, misattributions will need to be clarified, and productive synergies will need to be identified. The chapters in this volume are a welcome start to this process, but we expect and hope that others will join us in this effort.

Notes

1 From the outset, we want to emphasize that this ordering implies no relative value. Whenever the two approaches are listed in the text (e.g., "KA and IA") or in the structure of the volume, the reader should assume they are being discussed as equals.
2 As described in diSessa (1996), these are examples of a specific form of knowledge element called phenomenological primitives or p-prims (diSessa, 1993).
3 As described in McDermott (1993), these positionings are similar to those described by Garfinkel (1956) and Goffman (1979).
4 The problem of coordinating timescales from the KA perspective is discussed in diSessa, Sherin, and Levin (this volume).

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2

KNOWLEDGE ANALYSIS

An Introduction

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The purpose of this chapter is to introduce one of the two perspectives that are highlighted in this volume – Knowledge Analysis (KA). Briefly, KA is the study of the content and form of knowledge for the purpose of understanding learning. Our goal is to give a relatively deep account of KA, one that articulates its core premises with some precision. At the same time, we attempt to capture some of the breadth of the work that has been carried out under the KA banner. Up to this point, principles and practices of KA have been articulated mainly in the methods sections of a diverse body of research studies on thinking and learning, across several topic areas (mechanics, statistics and probability, algebra, special relativity, etc.). Thus, in this chapter, we aim to synthesize KA in a way that allows readers to recognize the unifying methodological principles behind a large body of research, while also giving insight into the real-world practice of Knowledge Analysis.

Readers outside the community of researchers who draw upon the methods of KA might be more familiar with two connected terms, *Knowledge in Pieces* (KiP) and *phenomenological primitives* (p-prims). To help readers get grounded with respect to the methodological focus of this chapter, here is how we understand the relationships among these terms:

- *KiP* is the name for a class of theoretical models of knowledge – models in which knowledge is seen as consisting of a complex system of elements.
- *P-prim* is the name for an element in one such model, a model that was developed by diSessa to describe intuitive knowledge of the physical world.
- KA is the name for the methodological approach to studying knowledge employed by KiP and allied researchers. In principle, research programs built on the basis of KA could result in very different kinds of models of knowledge. For that reason, KA is the most encompassing of these terms.

The purpose of this chapter is to take on the most expansive and explicitly methodological category, KA. However, because of the way that theory and method are linked, we believe it is important simultaneously to address the epistemological arm of the program, which here means, for the most part, KiP. In addition, we take it to be important to exemplify the program with specific models of knowledge that have arisen from employing KA. We will use p-prims and another prominent model arising from KA, coordination classes, as leitmotivs to exemplify a number of aspects of KA work. Several other contributions to this volume employ these models in one way or another, so defining and discussing them as examples here will do double duty.

We begin the main work of this chapter by situating KA historically, as well as in relation to more recent trends. Following this situating, we describe in some detail the theoretical and methodological foundations of KA. The final two sections of the chapter give our take on the current state of KA research. We first describe the broad landscape of current and past KA work. Then, in the last section, we lay out what we see as the most important near-future pursuits for KA research.

A Little History

There are good arguments that knowledge is among the most important concepts in education, if not the most important one. Students come into class without the knowledge that we intend them to have, and they go out (we hope) with it. However, the study of knowledge is a subtle business. What is knowledge, and what is the right language with which to characterize it in order to understand how individuals learn?

With the dawn of the cognitive revolution in education research, it seemed possible that we had a set of tools that would provide us with a solid handle on knowledge. In the cognitive perspective, knowledge is constituted in mental representations and processes of individuals – a type of mental stuff. Furthermore, knowledge is not correct information that exists outside of individuals, say, in textbooks. The cognitive revolution gave us methodologies for studying mental representations, as well as some language for describing them.

With the tools provided by the cognitive perspective came a new set of debates among educational researchers about the nature of knowledge (diSessa, 1993; Vosniadou & Brewer, 1992). While the nature of knowledge and learning has been a topic of study in several fields, many of the debates spurred by the cognitive revolution played out in the context of science teaching and learning, especially within the domain of physics. At their heart, these debates had to do with what students know about physics prior to formal instruction. It is in this context that KA was born.

Why did learning in the domain of physics play such an important role in the unfolding of the cognitive revolution in education research? To some

extent, this is probably an accident of history. But there are also reasons that the learning of physics highlighted what would turn out to be extremely important issues. On the one hand, formal physics seems to encompass a collection of ideas that lies far beyond the informal understanding of the average person. However, at the same time, it is manifestly true that all humans understand a tremendous amount about the natural world simply from our everyday interactions in this world. This leads to some core questions. For example, does it make sense to say that people know any physics, per se, prior to formal instruction?

Indeed, one of the earliest advances associated with the cognitive revolution was the demonstration that students do, in fact, know a great deal about the physical world prior to any formal physics instruction, and this knowledge lingers during and after instruction. However, it was found that even successful students harbored profound and robust "misconceptions." These misconceptions were profound in the sense that they pertained to some of the most central ideas in physics. They were robust in the sense that they seemed to be extremely resistant to change with instruction.

The recognition that a "naive physics" exists led to new questions about the nature of this knowledge and its role in learning. How, for example, is naive physics like and unlike formal physics knowledge? What happens to that knowledge during instruction? From the early 1980s to the early 1990s, the state-of-the-art presumption about naive knowledge in physics was that it was, in some fundamental respects, very similar to formal knowledge. Although this naive knowledge was wrong in content, it was nonetheless theoretical, coherent, "remarkably articulate," and fairly easy to characterize (McCloskey, 1983). Attributing the status of "theory" to naive ideas is, in general, known as "the theory theory." The most widely recognized such model was that students possessed a theory, called the impetus theory, wherein objects that are impelled to move acquire an "impetus," an internal force that drives them forward, but that impetus gradually dissipates. Furthermore, because this naive theory is incorrect, it was assumed that formal instruction must confront and replace it. An early and prominent version of this view appeared in an edited volume called *Mental Models* (Gentner & Stevens, 1983).

The origins of knowledge analysis might be traced to a set of ideas articulated by diSessa around this time. In this same edited volume, diSessa contributed a chapter that argued against the view that naive physics should be viewed as theory-like. Real theories, he argued, are based on a small number of laws that are applied consistently across a wide range of circumstances. In contrast, he maintained that naive physics consists of a large number of elements of knowledge that are inarticulate, seemingly contradictory, and which are applied in a manner that depends sensitively on the context at hand (diSessa, 1983, 1988, 1993). Furthermore, he argued that far from replacing this body of intuitive knowledge, instruction in formal physics must build a new understanding of physics on the

foundation it provides. diSessa called these knowledge elements *phenomenological primitives*: p-prims, for short.

The notion of p-prims was a seed out of which the larger epistemological and methodological program would grow. diSessa's turn marked a dramatic shift away from the epistemological assumptions behind the "theory theory" of naive physics. It is a shift that has implications for how we conceptualize knowledge and learning across many disciplines. The assumptions of this new program generalize those behind p-prims: (a) Prior (intuitive) knowledge will often be difficult to see, inarticulate, and will be applied in a manner that depends sensitively on context. Nonetheless, (b) even in the most abstruse of domains, learning always builds on this wealth of knowledge.

Situating Knowledge Analysis

The early incarnation of Knowledge Analysis described above was framed as a response to the literature on physics misconceptions and naive physics. But it was built on and reflected a set of ideas that had been developed over the preceding decades, and that continued to percolate around diverse areas of the cognitive sciences. For example, Minsky (1986) argued that minds are best understood as a community of voices – a "society of mind." And, outside of research on naive physics, the majority of cognitive literature, even at this early time, adopted a view in which human knowledge was seen as consisting of a large number of elements, activated in a manner that depends on context. For example, early articulations of the notion that knowledge consists of *schemas* had this character. Similarly, a significant part of the literature on problem solving, though concerned with behavior of a somewhat different character, nonetheless saw knowledge as a large number of *productions* that were cued and employed in a context-dependent manner (Anderson, 1987; Newell & Simon, 1972). In addition, researchers in artificial intelligence, working in parallel to model how humans understand the physical world, built systems that incorporated ideas similar to those expressed in diSessa's early work on naive physics (de Kleer, 1986; Forbus, 1984).

There was another popular strand of research in the 1980s and 1990s that is important to the story of knowledge analysis, and to this volume. At the same time that the cognitive revolution was beginning to take hold in education research, there was a growing voice of research that explicitly reacted against it. This movement, known by such names as "situated cognition" and "situativity theory," was epitomized in the work of Jean Lave (1988, 1991), Lucy Suchman (1993), and James Greeno (1998). Although this work was usually framed as a reaction against the cognitive view, it was nonetheless built on many of the same observations as early Knowledge Analysis work; namely, it was built on the observation that human cognitive behavior is highly sensitive to exigencies of context (consult Brown, et al., this volume, for examples and a broader discussion of contextuality

as a common concern in both Knowledge Analysis and Interaction Analysis). Suchman (1987) famously likened cognitive behavior to the experience of canoeing down rapids:

> When it really comes down to the details of responding to the current and handling a canoe, you effectively abandon the plan and fall back on whatever skills are available to you. The purpose of the plan in this case is not to get your canoe through the rapids, but rather to orient you in such a way that you can obtain the best possible position from which to use those embodied skills on which, in its final analysis, your success depends.
>
> *(p. 52)*

Researchers such as Lave and Suchman took observations of context dependence as motivation to reject core elements of the cognitive perspective on thinking and learning. Some of these researchers maintained a version of an information-processing perspective but saw representations (knowledge) as spread over people and the environment, rather than solely localized in the mind (Hutchins, 1995). Others, such as Jean Lave, rejected the information-processing metaphor entirely.

Jumping to the present day, there is much in the intellectual environment that remains the same, but there are also new developments. Researchers in science education continue to produce new examples of misconceptions across various topics. In some respects, the "theory-theory" view of naive science knowledge continues to exist, but it has gone in a number of diverse directions. Examples are Chi's work on ontological categories (Chi, 1992, 2013) and Vosniadou's (2013) continued work on mental models and framework theories. In the developmental arena, researchers such as Carey (1985, 2009) and Gopnik (2003) have proposed extensive frameworks in which theory-like systems appear.

In some respects, it is possible to see Interaction Analysis (IA) as a descendent of the situated cognition of the 1980s. But there have been important transformations. IA is not defined primarily as a reaction against traditional cognitive science, as was situated cognition. Instead, it incorporates the insights and methods of other analytic traditions, such as conversation and discourse analysis. This transformation is important for the work of this volume; it means that it might well be possible to adopt a stance in which IA and KA are seen as complementary, and not opposing, styles of work.

There are also some new theoretical trends. One example is the growing prominence of *embodied cognition* (Barsalou, 1999; Lakoff & Núñez, 2000; Varela, Rosch, & Thompson, 1992). Embodied cognition provides an interesting case for a number of reasons. On the one hand, work that describes itself as about embodied cognition has, from the start, had a strong superficial resemblance to work conducted under the Knowledge Analysis banner (see, for example, our later discussion of non-propositional encoding). One of the core aims of both

traditions has been to trace the bases of disciplinary expertise in domains such as physics to the knowledge that is employed in everyday thinking and action. For example, in some of his earliest work, diSessa suggested how parts of formal physics understanding might be built, at least in part, out of elements of simple everyday knowledge, such as notions of balancing and constraint. Similarly, working in one tradition of embodied cognition, Lakoff and Núñez (2000) attempted to show how even the most abstract mathematics was built on a small number of "conceptual metaphors," themselves rooted in shared bodily experience.

Given this similarity, one might expect to see great affinity among KA researchers for embodied cognition. However, as should be evident from other contributions to this volume, researchers in IA seem to have much more strongly and explicitly embraced embodied cognition. This is likely, in part, because embodied cognition is sometimes framed as rejection of the information-processing tradition out of which KA evolved. Thus we see that, although much has changed, some of the core debates about the nature and source of knowledge that existed when Knowledge Analysis was born continue to the present day, albeit in new forms.

Theoretical Foundations for Knowledge Analysis

In principle, KA should be of interest to a variety of theoretical perspectives on knowledge. When we can, we take such an expansive perspective. However, we illustrate more specific methodological foci using arguably the most visible theoretical orientation among those adhering to KA principles, Knowledge in Pieces (KiP). In doing so, our intention is not to marginalize other points of view but only to avoid complications and caveats while still providing helpful detail.

As stated in the introduction, KA is the methodological arm of an epistemological approach to learning. It focuses on the nature of knowledge and its transformations during learning. As an epistemological approach, it shares some concerns with philosophical approaches to knowledge, with Piaget's genetic epistemology (1972) and related educational approaches such as constructivism, and also with cognitive modeling. Cognitive modelers aim to make explicit, computer-runnable models of what knowledge people have and also how that knowledge works and develops. On the other hand, KA aims to produce a new and distinctive view of knowledge, one that is truly responsive to educational realities. It may be regarded as a more ambitious and technical version of constructivism. KA's educational focus certainly distinguishes it from philosophical orientations, probably also from Piagetian views, and, in some ways, from cognitive modeling as well. So, the knowledge relevant to KA turns out to look different from, even opposed to, that endorsed by other traditions. To remind readers of this fact, and to help ward off importing unhelpful assumptions from other perspectives, we call our focus knowledge* (pronounced "knowledge star," meaning a variant, updated version of the conventional concept of knowledge).

Principles

We list six principles of KA. One at a time, these principles are not unique to KA. However, as a set we believe they characterize a unique program of research.

1. *Knowledge is constituted in mental representations*. This first principle announces the focus of KA on knowledge. As mentioned, KA is essentially cognitivist in that we aim to describe knowledge and learning in terms of mental representations. One should think of this as aiming toward, but not necessarily achieving, just now, models of thinking and learning that are complete and precise enough to "run," say, on a computer.
2. *Knowledge can be non-propositional and encoded in various modes (e.g., visually encoded).* This principle, and the two that follow, characterize our assumptions about the nature of the knowledge we study; they distinguish knowledge★ from a more typical view of knowledge. Knowledge★, particularly in its early-developing forms – such as most of the intuitive and tacit foundations of cultural or individual knowledge – often seems difficult to express in words. Instead, the encoding of various ideas may be closer to that of sensory experience, such as kinesthetic experience, patterns of visual configuration, or instinctual affective reactions. In this way, as mentioned, aspects of KA are consonant with principles of embodied cognition. In parallel, knowledge★ is frequently, if not essentially, *reactive*, being called automatically into action by perceived circumstances. Reactive is in opposition to *reflective*; reflective knowledge may be discussed as an object of consideration and deliberately considered as to whether it should apply or not. Reactivity is the essential point in Suchman's canoeing metaphor.
3. *Studying the mental representations of individuals requires highly nuanced accounts of content*. KA has a strong commitment that what students (or experts!) mean by anything they say is extremely subtle while also being critical in understanding learning trajectories. Is it fair to say that the content of students' intuitive physics is equivalent to a self-aware belief that "forces impart an impetus that dies away"? KA studies often develop frameworks for describing details of the content of students' knowledge★, not just general laws of thinking or learning. See, for example, the framework for specification of aspects of the concept of force in diSessa, Gillespie, and Esterly (2004). An emphasis on the content of students' thinking makes KA studies all the more useful in the construction of plausible curricula, especially when building on naive ideas. In addition, the nuances of knowledge★ specification make micro-assessment and tracking of individuals' learning and individual differences in understanding much more tractable, even if these tasks are, at this stage, very time-consuming.
4. *Intuitive knowledge is an important target of study and forms of naive knowledge are diverse, rich, and generative.* The knowledge★ that humans possess is inherently diverse (encompassing many varieties) and rich (capable of being combined

and deployed in many different ways). In addition, time and time again one discovers that humans can quite easily adapt and extend what they know, so that any closed account of knowledge*, say, "what children know about any topic at a particular age," will necessarily have fuzzy edges and wide variability across individuals. Indeed, the seeds of later, "better" ways of knowing seem often to come from nearly invisible details in the depths of prior stages of knowing.

5. *Studying knowledge requires full accountability to data records that capture thinking and learning processes*. Our final two principles capture our focus on understanding the complexities of real-time thinking. KA is committed to producing models consistent with real-time process data; that is, data that are generated on a timescale of seconds to minutes as individuals solve problems, think out loud, or interact with other individuals. (See the discussion of microgenetic and microanalytic study, below.) Real-time accountability is rather uncommon across the existing range of cognitive or sociocultural approaches to studying learning. Even within conceptual change research, it is uncommon for researchers to attend to the thought sequences of students while learning. Instead, much conceptual change research produces "snapshots" of understanding at various points in time. Other approaches to learning look only at "factors" and their influence. The KA commitment is that one can see a lot about knowledge* in ongoing thought and action. From a practical point of view, also, teaching requires "massaging" students' thinking in real time, so it behooves us to know how that works. Finally, and most broadly, it also seems incontestable that, eventually, we should have a scientific account of the real-time details concerning how students think and learn.
6. *Intellectual performance is highly contextual*. KA research has documented how a person's intellectual performance is highly contextual, dependent on the particular situation in which one acts (diSessa, 1996; Wagner, 2006). This contextual dependence is frequently highlighted by approaches, such as situated cognition and interaction analysis, that do not focus on identifying knowledge. However, we believe it is simply untrue that cognitive modeling has difficulty with explaining contextuality. Cognitive modeling can also involve highly reactive knowledge, which is minutely and intimately dependent on both situations and the local and long-term history of the learner. If there is a difference of orientation among KA, IA (and situative approaches), and cognitive modeling along the dimension of contextuality, it might have to do more with *how* we conceptualize the particulars on which thinking depends rather than *that* contextuality is a factor. Concerning learning, contextuality is a two-edged sword. On the one hand, it bespeaks responsiveness to circumstances and richness of possibilities. On the other hand, the broad systematicities that constitute the essence of science are inherently difficult to achieve using highly contextual ideas.

Counter-principles

It helps in defining an intellectual line to delineate the things it does *not* espouse, or actively opposes. Here are some important ones for KA.

1. *Rejecting the "subset" model*. It is a natural instinct to view knowledge from an expert's point of view, listing the things s/he knows, and then trying to map the novice state in those terms. In such a view, knowledge is understood to be a subset of an expert's knowledge. "Here's what the student knows; here's what s/he doesn't know." However, as was pointed out, many naive ideas may be quite productive – both in their everyday use, but even more importantly, in contributing to "improved" ideas in learning. Yet, they may not, themselves, count as true, or even well-formed, ideas. The subset model tends toward characterizing students as thoroughly ignorant of scientific ideas, in effect opposing the basic constructivist principle that we must understand how scientific ideas arise from non-scientific ones. The basic lesson is that we must understand pre-instructional knowledge in its own terms.Once we understand how scientific knowledge comes to be, another epistemological revolution follows. Experts will not look at all like textbooks; their minds will not be filled with knowledge corresponding one-to-one with the topics and principles in books or lectures. In principle, one could start by studying how experts *really* think, and then move "backwards" toward the untrained state. In practice, most KA researchers believe it is easier and more important to approach professional techno-scientific thinking by understanding how it emerges out of naive thought.
2. *Skepticism toward common-sense knowledge terms.* In our everyday lives, we all regularly converse about knowledge. We talk about what our friends know and don't know. We talk about our own beliefs. As instructors, we might talk about the concepts to be covered in our courses. However, we believe that everyday terms such as concept, belief, and theory are vague, loaded with implicit assumptions, and not up to the task of a careful scientific analysis of knowledge. In fact, a decent high-level description of what we want from a KA point of view is a set of models of knowledge* types that are much more specific and durable than previous theories, truly accountable to all that we can see in humans' reasoning and knowing. See diSessa and Sherin (1998) for a broader discussion of why the concept of "concept" is theoretically lacking.In addition to being cautious about drawing on everyday terminology, we must be cautious about our use of related terminology from other academic disciplines. One example is the notion of *knowledge* as it is employed by philosophers. Traditional philosophical approaches take truth as an essential characteristic of knowledge – knowledge is necessarily true; things that are false or have no truth value are just something else. But, in any

study of knowledge*, truth is neither here nor there. Much of knowledge* – the resources for developing solid, effective scientific understanding – cannot count as true. So, they may escape our study. Instead, we need to trace the lines from perhaps inchoate, intuitive, inarticulate ideas through to the best understanding that modern science allows. We need an embracing idea of knowledge*.

3. *Skepticism toward a priori "modeling languages."* KA is skeptical of a priori approaches to defining knowledge, or ones that start, for example, with models of knowledge* that appear to prioritize ease of mapping to computational constructs[1] (Newell, 1980). The KA program seeks refined, complete, and explicit understanding of knowledge* and its associated processes of development and deployment, just as cognitive modeling does. But we aim for more direct empirical accountability in terms of forms of knowledge *as we discover and validate them in the thoughts and actions of our subjects.*

An Integrative View of the Program

Distinct principles or counter-principles help define a research program, but they disassemble it, rather than creating a gestalt. This section aims at creating such a gestalt in three stages. First, we introduce an image of the encompassing program as studying the form and content of, and transformative principles behind, knowledge* viewed as an evolving complex system. Second, we identify several modes of research that contribute to somewhat separable sub-goals to achieving the overall goal. Third, we show that identifying these modes and their relations contributes to an understanding of how apparently different kinds of studies can contribute to the same overall goal.

A Systems Perspective on Change and Development

KA focuses on systems of knowledge, including many instances of many different kinds of knowledge. Think of a "conceptual ecology" involving many concepts, many beliefs, and many intuitions (assuming, for simplicity, that concepts, beliefs, and intuitions constitute a sensible partitioning of relevant kinds of knowledge*). At any point in time, we need to list all such entities, and describe their relationships. For example, one intuitive belief, a documented "misconception," might relate two concepts: Any *force* (concept 1) gives rise to a *speed* (concept 2) *in proportion to* (relation between concepts) the force's magnitude.

Over time, particular new elements arise, and even new types of elements. Some older elements may fall out of use, or, more likely, remain but be used only for everyday, rather than techno-scientific, purposes. In addition, connections change, as the knowledge system is reconfigured to achieve expertise. Figure 2.1 is static, but of course, an important part of this inquiry is the principles by which

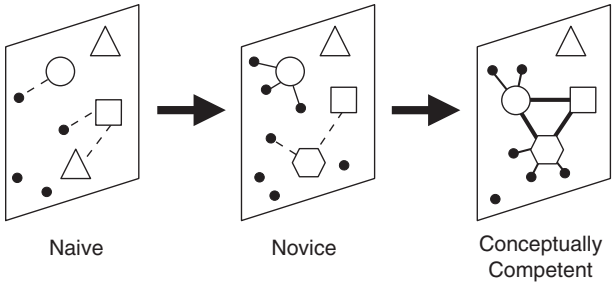

FIGURE 2.1 Snapshots of the development of knowledge★ systems. (On-line processing and moment-by-moment change are not depicted here.)

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knowledge★ works in real time, and how later states emerge gradually out of prior ones.

We can look at Figure 2.1 in terms of form (what are the types of knowledge and their relations?) or in terms of specific content. For example, "Speed is proportional to force" and "Length in inches is proportional to length in centimeters" have the same relational form but different content. Naturally, the content of expert knowledge is different from naive or incoming knowledge, but change in form might be just as important, or more so. Expert knowledge in a domain is typically assumed to show a higher degree of organization. Figure 2.1 suggests that how more and different organization comes about might be complicated, involving many changes.

One essential complication of the KA program of study is that the range of timescales is huge. On the one hand, we are committed to studying real-time thinking at the smallest observable time grain size. From classroom data or clinical videotape we probably cannot see much finer than a modest fraction of a second, say, on the order of 10^1 seconds, at best. On the other hand, we have educational commitments on far grander timescales. We want to understand how the most important and difficult ideas in science and mathematics emerge during learning, which may take several years, in the range of 10^8 seconds. Piaget came at this unification of very different timescales from the other direction. After focusing primarily on developmental timescales for most of his life, he came to accept the need to look at and integrate on-line thinking and local changes. His colleague, Bärbel Inhelder, spearheaded the formation of the "strategies group" at Geneva for this purpose (Inhelder et al., 1992).

Characterizing a Complex Knowledge System

What follows is a compact rendering, for reference and summary, of the above characterization of the foci of KA, with some extensions for completeness.

- **Functional descriptions**: What does the system do for those who possess it? What are the functions of a system's components? (For example, p-prims provide people with a sense of naturalness and ability to predict some events, or in complementary manner, evoke surprise and inquiry as to how some "unnatural" event could have come about.)
- **Structural descriptions**: What are the various pieces of the system; how do they emerge, connect with one another, and develop over time?
    - **State of the system**: What is the system's structure at any point in time?
        - **Taxonomy**: What are the various types of elements that are involved?
        - **Distribution**: What is the variety and variation of elements, within and across types?
        - **Relationality**: What is the nature and extent of systematicity among elements?
        - **Nesting**: If the relevant system is a subsystem or supersystem of another, what is the nature of the nesting?
    - **Dynamics**: How do we describe activity in the system?
        - **Processing** (short timescale: seconds to hours).
        - **Normal operation**: How does one describe everyday use of the relevant knowledge?
        - **Changes during normal operation**: How does one describe change during normal operation? In particular, what changes accumulate into longer-term development (***microgenesis***)?
        - **Changes in elements**: emergence, change of character, extinction.
        - **Changes in relationality**: reorganization and shifts in activation priorities of elements.
    - **Development** (long-term change: months or years; ***macrogenesis***)
        - **Changes in elements**: ultimate origins and evolution of individual elements toward expertise.
        - **Changes in relationality**: reorganization, and the emergence of new systems.

While the KA agenda is daunting, there are some synergies that make it more tractable. For example, knowing relevant knowledge elements – and knowing them very well – means that understanding of what happens to them during relatively short-term learning may become far clearer. diSessa (2014) shows a

worked-out example of exactly this process of analysis; it shows how a few well-understood p-prims, and other ideas, come to constitute a socially shared model of thermal equilibration among a group of students. Similarly, identifying local principles of change, one can then extrapolate to thinking about how many such changes may accumulate. Conversely, knowing about long-term changes at high resolution can help us understand which local changes are the critical ones.

Regimes of KA Study

Within the very wide range of types of studies, in terms of timescale, empirical, and theoretical focus, we identify here some "natural clusters" (we call them "regimes") that help partition and classify different types of KA study. Historically, KA studies have progressed along comprehensible trajectories, from one regime to another, capitalizing on synergistic relationships such as those suggested above.

Microanalytic Study

In this regime, one focuses on elements and how they are used in real-time thinking. Here, the focus is primarily on short-timescale phenomena – brief segments of reasoning. For example, a person might view some physical event in the world. In response, some element of knowledge★ would be cued and provide part of the basis for interpreting the phenomenon. The microanalytical focus of our modeling may be on just this short slice of reasoning: the process of cuing to activation of the relevant element of knowledge. The cuing of the element might, of course, have longer-term consequences. It may suggest or anticipate aspects of the direction of further reasoning.

The microanalytic regime seems well adapted to generating ideas about knowledge types. That is, it may well be analytical in the theoretical sense of developing theoretical categories. A characteristic of the microanalytic regime is that, as both empirical and theoretical categories develop, many contexts may be needed to triangulate different aspects of one element or type. Contextuality, for example, is impossible to determine from one or just a few contexts of use.

Methodologically, microanalytic studies tend to select short segments of thinking for analysis out of a fuller corpus of thinking. So, more integrative and longer-termed microgenetic and micro-operational goals (below) may not be directly or fully met. Sherin (2001) provides a transparent example of the principled selection of parts of a large corpus for microanalytic purposes.

Microgenetic Study

As educational researchers, we are of course interested in changes to knowledge (i.e., learning). Microgenetic studies step up from microanalytic ones specifically in

seeking to understand the processes that underlie the achievement of recognizably new states of understanding – not just a student's finding any way to interpret a situation, but finding a *new*, and relatively *stable*, way to interpret it. In our view, changes to knowledge may be a concomitant of even the briefest and most routine instances of reasoning. Thus, there may not be a big step from microanalytic to microgenetic study. Knowing elements well (microanalytic perspective), one may be able to infer changes (microgenetic perspective) much more easily than otherwise.

We use the prefix *micro* in describing this regime since, in the larger program, we need to see how time-local (micro) changes fit into long-term (macro) changes ("development," below).

Micro-operational Study

A substantial body of historical work has attempted to model reasoning at a timescale at which that reasoning can be seen to have a sequential, strategic quality. It is here that we begin to capture the overall flow of reasoning as it occurs over seconds, minutes, or even hours. This is the standard regime of cognitive modeling, but modeling reasoning at this level in a way that is consistent with the principles of KA poses significant challenges. The twin commitments to the complexity of knowledge and to the full details of real-time thinking result in a daunting micro-operational task. *All* the relevant elements and processes that might be involved over an extended period of time need to be described in careful detail. A KA-oriented model of extended thinking should ideally be complete and sufficient (should "run" on its own) – as opposed to affording scattered, if critical, insights (say, when one particular element is evoked), which is more typical of microanalytic or microgenetic study. In practice, this remains a long-term goal, and not a currently well-developed empirical regime.

True Developmental Study

This is the regime occupied by developmental psychology. Traditional developmental research is concerned with changes to individuals that occur over months or years, with an emphasis on changes that are maturational and occur during childhood. Developmental studies often provide easy starting points for research, because they provide us with highly contrasting styles of thinking about which to theorize. But, the KA challenge is to connect well with shorter timescale perspectives. As suggested earlier, synergies exist between developmental and shorter-term perspectives to the extent that long- and short-duration changes provide constraints and suggestions about each other. For example, can developmental patterns be realized with the elements and local processing mechanisms specified in microanalytic and microgenetic studies? diSessa (1993) speculates on global development based on shifting the parameters that determine elements' activation, which may be determined in microanalytic study.

Methodology

This section presents an image of KA in practice. Although a "practical guide to Knowledge Analysis" is beyond the scope of this chapter, readers are introduced to some current and characteristic methodological practices involved in doing KA.

Overview

While KA researchers employ many practices that can be found across multiple research traditions, when viewed as a whole, KA employs a set that is recognizable and distinct. To position KA in relation to the larger field, we introduce a simple, high-level framework (Martin & Sherin, 2013), one that we believe can be used to characterize any empirical research effort focused on human activity. The framework has five parts:

1. *Empirical set-up*. What instances of thinking and learning are studied? For example, do we look at interviews, classroom discussions, or everyday conversation?
2. *Capture*. What aspects of the learning phenomena are captured and how are they captured? For example, do we videotape the interaction? Take field notes?
3. *Reduction*. What do we attend to in what is captured? For example, do we only care about whether a student gave a right or wrong answer? Do we pay attention to gestures, or just the words that are spoken? Do we reduce the data to a set of codes?
4. *Pattern finding*. How do we find patterns in the data? Do we look for statistically significant correlations in codes? Do we read transcripts to draw impressions that may be generalized? We use "patterns," here, in a very general sense, referring even to such complex patterns as theories.
5. *Reporting*. How do we report our results to other researchers? For example, how are the results of pattern finding described in journal articles?

Empirical Set-up

KA research is concerned with the content, form, and dynamics of individual knowledge and how it develops. Such issues can be investigated in both researcher-manufactured contexts (such as clinical interviews) and in naturally occurring contexts (such as students working together in small groups on a problem). In both cases, the assumption is that what individuals say or do is a window into their thought processes. No matter the context, the KA goal is to uncover subjects' natural[2] ways of reasoning about phenomena, *not* to assess individuals' state of understanding with respect to a normative standard. The contexts that

individuals are asked to reason about are often complex conceptual situations as opposed to contexts that require only the execution of a procedure or allow the assessment of factual knowledge.

As discussed in the theoretical foundations section, a characteristic concern for KA is the issue of contextuality of knowledge use. The methodological implications of making contextuality a key focus are substantial, and the means of generating opportunities to observe it can vary. Subjects may be asked to reason about multiple representations of the "same" issue, or they may have multiple opportunities to consider the same event or idea. The researcher may, at some point, deliberately prompt other ways of thinking to measure the subject's receptivity.

Capture

In almost all cases, the phenomenon sampled is captured in video and audio. Concrete artifacts, such as drawings, are also collected. As KA is interested in how individuals perceive the world and how their knowledge about it is organized, it is critical for researchers to put themselves in the position to notice what subjects are focusing their attention on and what is salient to them. Thus, in many cases, care must be taken during the data-collection phase to make sure the camera is positioned so that indications such as subjects' eye gaze, gestures, and the way they interact with artifacts and materials are all available for later study. In recent years it has become common to convert all of this data to a digital form for rapid access, indexing, and annotation.

Reduction

In most cases, video recordings are transcribed. Many times the work that follows is done using primarily these transcriptions; however video is also frequently consulted, especially in situations where, for example, things like eye gaze or gradual construction of a visual representation are involved. KA research is not dogmatic when it comes to the features of interactions that *must* be captured in initial transcripts. As such, standardized practices for representing events of interest have not been developed within the community. Features of the interaction or context that are thought to be relevant to the question at hand are captured and the transcript is iteratively improved as necessary for the purpose of investigating the chosen focus. This could include marking features like gestures, eye gaze, and lengths of turns and pauses. It is not common to meticulously capture details such as intonation, rhythm, and pronunciation of words, although some of these might become important to certain interpretations (e.g., evaluating level of confidence, or as indicators of careful on-line thinking).