Research in Mathematics Education

Series Editors: Jinfa Cai · James A. Middleton

Charles Hohensee
Joanne Lobato *Editors*

Transfer of Learning

Progressive Perspectives for Mathematics Education and Related Fields

Springer

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Series Editors

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This series is designed to produce thematic volumes, allowing researchers to access numerous studies on a theme in a single, peer-reviewed source. Our intent for this series is to publish the latest research in the field in a timely fashion. This design is particularly geared toward highlighting the work of promising graduate students and junior faculty working in conjunction with senior scholars. The audience for this monograph series consists of those in the intersection between researchers and mathematics education leaders—people who need the highest quality research, methodological rigor, and potentially transformative implications ready at hand to help them make decisions regarding the improvement of teaching, learning, policy, and practice. With this vision, our mission of this book series is: (1) To support the sharing of critical research findings among members of the mathematics education community; (2) To support graduate students and junior faculty and induct them into the research community by pairing them with senior faculty in the production of the highest quality peer-reviewed research papers; and (3) To support the usefulness and widespread adoption of research-based innovation.

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Foreword

Helping learners develop understanding and skill in one context and then even store them, let alone apply them in another context, has been an enduring goal for decades. Recently, however, the study of transfer has transformed, becoming increasingly rigorous and useful for the improvement of mathematics learning experiences. This is one of the books in the *Research in Mathematics Education* series. Charles Hohensee and Joanne Lobato, the editors of this volume, provide us with a comprehensive look at transfer in mathematics education.

This is the first book in mathematics education research that addresses transfer. The chapters cover diverse approaches ranging from embodied cognition to more conventional assessment of near and far transfer and to sociocultural approaches examining the interaction of tools, goals, and actors in classroom contexts. Philosophically, this volume is eclectic. Transfer of learning is seen by the collective of authors as too important to pigeonhole into a single, narrow perspective. That is one of the delights of this book: If one can somehow utilize knowledge or practices learned in one place and time in another place and time, that is transfer. How transfer occurs, what aspects of a learning situation are transferable, and under what conditions teachers or curriculum designers may impact transfer are questions that each of the authors deals with from within their own theoretical framework. Six different but overlapping traditions interweave throughout the chapters, sometimes competing and sometimes complementing each other.

The extended discussions of transfer between mathematics and other science, technology, engineering, and mathematics (STEM) subject matter, we feel, will be of special interest to researchers and practitioners. The work presented here can guide the simultaneous design and planning of learning experiences in K-12 STEM courses. Additionally, the "so what" question regarding transfer is effectively addressed in this volume through several chapters examining transfer to and from out-of-school settings. This is a unique contribution to mathematics education at this time, marking this volume as a key resource for researchers and practitioners who seek to understand what about school mathematics is not only applicable but is actually applied by learners in their own lives beyond the bounds of their mathematics classroom.

Our intent for this series is to publish the latest research in the field in a timely fashion. This design is particularly geared towards highlighting the work of promising graduate students and junior faculty working in conjunction with senior scholars. The audience for this monograph series consists of those at the intersection of researchers and mathematics education leaders—people who need the highest quality research, methodological rigor, and potentially transformative implications ready at hand to help them make decisions regarding the improvement of teaching, learning, policy, and practice. With this vision, our mission for this book series is:

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We are grateful for the support of Melissa James from Springer in developing and publishing this book series as well as supporting the publication of this volume.

We thank the editors (Hohensee and Lobato) and all of the authors who have contributed to this innovative and comprehensive volume!

University of Delaware, Newark, DE, USA Jinfa Cai
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Preface

With this book, we have aggregated a number of progressive perspectives on the transfer of learning in the context of mathematics education and related fields. The book is part of Springer's growing Research in Mathematics Education monograph series, which is composed of thematic volumes of peer-reviewed, high-quality contributions on timely topics.

The publication of this book is particularly timely because, over the past 20 years, a new generation of transfer researchers have emerged that have been developing progressive perspectives and using them to frame empirical studies in STEM education research. The development of these progressive perspectives was in reaction to the rash of criticism of traditional transfer research. The progressive perspectives represented in the chapters of this book implicitly and explicitly address many of those criticisms.

A number of factors motivated us to embark on this edited volume on the transfer of learning. First, despite the negative critiques of traditional transfer research, we view the underlying phenomenon of transfer to be of critical importance for mathematics teaching and learning. Second, we perceived a need to bring together into a single volume recent efforts from researchers whose work could usefully inform future directions for transfer research in the domain of mathematics education. Third, we felt the time was right to bring together interdisciplinary contributions with links to mathematics education as a way to stimulate dialogue about transfer across disciplines.

It is our hope that the chapters in this book will be useful to those researchers who principally focus on transfer, as well as to those who do not typically focus on transfer but who find ideas contained in these chapters relevant to their work. To that end, we have tried to achieve a balance between theoretical chapters and those that are empirically based. We have also included authors from many different countries in order to provide an intriguing range of perspectives. Thus, we feel the book is well positioned to generate new and renewed excitement for transfer research and to motivate the field of mathematics education to focus more efforts on understanding this enduring and important topic.

Newark, DE, USA — Charles Hohensee
San Diego, CA, USA — Joanne Lobato

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About the Authors

Charles Hohensee is an Associate Professor in the School of Education at the University of Delaware. He received his Ph.D. in Mathematics Education from San Diego State University in 2011. Hohensee's research examines the phenomenon of *backward transfer*, which is about how learning something new influences a learner's prior knowledge. Hohensee has published a number of articles on transfer and backward transfer.

Joanne Lobato is a Professor of Mathematics Education in the Department of Mathematics and Statistics at San Diego State University. Lobato has a long-standing interest in the transfer of learning, having developed the actor-oriented transfer perspective and served as the transfer strand editor for the *Journal of the Learning Sciences*. She also conducts research on learning from dialogic videos, student noticing, and relationships between teaching practices and student learning. Lobato is an Associate Editor for *Mathematical Thinking and Learning*.

Part I
Progressive Theoretical Perspectives of Transfer

Chapter 1
Current Conceptualizations of the Transfer of Learning and Their Use in STEM Education Research

Joanne Lobato and Charles Hohensee

> We believe that the metaphor underlying transfer—namely, of transporting knowledge from one concrete situation to another—is fundamentally flawed… Our goal is to recommend not an "improved version" of transfer, but rather the abandonment altogether of "transfer" as a view of how learning takes place. (Carraher & Schliemann, 2002, p. 20)

> We believe that the distinction between acquiring knowledge and applying it [transfer] is inappropriate for education. (Hiebert et al., 1996, p. 14)

> A persistent follower of the PM [participation metaphor] must realize, sooner or later, that from a purely analytical point of view, the metaphorical message of the notion of transfer does not fit into PM-generated conceptual frameworks. (Sfard, 1998, p. 9)

As these epigraphs illustrate, 20–25 years ago, mathematics education research largely turned away from transfer as a viable conceptual construct, and consequently, away from conducting and publishing transfer studies. In contrast, in the past 10 years, there has been a marked upsurge in publications on the transfer of learning in mathematics education research specifically and STEM education research more broadly. Such studies have been grounded in progressive perspectives on transfer rather than in the traditional perspective. This chapter begins with a brief account of this evolution, from rejection of the traditional transfer approach to the development and use of progressive transfer perspectives. In the main body of the chapter, we present the key features of six progressive perspectives on the transfer of learning, using examples of their recent use in STEM education research. Finally, we end with a discussion of the motivation for and organization of this book.

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1.1 The Emergence of Progressive Transfer Perspectives

1.1.1 Traditional Transfer Perspective and Critiques

By the traditional transfer perspective, we refer broadly to the family of approaches that emerged during the cognitive revolution of the last half of the twentieth century and came to dominate transfer research (e.g., by Bassok & Holyoak, 1993; Gentner, 1983, 1989; Ross, 1984; Singley & Anderson, 1989). Although different strands exist within this perspective, they share multiple features. First, transfer is defined as the application of knowledge or skills learned in one situation to a new or varied context (Alexander & Murphy, 1999; Bransford, Brown, & Cocking, 2000). Second, the formation of sufficiently abstract representations is a necessary condition for transfer, where abstraction is conceived as a process of decontextualization (Fuchs et al., 2003; Gentner, 1983; Reeves & Weisberg, 1994). Third, the occurrence of transfer is attributed to the psychological invariance of symbolic mental representations. Specifically, transfer occurs if the representations that people construct of initial learning and transfer situations are identical, overlap, or can be related via mapping (Anderson, Corbett, Koedinger, & Pelletier, 1995; Gentner, Loewenstein, & Thompson, 2003; Gick & Holyoak, 1983, 1987; Novick, 1988; Reed, 1993; Sternberg & Frensch, 1993).

Methodologically, traditional transfer studies typically present subjects with a sequence of tasks that share some structural features (e.g., a common solution approach or shared principle) but have different surface forms (e.g., different word problem contexts), according to an expert's knowledge of the topic. Subjects are then taught some solution strategy, principle, or procedure with the initial learning task. If the subjects perform better on a transfer task than a control group (who receive the transfer task but no learning tasks), then transfer is said to have occurred (Singley & Anderson, 1989). Some researchers have made adaptations to this basic approach by using multiple measures to capture the transfer of learning (e.g., Chen & Klahr, 1999) or verbal protocol methods to examine solution procedures (e.g., Bassok & Holyok, 1989; Nokes, 2009), though, according to Novick (1988), most traditional transfer studies rely primarily on performance measures. [For a more nuanced discussion of differences among cognitivist perspectives and a historical account of the linkages between cognitivist perspectives and Thorndike's (1906) associationist transfer theory of common elements see Cox (1997) and Lobato (2006, 2012).]

The traditional transfer perspective encountered a rash of criticism beginning in the mid-1980s as situated cognition and socio-cultural perspectives on learning became popular (Gruber, Law, Mandl, & Renkl, 1996; Laboratory of Comparative Human Cognition, 1983; Lave, 1988; Lerman, 1999; Packer, 2001). We briefly review three critiques of the theoretical and methodological roots of transfer. First, the traditional transfer perspective is rooted in a conception of knowledge as tools that can be acquired in one situation and transported unchanged to another situation (Greeno, 1997; Packer, 2001). The tools are assumed to be independent of the situations in which they are used. As Lave (1988) put it, "the beneficial cognitive consequences of decontextualized learning, freeing oneself from experience" are seen as "a condition for generalization about experience" (p. 41). However, from a situated perspective, the notion of detaching from concrete experience is problematic because knowledge cannot be isolated from practice and meaningfully studied (Hall, 1996; van Oers, 1998). Second, the focus on the invariance of mental representations as a transfer mechanism is severely limited by ignoring the contribution of the environment, artifacts, and other people to the organization and support of the generalization of learning (Beach, 1995, 1999; Guberman & Greenfield, 1991; Pea, 1987). Finally, traditional transfer studies privilege the perspective of the observer and rely on models of expert performance, accepting as evidence of transfer only specific correspondences defined a priori as being the "right" mappings (Evans, 1998; Lobato, 2003). Consequently, transfer experiments can become what Lave (1988) called an "unnatural, laboratory game in which the task becomes to get the subject to match the experimenter's expectations," rather than an investigation of the "processes employed as people naturally bring their knowledge to bear on novel problems" (p. 20).

1.1.2 Response to Critiques in STEM Education Research

In the wake of these critiques, transfer fell out as an important area of research in mathematics education. Carraher and Schliemann (2002) advocated abandoning transfer as a research construct because of the deep association of transfer with what they considered faulty conceptual roots. Lave, a social anthropologist, whose work extended to mathematics education, also recommended moving away from the transfer construct. For example, in a study of the mathematics used by adult grocery shoppers, Lave (1988) concluded that the shoppers did not transfer relevant school mathematics. Although she acknowledged the existence of "continuity of activity across situations," she quickly added that "learning transfer is not the central source of continuity" (p. 186). Other researchers adopted the view that learning and transfer are conceptually indistinguishable, thus negating the need to devote special attention to transfer (e.g., Campione, Shapiro, & Brown, 1995; Hammer, Elby, Scherr, & Redish, 2005).

However, the underlying phenomenon that was narrowly and imperfectly captured by the construct of transfer remains important in mathematics teaching and learning. For example, whenever math teachers are faced with the task of constructing an exam, they have to make decisions about whether to repeat tasks presented in the instructional unit or whether it's "fair" to include novel tasks—a decision that seems to draw upon assumptions about transfer, not just learning. Similarly, researchers conducting an evaluation of an innovative instructional treatment need to decide how closely to pair assessment items with instructional activities. Researchers operating from a Realistic Mathematics Education perspective may wonder how activities grounded in real-world contexts transfer to abstract domains (e.g., Stephan & Akyuz, 2012). Even in critiques of transfer, researchers acknowledge that “any new conceptualization—thus, any learning—is only possible thanks to our ability to transfer existing conceptual schemes into new contexts” (Sfard, 1998, p. 9). To resolve this tension between the avoidance of transfer and the necessity of transfer, Lerman (2000), in his work on the “social turn” in mathematics education research, argued that “the notion of transfer of knowledge, present as decontextualized mental objects in the minds of individuals, from one situation to another, becomes untenable but at the very least requires reformulation” (p. 25). We turn next to the development of a number of such reformulations of transfer.

1.1.3 Development and Uptake of Progressive Perspectives

From 1993 to 2006, several progressive perspectives on the transfer of learning emerged. In the next section of this chapter, we present the following six theoretical perspectives: (a) *preparation for future learning* (Bransford & Schwartz,1999); (b) *actor-oriented transfer* (Lobato, 1996), (c) *transfer in pieces* (Wagner, 2006); (d) *expansive framing* (Engle, 2006); (e) *consequential transitions* (Beach, 1999); and (f) an *activity-theoretic perspective* (Tuomi-Gröhn & Engeström, 2003). Another notable contribution is the reformulation of transfer from the lens of situated cognition, developed by James Greeno, referred to as the affordances-and-constraints perspective (Greeno, 1997; Greeno, Smith, & Moore, 1993). Although this approach was never fully developed, and Greeno later shifted from using the term “transfer” to “productivity” (Hatano & Greeno, 1999, p. 647), his significant contributions influenced the development of the actor-oriented transfer perspective and the expansive-framing perspective. During this same time period, The National Science Foundation funded two transfer conferences: the first supported by the Social, Behavioral, and Economic Sciences Directorate (Mestre, 2003), and the second supported by the Education and Human Resources Directorate (Lobato, 2004). Thus, when the *Journal of the Learning Sciences* sponsored a transfer strand in 2006, the time seemed ripe to attract empirical papers grounded in progressive perspectives on transfer and theoretical papers that further developed alternative approaches to transfer. The first author of this chapter, who served as the strand editor, was surprised to find that few empirical studies using the emerging progressive perspectives were submitted, while other submissions were grounded unquestioningly in the traditional transfer perspective.

Three factors likely contributed to what seemed like a slow proliferation of ideas from progressive perspectives on transfer. First, reformulating transfer is not simply a matter of offering a new definition of transfer. A network of related constructs need to be re-imagined. Engle (2012), arguing that by 2012 the field was seeing a resurgence of transfer research, attributed that resurgence to: (a) the treatment of transfer as a complex, multifaceted social and cognitive phenomenon, rather than a simple, unitary construct, (b) the articulation of new processes that mediate transfer, and (c) a shift in perspective from expert models to an understanding of the “diverse and often unanticipated ways in which students make use of prior learning” (p. 348).

Second, because the traditional transfer perspective was solidly rooted in information processing, and progressive perspectives largely emerged from situated and socio-cultural perspectives, there were associated difficulties, resistance, and misunderstandings that often result from changing well-established constructs. This can be seen in a lively exchange published by the *Educational Researcher* between advocates of the traditional transfer perspective (Anderson, Reder, & Simon, 1996, 1997) and an advocate of a situated perspective on transfer (Greeno, 1997). Specifically, Anderson et al. (1997) casually dismissed any discrepancies between the two approaches as differences in form and not substance rather than acknowledging that each held a different set of theoretical assumptions and commitments. Finally, while the methods used in the traditional transfer perspective were well established, methods appropriate for progressive perspectives had to be formulated (e.g., Lobato, 2008a; Schwartz & Martin, 2004).

In the past 10 years, the situation has changed. There has been a marked upsurge in publications on the transfer of learning in math education research specifically and STEM education research more broadly. We conducted an informal search for articles published between 2008 and 2019 in mathematics education journals (with a less thorough search in science education journals) that were grounded in progressive perspectives on the transfer of learning. Even with this non-comprehensive search, we found 65 articles, published by a variety of STEM education researchers. We concluded that something had shifted in the field. Perhaps adequate time had finally passed for progressive transfer perspectives to be developed sufficiently for wider implementation. We turn next to a presentation of the six major progressive perspectives that we found in these articles, with illustrations of their use from a subset of the 65 articles.

1.2 Six Progressive Perspectives Used in STEM Education

1.2.1 Preparation for Future Learning

The *preparation for future learning* (PFL) perspective on transfer (developed by Bransford & Schwartz, 1999) responds to the critique that the traditional transfer approach ignores real-world conditions that people can often exploit, such as seeking additional learning resources and having opportunities to obtain feedback. Traditional tests for transfer typically take place in environments where people do not have access to information sources other than what they have learned previously. In contrast, the PFL approach examines how an instructional experience (such as investigating a set of contrasting cases) prepares people to benefit from a learning opportunity. In articulating the PFL perspective, Bransford and Schwartz (1999) point to a study by Singley and Anderson in which there appeared to be no transfer from learning one text editor to another, using a traditional test of transfer. However, the benefits of the prior experiences with a text editor were evident several days into learning the second program. In sum, the transfer of prior knowledge may not be apparent until people have been given the opportunity to learn new information.

Key Features Schwartz and colleagues have developed a methodological approach utilized in PFL studies, which they call the *double transfer paradigm* (Schwartz, Bransford, & Sears, 2005; Schwartz & Martin, 2004). Students are assigned one of two instructional treatments. One of the treatments is conceived as a preparatory activity and may focus on inventing a method during problem solving (Schwartz & Martin, 2004), using contrasting cases (Roelle & Berthold, 2015), or having a hands-on experience (for instance, in a science museum; Watson, 2010). The other treatment (which serves as a control) is usually a more traditional teaching experience (such as lecture followed by practice). Half of the students from both treatments are then given access to an additional learning resource, such as a sample worked problem or a lecture, followed by a request to solve a target transfer problem. The other half of the students in each treatment solve the target transfer problem directly without access to the learning resource. The researchers then look both at what people *transfer in* from the instructional treatment to learn from the resource and what they *transfer out* to solve a target problem.

For example, Schwartz and Martin (2004) used the double transfer paradigm with Grade 9 Algebra 1 students learning about the statistics concept of standardization. The students were assigned to two treatments—*invention* versus *tell-and-practice*. Students in the invention treatment engaged in problem solving to invent their own ways to compare two exceptional scores from different distributions and decide which was better. The tell-and-practice group was taught a visual method for determining standardization and then asked to use that method on a practice task. Half of the students from each treatment group were given the common learning resource of a worked example for a task from the targeted domain. Then all students were given a transfer task. The results showed that the students from the invention treatment, who also received the learning resource, were the only group to perform well on the transfer task. This is despite the fact that the students struggled with the invention activity and did not complete it successfully. Additionally, the students from both treatment groups performed about the same on the transfer task, when they did not have access to the learning resource. Schwartz and Martin (2004) hypothesized that the students in the invention treatment were more likely to notice important dimensions of the standardization concept (such as range and number of observations) than the students in the tell-and-practice treatment and then use this knowledge to learn more deeply from the worked example.

Purpose and Uses Although not all PFL studies utilize the double transfer methodological design, many focus on the nature of the preparatory activity, the transferring in to the common learning resource, and the links between the two experiences. For example, Vahey and colleagues extended the PFL approach to design a series of interdisciplinary experiences for middle school students related to the targeted mathematical content of proportional reasoning (Swan et al., 2013; Vahey et al., 2012). Students first engaged with a complex, real-world water allocation problem involving countries from the Middle East in their social studies class, before receiving more formal introduction to proportions in math class, followed by opportunities to transfer out that knowledge to activities in their science and language arts classes. While the preparatory water allocation problem was messy and frustrating for students, it appeared to direct their attention to key dimensions of the situation (such as the importance of attending to more than one quantity when making decisions in a proportional situation), which then shaped what was learned about proportionality in the math classroom.

In a second example, this one with U.S. prospective math teachers, Jacobson (2017) drew upon the PFL perspective to compare different types of early field experiences on the common learning resource of teacher education coursework. *Instruction-focused* field experiences included opportunities for prospective teachers to teach, whereas *exploration-focused* field experiences focused on observing or interviewing students but did not include teaching. Participating in early, instruction-focused field experiences was positively related to outcome measures for the teacher education courses (i.e., mathematical knowledge for teaching and beliefs about active-learning and math-as-inquiry), which was not the case for exploration-focused field experiences. Jacobson concluded,

> Rather than being merely a context for practicing what has already been learned, field experience—especially early instruction-focused field experience—may prepare prospective teachers to learn mathematics and develop beliefs about mathematics (i.e., gain applicative knowledge) from learning opportunities such as concurrent and subsequent university coursework and from the resources available during student teaching. (p. 181)

1.2.2 Actor-Oriented Transfer Perspective

From the *actor-oriented transfer* (AOT) perspective, the conceptualization of transfer shifts from what MacKay (1969) calls an *observer's* (expert's) viewpoint to an *actor's* (learner's) viewpoint (Lobato, 2003). By adopting an actor's perspective on transfer, one seeks to understand the ways in which people generalize their learning experiences beyond the conditions of initial learning, by looking for evidence of the influence of prior experiences on actors' activity in novel situations, rather than predetermining what counts as transfer using models of expert performance (Lobato, 2012). A researcher operating from the AOT perspective does not measure transfer against a particular cognitive or behavioral target but rather investigates instances in which the students' prior experiences shape their activity in the transfer situation, even if the result is non-normative or incorrect performance. Consequently, several studies have demonstrated instances in which students provided little or no evidence of transfer from a traditional perspective; however, when the data were re-analyzed from an AOT perspective, evidence was found that students had constructed relationships between previous learning activities and new situations, and that these perceived relationships influenced students' engagement in the new situations (Cui, 2006; Karakok, 2009; Lobato, 2008b; Thompson, 2011).

Key Features Because AOT research assumes that people regularly generalize their learning experiences, the research question shifts from whether or not transfer occurred to an investigation of the interpretative nature of the connections that people construct between learning and transfer situations, guided by aspects of the situations that they find personally salient (Lobato, 2008a). Consequently, the research methods are typically qualitative in nature, drawing upon interview or observational data and using coding methods that identify the personal, and often surprising, interpretations and connections constructed by actors (Lobato & Siebert, 2002). For example, Roorda, Vos, and Goedhart (2015) conducted a 2-year longitudinal study of high school students' transfer of learning experiences related to instantaneous rates of change from both mathematics and physics classes to novel tasks in a series of interviews. Their analysis identified the particular ideas, language, and procedures from the math and physics classes that appeared to influence the students' work on the interview tasks. Similarly, Nagle, Casey, and Moore-Russo (2017) revealed the specific ways in which Grade 8 students connected their ideas about slope and covariational reasoning to novel statistics tasks in which they were asked to place the line of best fit informally.

In moving to explanatory accounts of the occurrence of transfer, the AOT perspective treats transfer as a distributed phenomenon across individual cognition, social interactions, material resources, and normed practices. For example, in our own work, we posited *noticing* as a multi-faceted transfer process (Lobato, Hohensee, & Rhodehamel, 2013; Lobato, Rhodehamel, & Hohensee, 2012). Specifically, we offered an explanatory account of the occurrence of transfer in a classroom-based study by coordinating the particular mathematical features that individuals attended to, with the social organization of that noticing through discourse practices and the nature of mathematical activity.

Purpose and Uses The AOT perspective is particularly useful within the context of design-based research, where information about the often surprising ways in which people generalize their learning experiences and interpret transfer situations, can usefully inform and improve the design of the instructional environment (Lobato, 2003, 2008a). For example, Johnson, McClintock, and Hornbein (2017) designed two dynamic computer environments to explore the transfer of covariational reasoning from activities set in a Ferris wheel context to a bottle-filling context. Their investigation revealed the transfer of covariational reasoning involving quantities that the students conceived as measureable. It also illuminated the increased complexity of the bottle-filling context, namely that students could perceive that liquid was accumulating in a container without conceiving of an attribute in the situation that could be measured. In turn, the information that was gained informed subsequent design and instructional responses, as indicated in the follow-up chapter by Johnson and colleagues in this volume.

The AOT perspective was originally developed to model students' generalizations of their subject-matter learning experiences in school or design-based research instructional sessions. It has been extended in several ways, including the investigation of task-to-task transfer via written problem-solving activities outside of school (Mamolo & Zazkis, 2012) and teaching interviews (Lockwood, 2011). The AOT perspective has also been used in research on teachers. For example, Penuel, Phillips, and Harris (2014) examined teachers' curriculum implementation through an AOT lens. The analysis focused on the teachers' differing interpretations of the goals and guidance embedded in the materials for a curricular unit and how those perceptions were related to patterns of enactment. Similarly, Sinha et al. (2013) examined how a group of elementary teachers tackled new curricular units in their school after working with a research team on an initial reform-oriented unit.

1.2.3 Transfer-in-Pieces Perspective

The *transfer-in-pieces* perspective is a progressive perspective on transfer attributed to Joseph Wagner (2006, 2010). According to Wagner (2006), transfer is conceptualized as "the incremental growth, systematization, and organization of knowledge resources that only gradually extend the span of situations in which a concept is perceived as applicable" (p. 10). This incremental-growth perspective on transfer is progressive because it contrasts with the traditional view that transfer is the "all-or-nothing transportation of an abstract knowledge structure across situations" (p. 10).

Central to this perspective is the notion of *concept projections* (diSessa & Wagner, 2005), which are particular knowledge resources that allow the knower to interpret a situation's affordances in a meaningful way. For example, a concept projection that young children may have is to recognize situations that involve equal sharing as being about division. A second concept projection is to recognize situations that involve removing equal-sized groups as being about division as well. Forming and connecting concept projections allows an individual to see the "same thing" across multiple problems (in this case division), which counts as transfer from this perspective and results in the individual developing a more robust generalizable concept. That is, coming to recognize a concept in different contextual situations is a form of transfer that depends upon the individual connecting multiple concept projections (Wagner, 2010).

Key Features To explain key features of the transfer-in-pieces perspective on transfer, we first must describe features of the *knowledge-in-pieces framework* for how knowledge develops (diSessa, 1993), because it is on that framework that the transfer-in-pieces perspective is based. Then, we explain why those features are relevant to conceptualizing transfer.

Knowledge-in-Pieces Framework A core principle underlying the knowledge-in-pieces framework, which was initially developed through science education research, is that understandings of concepts are fundamentally based on the ways individuals derive information from the world (diSessa, 1993). For example, how well a student understands linear functions will be largely determined by the ways the student gathers information from the world about dependency relationships, rates, speed, steepness, and so on. Moreover, the origins of knowledge are based on intuitive, unsystematically-collected information from the world, and individuals' knowledge advances as they develop more systematic ways to derive that information.

According to diSessa and Sherin (1998), two important interrelated knowledge resources work together to derive and interpret information from the world, namely *readout strategies* and *causal nets*. Readout strategies refer to the set of strategies that individuals employ to determine what to focus on and subsequently notice about the world (i.e., what to notice about a particular perceptual or conceptual field). Causal nets then refer to the set of inferences individuals can make about the information collected by the readout strategies. In other words, readout strategies are used to gather information whereas causal nets are used to interpret that information. As these knowledge resources become more systematic, the associated knowledge develops.

Applying Knowledge-in-Pieces to Transfer-in-Pieces Wagner's (2006) conceptualization of transfer was based on the ideas described above. Specifically, Wagner argued that readout strategies and causal nets are processes that individuals use, not only to gather information about the world, but also to make decisions about when transfer is appropriate. When a person encounters a new context in the pursuit of particular goals, readout strategies will guide what gets attended to and noticed in the new situation, causal nets will be used to make inferences about what was noticed, and knowledge resources that were useful in prior activities related to those goals will become available. As readout strategies and causal nets become more systematic and organized, transfer of particular knowledge is more likely to occur in a greater span of novel contexts.

Purpose and Uses One purpose of Wagner's (2006) progressive perspective is to address the apparent contradiction that instances of transfer are rare in empirical studies conducted from a traditional perspective (Detterman, 1993); yet it is widely held that transfer is pervasive in everyday life (Brown, 1989). From Wagner's transfer-in-pieces perspective, the reason transfer has been difficult to find empirically is because researchers aligned with the traditional perspective mistakenly look only for an all-at-once phenomenon. In contrast, research guided by a transfer-in-pieces perspective looks "for incremental indications of transfer" (p. 40), and "trace[s] the development" (p. 13) of transfer.

A second purpose of Wagner's perspective on transfer is to offer a new way to conceptualize the mechanisms underlying transfer. The traditional perspective "locate[s] the mechanism of transfer in the construction or induction of schemata represented at appropriate levels of abstraction" (Wagner, 2006, p. 64). However, Wagner (2006) presented a case study in which a student's ability to articulate an abstraction came after, rather than before, he transferred his knowledge to a new context. Therefore, constructing an abstraction cannot be solely driving transfer. Instead, Wagner explained the mechanisms of transfer in terms of readout strategies and causal nets. Specifically, Wagner (2006) used the same case study to track the incremental development of knowledge resources that enabled the undergraduate student to gradually transfer his developing knowledge of the law of large numbers to a wider array of contexts. As described by Wagner:

> [The student] took different ideas initially applicable only in isolated contexts …. The isolated contexts to which they applied individually grew incrementally into a larger family of situations perceived by [the student] to be alike, in that they all offered affordances for the ideas in the common frame. (p. 63)

Had this study been conducted using a traditional perspective, transfer would likely not have been observed because it happened gradually, rather than all at once.

1.2.4 Expansive Framing

The *expansive-framing* perspective on transfer, attributed to Randi Engle responds to the critique that the focus on cognitive mechanisms from a traditional transfer perspective has failed to acknowledge the contribution of social interactions, language, and cultural artifacts, to the occurrence of transfer (Engle, 2006; Engle, Lam, Meyer, & Nix, 2012; Engle, Nguyen, & Mendelson, 2011). The construct of *framing*, first offered by Bateson (1955/ 1972) and later developed by Goffman (1974), refers to what sense participants have of the nature of a given activity. For example, a lesson on quadratic functions may be framed as something useful only for the next exam, or it may be framed as being useful for understanding real-world phenomena, such as the acceleration of a car. Engle referred to the latter as an example of *expansive framing* and advanced the hypothesis that transfer is more likely to occur to the extent that learning and transfer contexts have been framed to create intercontextuality. When a high degree of intercontextuality occurs, the content established during learning is considered relevant to the likely transfer situations.

Key Features Engle et al. (2011) offered a framework of five types of expansive framing that are productive for transfer. The first three types focus on different aspects of the setting—time, place, and participants. The first type refers to the framing of a learning activity as being temporally connected with ongoing or future activity (versus being an isolated event). Second, lessons can be framed as being relevant to activity that occurs in other places, such as in a profession. Third, the learning activities can be framed as being relevant to a larger community beyond the classroom. The fourth type of expansive framing involves the topic that is being learned. The content of individual lessons can be framed as being connected to each other and part of a larger whole (e.g., graphs, equations and tables framed as representations of functions). Finally, the last type of framing involves how participants are positioned relative to the creation of knowledge in the field. In expansive framing, students are positioned as being capable of authoring their own ideas and are asked to revoice and credit other students with authorship (rather than framing explanation and revoicing as elaboration only of the textbook's ideas). Research from the expansive-framing perspective not only identifies teacher actions or features of instructional materials but also the aspects of expansiveness that appear to be appropriated or perceived by students (Lam, Mendelson, Meyer, & Goldwasser, 2014).

To test their hypotheses about the relationship between expansive framing and transfer, Engle et al. (2011) designed a tutoring experiment with two framing conditions (expansive versus bounded) using 28 high school biology students. Each student participated individually in 3–4 hours of tutoring on the cardiovascular system over two sessions, preceded by a pre-test and followed by a survey (to assess how students perceived the framing) and a post-test with transfer tasks about the respiratory system. The expansive-framing treatment attempted to address all 5 types of expansive framing. According to the survey, students generally perceived the intended differences in framing by condition, with the framing of time and authorship role being the most salient to them. On the measures of transfer, the students in the expansive-framing condition were more likely to transfer facts, a conceptual principle (the differential pressure principle), and a strategy (drawing diagrams) than those in the bounded condition.

Purpose and Uses The expansive-framing perspective first emerged in response to the inadequacy of traditional transfer processes to account fully for instances of transfer in a particular classroom setting. Specifically, Engle (2006) initially attempted to explain the observation that a group of fifth-grade students transferred graded and multi-causal arguments from a learning context (i.e., explaining whale endangerment) to a novel context (i.e., explaining the endangerment of another species) through cognitive modeling. She found that analogical mapping and the construction of abstract mental representations explained some but not all of the transfer findings. That is when she turned to framing.

Since that time, the expansive-framing perspective has been extended in at least three ways. Becherer (2015) used qualitative, rather than quantitative, methods to relate differing framing moves across two classrooms to different types of transfer (routine versus adaptive). Hickey, Chartrand, and Andrews (2020) built upon expansive framing to generate an assessment framework that embeds expansively-framed engagement within multiple levels of increasingly formal assessments. In contrast, Zuiker (2014) combined Beach's (1999) conception that transfer is about making transitions with Engle's transfer process of expansive framing.

1.2.5 Consequential-Transitions Perspective

The *consequential-transitions* perspective is a progressive conceptualization of transfer that originated with King Beach (1999). Instead of the traditional conceptualization that transfer is the use of prior knowledge to solve novel problems, Beach reconceptualized transfer more broadly as when individuals are faced with making *transitions* to accommodate changing relations between themselves and social activities. According to this perspective, transfer is described as the "continuity and transformation of knowledge, skill, and identity across various forms of social organization" and as involving "multiple interrelated processes rather than a single general procedure" (p. 112). Beach viewed these transitions as *consequential* to the individual because they may involve struggle and affect one's social position. An example of a consequential transition would be when students are faced with learning about algebra after years of learning arithmetic. Although Beach described transfer of learning in terms of consequential transitions, he also viewed consequential transitions as encompassing generalization that extends beyond the transfer of learning.

Key Features There are four types of consequential transitions, (a) lateral, (b) collateral, (c) encompassing, and (d) mediational. *Lateral consequential transitions* occur when individuals move in a single direction from one social activity to another. This type of transition is the least complex of the four types and the most closely associated with the traditional conceptualization of transfer. For example, Nepali high school students experienced a lateral transition when becoming shopkeepers (Beach, 1999). During this one-way transition (i.e., they did not subsequently return to school), the students were faced with transforming their knowledge of school mathematics for use in the practices of shopkeeping.

Collateral consequential transitions occur when individuals move back and forth between activities (i.e., these transitions are multi-directional). They are more common than lateral transitions but also more complex. For example, the Nepali shopkeepers who were living in the same village as the Nepali students described above, experienced a collateral transition when they went back to school to take adult education evening classes (Beach, 1999). In contrast to the students whose transition was in a single direction, these shopkeepers experienced a transition that moved back and forth between the mathematics activities associated with running their shops during the day and the arithmetic activities they engaged in during the evening classes.

Encompassing consequential transitions occur when individuals participate in an activity that is itself changing. This type of transition can be generational in nature (i.e., it can be particularly challenging for older generations to adapt to changes in social activities created by younger generations). For example, conventional machinists, who were accustomed to manual machining, experienced an encompassing transition when faced with having to adapt to computerized machining (Beach, 1999).

Mediational consequential transitions occur when individuals learn to participate in activities, typically educational, that simulate the actual activity. These types of transitions serve as bridges between "where the participants are currently and where they are going" (p. 118). For example, part-time actors experienced a mediational transition when attending bartending classes at a vocational school (Beach, 1999). These individuals were learning to participate in activities that approximated bartending in a restaurant. However, the activities did not constitute full-fledged bartending because, for example, the individuals were still learning to shift away from consulting written directions to make drinks.

Purpose and Uses We outline three purposes of this progressive perspective. First, Beach's consequential-transitions perspective conceives of and examines transfer as a set of interrelated psychological *and* social processes. In contrast, the traditional perspective conceives of transfer singularly as a psychological process. Second, the consequential-transitions perspective accounts for the *context* of transfer (i.e., the social activities serve as the context), whereas the traditional perspective accounts for how knowledge becomes increasingly decontextualized. Third, the consequential-transitions perspective captures the effects of transfer on individuals' identities and their social position, as well as the concomitant struggles involved. Conversely, the traditional conceptualization considers transfer in a way that ignores issues of identity and social positioning.

Two progressive transfer studies that have made use of Beach's consequential-transitions perspective are Jackson (2011) and Hohensee and Suppa (2020). Jackson used *collateral transitions* to examine a child's back and forth transition between doing mathematics at school and at home. This lens afforded an examination of transfer that foregrounded the setting and that revealed the complexities of transferring knowledge between settings. A traditional perspective would not have afforded these insights. Jackson has a follow-up chapter in this book.

Hohensee and Suppa (2020) used *encompassing transitions* as the lens. They examined prospective teachers' experiences with learning about early algebra in a teacher preparation course after the prospective teachers had already learned about regular algebra in high school. This lens was used because the prospective teachers felt as if algebra was being changed on them, and they were faced with adapting to those changes. Results revealed ways the prospective teachers struggled with making this transition.

1.2.6 Activity-Theoretic Perspective

The *activity-theoretic perspective* attributed to Yrjö Engeström (e.g., Engeström & Sannino, 2010; Tuomi-Gröhn & Engeström, 2003) is a progressive take on transfer that is rooted in activity theory (Engeström, 2001). Instead of the traditional conceptualization that transfer is an individual cognitive process (Detterman, 1993), Engeström's activity-theoretic perspective reconceptualizes transfer as a collective process that happens within social activity systems. Furthermore, according to this perspective, transfer is conceptualized as occurring on two dimensions. First, it involves expansion of a social activity within a social system, what Tuomi-Gröhn and Engeström (2003) referred to as a "transformation in collective activity systems and institutions (e.g., schools and workplaces)" (p. 30). Second, there is a proliferation of the newly expanded activity to other social activity systems, for example, by "recruiting a growing number of participants in the transformation effort" (p. 31). An essential difference between Engeström's activity-theoretic perspective and Beach's (1999) consequential transitions perspective is that the former is about organizations creating change within social systems, whereas the latter is about individuals adapting to changes within social systems.

Key Features An important feature of this activity-theoretic perspective is that transfer is a collective process that involves a cycle of seven strategic actions. These actions, in the order in which they occur, are: *questioning*, *analyzing*, *modeling*, *examining the model*, *implementing*, *consolidating and proliferating*, and *evaluating* (Tuomi-Gröhn & Engeström, 2003). The cycle begins when members of an organization *question* (or criticize, reject and/or have conflicting points of view about) an existing social practice (Engeström & Sannino, 2010). This action serves as the trigger for the transfer process. For example, in a study by Engeström (2009), students began to question why their school did not provide them access to computers during recess.

The second action the organization engages in is an *analysis* of the question. The analysis may include an examination of the origins and history of the social practice in question to identify causes, or the "inner systemic relations" of the practice to identify explanatory mechanisms (Engeström & Sannino, 2010, p. 7). For example, the teachers who were considering making computers available to students during recess, intensely debated the idea among themselves and then consulted another school that had been providing their students access to computers about how their students were interacting with the computers.

The third and fourth actions, *modeling* and *examining the model*, involve developing a representation of past and present issues raised during questioning, as well as a future vision for that practice that addresses the issues, and then making the model publicly sharable and scrutinizable. In the computers-in-school example, a subcommittee of teachers created a model for putting computers in school hallways by reconceptualizing the school as a work environment for both students and teachers (Engeström, 2009). The model was then debated among the teachers.

The final three actions, *implementing*, *consolidating/proliferating*, and *evaluating*, are respectively, when the organization puts the model into practice, when the implemented model is used to influence other social practices, and when the organization monitors and reflects upon the newly implemented ideas. It is during these three actions that the two types of transfer described previously occur. Specifically, during implementation, there is the "transfer of new models into practice," and during proliferation, there is the "transfer of local innovations and new forms of practice into other activity systems and organizations" (Tuomi-Gröhn & Engeström, 2003, p. 32). In the school example, the computers-in-hallways idea was eventually implemented as part of an effort to make the physical environment more pleasant (Engeström, 2009).

Purpose and Uses One purpose for this activity-theoretic perspective on transfer is to capture types of transfer that occur at the organizational level rather than at the individual level (i.e., "collective developmental transfer;" Tuomi-Gröhn & Engeström, 2003, p. 34). Second, this progressive perspective captures transfer in complex activity systems, such as workplaces and schools. Third, this perspective accounts for transfer that is "not triggered by an instructor giving a task to be learned … [but] when some practitioners reject the given wisdom and begin to question it" (p. 32).

Several studies in mathematics education have made use of Engeström's activity-theoretic perspective on transfer. Tomaz and David (2015) used this perspective to examine how students working on a project came to modify particular mathematical activities they had been taught regarding proportional reasoning. Tomaz and David have a follow-up chapter in this book. Additionally, FitzSimons (2003) used an activity-theoretic lens to understand an adult mathematics learner as she transferred her school-based mathematics learning across a school-home boundary to help her children with their mathematics homework.

1.3 Motivation for and Organization of This Book

We view this point in the history of transfer research as an opportune time for a book to be published on progressive perspectives on the transfer of learning. The six progressive perspectives that we reviewed in the previous section provide a well-developed foundation for additional theoretical contributions. The renewed interest in transfer research can serve as a catalyst to broaden the use of progressive transfer perspectives among mathematics education researchers, as well as among researchers in related fields, and particularly among those who might otherwise not have considered a focus on transfer.

Consequently we had three main goals when we embarked on this venture of bringing contributors together for this book. First, we wanted to provide a venue to showcase and aggregate leading-edge research on the transfer of learning from progressive perspectives. Second, we hoped to establish transfer as a valued subfield of research within mathematics and science education research. Third, we anticipated that this book could provide researchers with a foundation for forging a path for future transfer research. The collection of theoretical and empirical chapters that comprise this book represent an exciting array of progressive perspectives on transfer that could set a course for how transfer research moves forward.

The book has been organized into four parts. Part I is comprised of six chapters, including this chapter (i.e., Chaps. 1, 2, 3, 4, 5 and 6), that theoretically explore progressive perspectives on transfer. Nathan and Alibali theorize about transfer from an embodied and distributed perspective. Johnson, McClintock, and Gardner's account of transfer interweaves theories about AOT, variation (Marton, 2006), and quantitative reasoning (Thompson, 2011). Hohensee argues for theory development about an extension of AOT called backward transfer. Karakok discusses potential parallels and associations between AOT and mathematical creativity. Finally, Danish, Saleh, Gomoll, Sigley, and Hmelo-Silver use an activity-theoretic approach to theorize about how the object of students' shared activities helps determine which mathematical tools students see as applicable for new activities.

Part II is comprised of five chapters (i.e., Chaps. 7, 8, 9, 10 and 11) that examine transfer empirically as it occurs in STEM classrooms. Moore uses AOT to examine how the meanings that pre-service secondary teachers constructed for particular graphs influenced their thinking about other graphs. Lockwood and Reed also use AOT and explore the ways an undergraduate's thinking on a particular combinatorial problem influenced his thinking on other problems. Michelsen draws on the expansive-framing perspective to investigate intercontextuality between tenth-grade students' mathematics and biology classes. Tomaz and David employ Engeström's activity-theoretic perspective to consider the boundary-crossing of seventh-graders when they were studying a common topic across three content areas. Finally, Grover draws upon the PFL approach to transfer, as well as the expansive-framing perspective, to look at how middle school students learned text-based computer programming after learning block-based programming.

Part III is comprised of four chapters (i.e., Chaps. 12, 13, 14 and 15) that empirically examine transfer when it occurs, in whole or in part, outside of school settings. Jackson tracks two 10-year-old students' mathematical activities at home and in school to illustrate how conceptualizations of transfer can be informed by ethnographic accounts of learning. Pugh, Bergstrom, Olson, and Kriescher present their *transformative experience* perspective on transfer and extend it to include the idea of motivation to account for how students applied school-based learning in out-of-school contexts. Billett examines how individuals adapted what they learned in school and other social settings to occupational contexts. Finally, Triantafillou and Potari use Engeström's activity-theoretic perspective, along with objectification theory (Radford, 2008), to look at how engineering students applied school-based knowledge to their apprenticeship.

Finally, Part IV is comprised of three chapters (i.e., Chaps. 16, 17 and 18) that examine how transfer relates to teaching and researching. Diamond investigates what teachers believe about how to support students in transferring their learning. Mamolo uses the AOT lens to explore how a prospective teacher's own K–12 experiences influenced their responses during scripted role playing. Finally, Evans tackles the transferability of research findings by examining different aspects of the context in which research occurs.

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