The Challenge and Promise of Complexity Theory for Teacher Education Research

by Marilyn Cochran-Smith, Fiona Ell, Larry Ludlow, Lexie Grudnoff & Graeme Aitken — 2014

Background/Context: *In many countries, there are multiple studies intended to improve initial teacher education. These have generally focused on pieces of teacher education rather than wholes, and have used an underlying linear logic. It may be, however, that what is needed are new research questions and theoretical frameworks that account for wholes, not just parts, and take complex, rather than reductionist perspectives.*

Purpose: *This article examines the challenges and the promises of complexity theory as a framework for teacher education research. One purpose is to elaborate the basic tenets of complexity theory, summarize its previous uses, and identify key challenges. A second purpose is to propose a new research platform that combines complexity theory with critical realism (CT-CR) and prompts a new set of empirical questions and research methods.*

Research Design: *Drawing on scholarship from sociology and education, the underlying design—or logic—of this analytic essay is this: explanation of the basic tenets of complexity theory applied to teacher education, assessment of previous research informed by complexity theory, response to the major epistemological and methodological challenges involved in using complexity theory as a research framework, and proposal of a new set of questions and methods.*

Findings/Results: *Complexity theory is appealing to teacher education researchers who want to avoid simplistic and reductionist perspectives. However, most previous complexity research has not addressed the critiques: the proclivity of complexity theory for retrospective description; the assertion that, given its rejection of linear causality, complexity theory cannot provide causal explanations with implications for practice; and the charge that complexity-informed research cannot deal with the values and power inequalities inherent in*

About the Author
- Marilyn Cochran-Smith
  Boston College
  MARILYN COCHRAN-SMITH is the Cawthorne Professor of Teacher Education at the Lynch School of Education, Boston College. Her research interests include teacher education policy, practice, and research nationally and internationally. Recent publications include Cochran-Smith, M., Cannady, M., McEachern, K., Piazza, P., Power, C., & Ryan, A. (2012). "Teachers' education and outcomes: mapping the research terrain." *Teachers College Record, 114*(10), 1-49; and Cochran-Smith, M., McQuillan, Mitchell, K., Terrell, D., Barnatt, J., D'Souza, L., Jong, C., Shakman, K. Lam, K., & Gleeson, A. M. (2012). A longitudinal study of teaching practice and early career decisions: A cautionary tale. *American*

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the normative enterprise of education. Integrating complexity theory with critical realism provides a way to address these fundamental challenges. Building on this new platform, the essay proposes a new set of empirical questions about initial teacher education along with several innovative research methods to address those questions.

***Conclusions/Recommendations**: This essay concludes that the combination of complexity theory and critical realism offers a unique platform for teacher education research, which has theoretical consistency, methodological integrity, and practical significance. The essay recommends that its proposed new empirical questions and methods may have the capacity to show us where to look and what processes to trace as teacher candidates learn to enact practice that enhances the learning of all students, including those not well-served by the current system.*

In many countries around the world, there are efforts to reform initial teacher education (Furlong, Cochran-Smith, & Brennan, 2009). The overall logic of many of these reforms is this: (a) teacher quality is the most powerful influence on student achievement (Hattie, 2008; Sanders & Horn, 1998) and is the linchpin of education reform generally (Darling-Hammond, 2010; McKinsey, 2007, 2010); (b) initial teacher education policies, programs, and pathways produce teachers and are thus responsible for teacher quality (McKinsey, 2007; World Bank, 2010); (c) however, current levels of teacher quality are inadequate to the challenges of the 21st century (OECD, 2005; U.S. Department of Education, 2002); (d) therefore, initial teacher education needs to be reformed in order to leverage greater teacher quality (Duncan, 2009; OECD, 2005). This kind of linear thinking sits behind many research and reform initiatives related to teacher preparation.

In multiple efforts to identify leverage points for improvement, research has yielded important information about many of the parts of initial teacher education, such as policies regarding entry pathways and licensure, teachers' knowledge and beliefs, courses and program structures, school-university relationships, and practice-based learning opportunities, but it has been difficult to put these pieces together and see the whole picture. Unfortunately, our growing knowledge of the pieces and parts of teacher education has not provided powerful enough explanations about how teacher education functions as a whole or why disappointing outcomes continue to occur, such as beginning teachers' seeming inability to enact the transformative practices aligned with the goals of their preparation programs (Kennedy, 1999; Korthagen, 2010) or the persistence of disparities in the learning opportunities and

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- Fiona Ell
University of Auckland
E-mail Author
FIONA ELL is a lecturer at the Faculty of Education in the University of Auckland. Her research interests include mathematics education, teacher education, and education policy. Recent publications include: Ell, F. (2012). "Teacher education in New Zealand." *Journal of Education for Teaching, 37* (4),: 443--440; and Ell, F., & Grudnoff, L. (2013). The politics of responsibility: Teacher education and persistent underachievement in New Zealand. *The Educational Forum,. 77*(1), 73--86.
- Larry Ludlow
Boston College
E-mail Author
LARRY LUDLOW is Professor and Chair of the Educational Research, Measurement and Evaluation Department at the Lynch School of Education, Boston College. His research interests include Rasch model instrument development applications, longitudinal models for faculty course evaluations, and higher education accountability indicators. Recent publications include: Ludlow, L. H., Rollison, J., Cronin, J., & Wallingford, T. (2012). "Development of the teaching economic literacy: Confidence and anxiety (TELCA) instrument." *International Journal of Educational and Psychological Assessment, 9*(2), 82--103. http://tijepa.books.officelive.com/main.aspx);, and Ludlow, L. H., Pedulla, J., Reagan, E. M., Enterline, S., Cannady, M., & Chappe, S. (2011). Design and implementation issues in longitudinal research. *Educational Policy Analysis Archives*. North America, 19, Apr. 2011. http://epaa.asu.edu/ojs/article/view/802/906)
- Lexie Grudnoff
University of Auckland
E-mail Author
LEXIE GRUDNOFF is deputy dean teacher education at the Faculty of Education, The University of Auckland. Her research interests focus on initial teacher education and beginning teacher learning and development. She is current chair of the Teacher Education Forum Aotearoa New Zealand. Recent publications include: Grudnoff, L. (2012). All's well? New Zealand beginning teachers' experience of induction

outcomes of particular groups of students based on race/ethnicity, language background, and/or socioeconomic status (Alton-Lee, 2003; Villegas & Lucas; 2001). If teacher education research has not yielded such explanations, perhaps it is because of the linear logic underlying much of this research and its tendency to break teacher education into parts for study. This has led to the investigation of certain types of questions while others have been given little or no attention. To develop more powerful explanations about teacher education, we may need new and more powerful research questions and theoretical frameworks.

In this article, we consider both the challenges and the promises of complexity theory as a theoretical framework that opens up new questions, gives us new places to look for explanations, and offers new ways of understanding teacher education processes and outcomes. In the first section of the article, we provide background for this discussion by elaborating the basic tenets of complexity theory, summarizing its previous uses in teacher education research, and considering the contributions this research has made. Next, the article identifies three challenges involved in contemporary attempts to use complexity theory as a framework for research on teacher education, challenges that must be adequately addressed in order for this new line of research to develop with theoretical consistency, methodological integrity, and practical significance. Along these lines, we suggest that integrating complexity theory with the critical realist program of scientific understanding and inquiry provides a way to address these fundamental challenges. Finally, informed by the unique perspective we outline in the second section of the article, in the third and final section, we turn to methodological issues. Here, building on the platform provided by complexity theory integrated with critical realism, we pose a new set of empirical questions about initial teacher education and propose several innovative research methods that may help to address those questions, drawing on approaches used in other social sciences. We conclude by considering the implications for policy, research, and practice.

This article is a product of Project RITE (Rethinking Initial Teacher Education), an ambitious new program of research and practice in teacher education led by researchers at the University of Auckland in New Zealand and Boston College in the United States. The major purpose of Project RITE is to conduct and disseminate research, informed by complexity theory, on the relationships between initial teacher education policies and practices and school students' learning. This article presents the first phase of Project RITE. It elaborates the key epistemological, ontological, and methodological issues involved in integrating complexity theory with critical realism

provision in their first six months in school. *Professional Development in Education, 38*(3), 471--485;, and Ell, F., & Hill, M., & Grudnoff, L. (2012). "Finding out more about teacher candidates' prior knowledge: Implications for teacher educators," *Asia-Pacific Journal of Teacher Education, 40*(1), 55--65.

- Graeme Aitken
University of Auckland
E-mail Author

GRAEME AITKEN is the dean of education at The University of Auckland. His research is focused on teaching effectiveness and curriculum development and design. He aims through his research to offer insights into practice that help decision making by policymakers, schools, and teachers in the best interests of learners and learning. Recent publications include Sinnema, C., & Aitken, G. (2012). *Effective pedagogy in social sciences* (Educational Practices Series – 23) Geneva: International Bureau of Education; and Sinnema, C., & Aitken, G. (2013). Commonalities in national curricula. In M. Priestley & G. J. J. Biesta (Eds.), *Reinventing the curriculum: New trends in curriculum policy and practice*. London, UK: Bloomsbury.

as a platform for research on initial teacher education aimed at understanding the initial conditions, system interactions, and underlying causal structures that facilitate the emergence of desired outcomes in initial teacher education. The RITE team's current empirical work based on this platform is mentioned later in the article.

RETHINKING TEACHER EDUCATION RESEARCH THROUGH THE PRISM OF COMPLEXITY THEORY

As we suggested at the beginning of this article, research on initial teacher education has generally focused on selected pieces and parts of teacher preparation. This approach assumes (either implicitly or explicitly) that initial teacher education is a complicated phenomenon made up of many discrete policies, programs, entry pathways, processes, and people who function in various roles; it is further assumed that these pieces can be identified, studied, and improved apart from the whole. This approach has generally not yielded deep enough understanding of the phenomenon of teacher education nor generated powerful enough knowledge to solve the seemingly intractable problems of initial teacher education and teacher quality. Below, we identify several key tenets of complexity theory, based on the work of multiple contemporary scholars who work from differing perspectives on complexity and whose ideas have been widely disseminated in discussions that link complexity with social science and/or education research.

COMPLEXITY THEORY

Davis, Phelps, and Wells (2004) rightly emphasized that there is no single definition of complexity or complexity research. The lack of a single definition is not surprising, given that what has variously been referred to as "complexity theory," "complexity research," "complexity science," and "complexity thinking" now draws from several generations of development, beginning in the 1950s and 1960s, in evolutionary biology, chaos theory, information and communications theory, quantum physics, chemistry, cybernetics, systems theory, mathematics, artificial intelligence, nonlinear dynamics, economics, and management sciences. More recent lines of application and development have emerged in anthropology, family research, health, psychology, business, politics, sociology, organizational theory, leadership, and education (Alhadeff-Jones, 2008; Davis & Sumara, 2006; Mason, 2008; Wheatley, 2006).

In this article, we concentrate on complexity theory as it has been applied to research in the social sciences and education. In the social sciences, complexity theory has evolved into substantially different, and not necessarily compatible, branches of study. For example, philosopher, Paul Cilliers

(1998) integrated complexity theory with postmodernism, while sociologists David Byrne (1998), Michael Reed and David Harvey (1992), and Sylvia Walby (2007) connected complexity theory to critical realism. Our approach here is consistent with the latter, a point we take up in some detail in a later section of this article on challenges to research on teacher education from the perspective of complexity. Despite the considerable divergence among applications of complexity theory to the social sciences, in the section that follows, we focus on what most of these have in common in order to remind readers about, or introduce them to, the key tenets of complexity theory.

Complexity theory is a loose collection of scholarly work that takes up important questions about systems and how systems change, develop, learn, and evolve (Mason, 2008; Morrison, 2008; Walby, 2007; Wheatley, 2006). Rather than parts, complexity theory emphasizes wholes, relationships, open systems, and environments (Byrne, 1998; Davis & Sumara, 2006). From the perspective of complexity, multidimensional relationships and dynamic interactions among agents and elements, rather than predictable linear effects, are responsible for patterns and phenomena (Byrne, 1998; Cilliers, 1998; Haggis, 2008). Here, disequilibrium is regarded as an inherent part of complex systems, not an undesirable state (Byrne, 1998; Cilliers, 1998; Morrison, 2008), and the notions of self-organization, emergence, and bottom-up change processes are critical (Cilliers, 1998; Davis & Sumara, 2006; Mason, 2008; Morrison, 2008). In addition to these overarching constructs related to continuity and change in systems, most applications of complexity theory to the social sciences also have in common the major ideas and perspectives they reject. These include the assumption that how the world works can be explained using 17th century Newtonian machine imagery (Davis, Phelps, & Wells, 2004; Richardson & Cilliers, 2001; Wheatley, 2006), the idea that a completely objective and accessible reality exists “out there” waiting to be discovered (Byrne, 1998; Wheatley, 2006), linear models of cause and effect (Horn, 2008; Mason, 2008; Morrison, 2008; Radford, 2006), analytic/reductionist views of phenomena (Horn, 2008; Radford, 2006; Richardson & Cilliers, 2001), and positivist research methods that aim to reduce complex phenomena to the key factors that determine outcomes (Byrne, 1998; Morrison, 2008; Walby, 2007).

Central to complexity theory is the idea that complex systems are fundamentally different from complicated systems (Bryne, 1998; Cilliers, 1998). Both complicated and complex systems have multiple parts and interactions, and they are difficult to understand at first glance. In the case of complicated systems, however, wholes are equal to the sums of their parts, and their function and its outcomes can be fully understood by

considering separately the parts and processes of the system. This means that if complicated systems are taken apart and the pieces examined closely, then the nature of the system's function is revealed. One complexity scholar included jumbo jets and CD players among his examples of complicated systems (Cilliers, 1998). In contrast, with complex systems, complexity is manifested at the level of the system itself; it results from the interactions and nonlinear relationships of component parts and from intricate feedback loops in the system (Cilliers, 1998). With complex systems, wholes are much more than the sums of their parts (Byrne, 1998; Cilliers, 1998). Taking complex systems apart results in losing key aspects of how they work and what makes them work in the first place since unexpected consequences can arise as the result of the interactions of parts. This means that outcomes are emergent and unpredictable, although not random and not inexplicable. Cilliers offered bacteria, the brain, and social systems as examples of complex systems. In discussions of complexity theory and education, individuals (e.g., teachers, students, and principals), classrooms, schools, school districts, teacher education programs and courses, professional learning contexts, school–university collaborations, student teaching supervision, and mentoring relationships have all been regarded as complex systems (e.g., Clarke & Erickson, 2009; Davis, Sumara, & D'Amour, 2012; Nielson, Triggs, Clarke, & Collins, 2010; Opfer & Pedder, 2011; Radford, 2006; Schneider & Somers, 2006; Waks, 2011).

INITIAL TEACHER EDUCATION AND COMPLEX SYSTEMS

Beyond appearing to be more than the sum of their parts, there are five key aspects of complex systems, which are generally identified across the complexity literature. Complex systems have a form that is determined by initial conditions and control parameters resulting in open but boundaried systems that are nested in and intersect with other systems (Byrne, 1998; Houchin & MacLean, 2005; Mason, 2008; Waks, 2011). They are characterised by multiple interactions that are nonlinear, short range, redundant, and diverse (Byrne, 1998; Cilliers, 1998; Haggis, 2008; Mason, 2008; Morrison, 2008; Waks, 2011). They are dynamic and far from equlibrium (Byrne, 1998; Cilliers, 1998; Davis & Sumara, 2006; Houchin & MacLean, 2005; Morrison, 2008; Wheatley, 2006). They change, grow, and learn through feedback loops, where small changes can make a big difference, and, thus, they have an important history (Byrne, 1998; Davis & Sumara, 2006; Mason, 2008; Morrison, 2008; Richardson & Cilliers, 2001; Wheatley, 2006). Finally, complex systems are self-producing, self-reproducing, and, thus, in a state of emergence (Byrne, 1998; Cilliers, 1998; Davis & Sumara, 2006; Haggis, 2008; Morrison, 2008).

Below, we consider these five aspects of complex systems in terms of the context of initial teacher education. We provide brief examples of how the characteristics of complex systems are evident in teacher education in order to clarify what these characteristics mean and to illustrate their applicability to teacher education.

Teacher education's form is determined by societal and statutory parameters, and its form shifts over time. A particular instance of teacher education, for example an undergraduate teacher preparation program at a university, has boundaries defined by its institutional position and the structure of the qualification, but it is also nested within teacher education more broadly and within the education system generally. Teacher education programs intersect with individuals, school systems, and family systems, as well as legislative processes and regulatory bodies. The relationships between teacher education and the systems in which it is embedded or involved affect how teacher preparation is provided and how it functions. In addition, teacher education may be regarded as a complex system at multiple levels. These include teacher education’s individual participants (e.g., teacher candidates, school-based cooperating teachers, and course instructors), who are themselves complex systems, particularly university-based or alternate-route teacher education programs and pathways as systems; state or national teacher preparation, accreditation, and certification systems; national and international networks of actors and agencies engaged in the professional preparation of teachers and/or in research about teacher preparation; and the overall global enterprise of recruiting, selecting, preparing, supporting, and evaluating teachers in order to achieve economic, enculturation, and social goals. These interdependent and complex teacher education systems shift and change over time. In addition, cutting across all these levels are wider social and societal systems. This means that teacher education is shaped by the same multiple intersecting social inequalities (Walby, 2007) that characterize larger social systems.

Understood as a complex system, teacher education at all of these levels is replete with high-frequency, short-range, local interactions, the influence of which is enhanced, diminished, or changed along the way. For example, in a university-based teacher education program with large lecture classes, instructors make (and directly explain) assignments to their teacher candidate students. However, these assignments may be further explained (interpreted, modified, or augmented) by the leaders of smaller discussion or tutorial groups. In turn, these may be still further reinterpreted when teacher candidates interact with one another about the assignment through social media channels, to which instructors are not

privy. Along the way, multiple interpretations of a particular assignment's purpose and requirements may emerge, none of which match the instructor's original intention. Further, teacher candidates as individuals interact with the task as they complete it, affecting the way the assignment is viewed. Larger patterns emerge from the structure of local, short-range interactions between and among agents and elements.

With its myriad elements constantly interacting in dynamic ways, teacher education is never standing still, although it may be growing or shrinking in actual size, influence, or popularity. This means it is operating in disequilibrium. The constant flow of interactions and information creates energy that keeps the system operating in a complex manner. Disequilibrium is necessary for a system to be considered complex, and the flow of information through a system maintains disequilibrium by stimulating the structures and processes of the system. For example, school-based leaders and associate teachers at a given school or schools might express dissatisfaction with their perceived lack of information about the expectations of the teacher education program that sends them teacher candidates, which increases the information flow and, thus, the degree of disequilibrium of a system. This negative perception might result in a principal's decision to no longer accept candidates from the program, but it might also lead to a new school–university partnership, which could prompt innovative ways to organize and evaluate teacher candidates' experiences at the school.

Disequilibrium powers a complex system's learning and change. This develops into a history that critically influences what occurs in the present. The different forms of initial teacher education in different countries, for example, reflect their systems' histories, which provide a crucial background to understanding their current function. Feedback loops within the system amplify or regulate the effects of perturbations on the system. Small events can have large effects. For example, a single teacher candidate might witness a desirable school event (e.g., a child learning a concept after several teaching sessions) and then talk about this event to multiple teacher candidates who also talk to other peers. With time, the school involved may be deemed a "great school" on the teacher candidate grapevine, resulting eventually in the desire of another teacher candidate, who has no firsthand experience with the school, to be placed at that school. Here, the effect of a relatively small event is amplified as a result of multiple, nonlinear interactions.

Finally, teacher education understood as a complex system is emergent. It produces and reproduces itself through interactions at multiple levels, defined by control parameters

and affected by the other systems around and within it. Influenced by both the history of the system and the external environment, the process of self-organization changes the relationships among the elements of the system as new relationships emerge. For example, in initial teacher education in some countries, the political and policy climate has changed dramatically over the last 30 years, including shifting notions of accountability and increasing emphasis on market-based reforms. To cope with these changing demands, new kinds of program structures and pathways into teaching have emerged, for better or for worse, and teacher education systems (e.g., individual teacher educators and leaders, particular teacher education programs, research projects, and policymakers) have "learned" to focus more on performance assessment and on demonstrating that they add value to beginning teachers' effectiveness.

COMPLEXITY STUDIES OF TEACHER EDUCATION

Building on the above general description of complexity theory and its application to teacher education, we now briefly consider previous scholarship in teacher education that is guided by the lens of complexity. It should be noted that our discussion is not intended as a detailed or thorough review of the research methods or findings of previous research. Rather our discussion provides a brief overview of this body of scholarship, focusing on how complexity theory has been used in both conceptual and empirical research related to teacher education. Our point is to highlight different uses of complexity theory and the contributions previous research has made as a prelude to our main discussion in this article about the promise of a new platform for research on teacher education.

In previous research that links complexity theory with teacher education, we identified three ways that researchers have utilized complexity theory or complexity thinking to shape their inquiries. Based on these, we considered the previous research in terms of three general groupings, the first conceptual and the other two empirical: (a) conceptual research that uses key theoretical constructs and ideas from complexity theory to challenge the conceptual or methodological assumptions commonly underlying research and practice related to teacher education and to suggest how complexity theory can reconceptualize the field; (b) empirical research that uses concepts and frameworks derived from complexity theory to describe and interpret in new ways particular cases or aspects of teacher education practice; and (c) empirical research that uses complexity theory both as an animating framework for the transformation of key aspects of teacher education programs and practices and as a framework for documenting and understanding initiatives aimed at

transformation. We highlight the contributions of this research by describing each of the uses of complexity theory in teacher education with selected examples.

Reconceptualizing Teacher Education and Learning to Teach

There is an emerging body of conceptual scholarship that explicates concepts and constructs from complexity theory and demonstrates their potential to reconceptualize and retheorize research and/or practice and policy in teacher education and teacher learning. Brent Davis and Dennis Sumara, who have written extensively about complexity and education/teacher education for more than a decade, are the most prolific and seminal scholars in this category (e.g., Davis, Phelps, & Wells, 2004; Davis & Simmt, 2003; Davis & Sumara, 2006, 2007, 2008, 2010; Sumara & Davis, 1997).

Three of Davis and Sumara's concepts illustrate how complexity theory can be used to reconceptualize research and practice in teacher education. Their concept of "enactivism" (Davis & Sumara, 1997) rejected both prevailing "representational" notions of cognition and dominant views of knowledge as object in favor of organic notions of cognition as existing in the "interstices of a complex ecology of organismic relationality" (p. 110). This means that teaching and learning cannot be understood in terms of direct, causal, linear, and manipulable relationships among various components, but in terms of the dynamic and changing relationships between individuals and the collective. Secondly, Davis and Sumara (1997) applied to teacher education the distinction between complicated systems, which, as we noted above, can be described with mechanical metaphors and understood by decomposing and analyzing how component parts are assembled, and complex systems, which are dynamic and adaptive with organisms and environments engaging dialectically. As Davis and Sumara (1997) rightly argued, teaching and learning have for too long been regarded as complicated "exclusive concern with the components of teaching . . . has always been and continues to be inadequate for preparing teachers for the complex situations within which they will be working" (p. 121). Thirdly, Davis and Sumara (2006) suggested that, over time, the transdisciplinary umbrella of complexity thinking has evolved into a "pragmatics of transformation" (p. 130), or a framework that "offers explicit advice on how to work with, occasion, and affect complexity unities" (p. 130) in group and collaborative settings in order to construct the conditions necessary for the complex "emergence of the as-yet unimagined" (p. 135). This idea is directly related to the issue of agency in teacher education and suggests changes in the ways we think about the role of teacher educators in creating the social, organizational, and intellectual structures of teacher education programs and

pathways.

Although Davis and Sumara (2006) pointed out that "complexity thinking is not a ready-made discourse that can be imported into and imposed onto education research and practice" (p. 8), they suggested that "a great many phenomena that are currently of interest to educational research might be considered in terms of complex dynamics" (p. 6). Davis and Sumara's use of complexity thinking to reconceptualize learning to teach as complex and dynamic calls for new questions, new forms of inquiry, and new interpretive frameworks in teacher education research, while it also suggests approaches to reinventing and transforming the conditions and contexts of learning to teach.

Along different lines, Opfer and Pedder (2011) drew on key ideas from complexity theory to suggest new ways to understand and investigate research on teachers' professional learning. In a literature review on this topic, they argued that much of professional development for teachers is ineffective because it concentrates on specific processes or programs in isolation and because it is driven by an underlying process-product logic that fails to account for the fact that teachers' learning is deeply embedded in their professional lives and in the working conditions of their schools. They suggested that in the act of simplification, we lose the vital elements that could yield more useful explanations. Instead of simplifying, they suggested that researchers should conceptualize teacher professional learning as three overlapping and recursive complex systems—the system of the individual teacher, the system of the school, and the system of professional learning activity. From this perspective, Opfer and Pedder suggested that the goal of research on professional learning is the identification of "emergent patterns of interaction within and between levels of activity that would constitute an explanatory theory of teacher learning as a complex system" (p. 379).

Other scholars have also argued in favor of complexity theory as a framework for reconceptualizing teacher education practice by demonstrating its capacity to re-theorize key aspects and strategies of teaching and teacher education. For example, Phelps (2005) showed that complexity theory's concepts of instability and disequilibrium can be utilized to explain how teacher candidates engage in reflective journal writing to learn to use technology. Clarke and Collins (2006) used generative ideas from complexity theory, such as networked structures, to analyze changes in the student teaching practicum and other widely used coursework and fieldwork strategies in teacher education, including how uncertainty and improvisation are regarded. Fels (2004) used complexity's notions of emergence and order to reconsider how

teacher candidates come to understand that pedagogy and learning are unpredictable, uncontrollable, and co-evolving experiences. Finally, a number of other scholars have argued in general that aspects of teacher preparation can and should be reconceptualized as complex systems (e.g., Bloom, 2011; Reynolds, 2011; Smitherman Pratt, 2011; Waks, 2011).

With this first category of conceptual research, the major contribution is retheorizing and reconsidering aspects of teacher education/teacher learning research and practice from complexity lenses. To do this, the scholarship in this category introduces or elaborates key generative ideas from complexity theory and, at the same time, critiques or rejects many of the prevalent assumptions in teacher education research and practice, such as transmission-oriented approaches to teacher training, linear views of teaching and learning, and the traditional knowledge hierarchies that serve to separate theory and practice in teacher education. Instead of these traditional perspectives, the generative work in this category suggests new ways to conceptualize and study some of the major questions related to teacher education and calls for new programs of research and new approaches to practice.

Case Studies and/or Descriptive Analyses of Practice

The studies in our second category are related to, but also different from, those in the first. With the analytic essays in the first category, the focus is on the development and application to teacher education of concepts derived from complexity theory. In contrast, the studies in the second category are empirical. They use ideas from complexity theory as a theoretical lens to guide the analysis of empirical data that represent particular aspects of teacher education or particular sites of practice. These analyses are often presented in the form of case studies or rich descriptions of practice. Much of the research in this category uses complexity theory retrospectively in the sense that it generates interpretations and analyses of "what happened" with a particular teacher education/professional learning project, program, course, event, situation, clinical setting, or context that has already occurred (and, in some cases, has already been studied from another theoretical perspective).

For example, Clarke, Erickson, Collins, and Phelan (2005) used the notion of learning systems along with a self-study research design to investigate the longevity, quality, and workings of an alternative cohort and inquiry-based teacher education program. Kiefer (2006), a professor of English, used the ideas of nonlinearity and emergent self-organizations to describe and unpack the dynamics of physical and virtual writing classes, prompted by her troubling experiences as the teacher of two

"dysfunctional" classes. Cvetek (2008), a language teacher educator, drew on ideas from complexity theory to analyze the difficulties student teachers described in planning and carrying out lessons in language classrooms; he recommended that student teachers be taught to be "agents of chaos" (p. 253). Along different lines, Kalin, Barney, and Irwin (2009) called for a conceptual shift from technical mentoring to "complexity thinking mentorship" (p. 354), based on their analyses of dissertation mentoring in arts-based education research. Finally, in a study designed to test the capacity of complexity theory to provide insights about the learning of school mathematics departments, Beswick, Watson, and Geest (2010) used interviews and observations of department meetings to study shifts in individuals' thinking, conceptualized as emergent phenomena.

Most of the studies in this second category share a number of characteristics. Their purpose is to provide deeper and more complex descriptions, analyses, and interpretations of current or past events, initiatives, or contexts that are common to teacher education. They use fairly standard forms of qualitative data collection and analysis, including interviews, observations, transcriptions of conversations, and other documentations of practice as well as constant comparative analyses of data and/or analytic induction. Often, these studies use some version of a practitioner research design wherein the practitioner is also the researcher, and the site of practice is also the research site (Cochran-Smith & Lytle, 2009).

In terms of data collection and analysis, then, many of the studies in this second group resemble other qualitative studies of teacher education. The difference is the theoretical frame—that is, the complexity concepts, constructs, and lenses that guide the studies generate differently focused questions and different interpretations. As our examples illustrate, with the studies in the second category, researchers engage in "complexity thinking," which Davis & Sumara (2006) described as a "research attitude," to unpack recurring dilemmas of practice or to analyze from new perspectives common strategies and approaches in teacher education. The conclusions reached by many of these researchers about complexity theory as a tool for research on teacher education are similar to McQuillan's (2008) conclusion regarding his complexity-informed retrospective account of the dynamics of small school reform: "Complexity theory: it's good to think with" (p. 1772). We use this quote here to emphasize that the primary aim of most of the studies in this second category is to describe and interpret what is happening (or has happened) rather than to change it directly. Although the studies in this second category have important implications for improving practice or policy in teacher education, they are different from

the studies in our third category, below, in that the studies in the second category do not directly initiate and study change.

Transforming Teacher Education/Professional Learning

The studies in the third category are also empirical, and they are broadly similar to those in the second category in several ways, including data collection and analysis procedures, the role of practitioner researchers, and a focus on key recurring aspects or dilemmas of teacher education. However, the studies in this third category differ importantly in purpose. In contrast to the studies in the second category, which often use complexity theory retrospectively to describe what has happened, the studies in this third category use complexity theory prospectively as a framework for both guiding the transformation of key aspects of teacher education and studying that transformation.

There are very few studies in this category. Zellermayer and Margolin (2005), for example, were guided by the notion of complex, adaptive systems and the notion of transformation as something that occurs from the bottom up in their structuring of professional learning groups of student teaching supervisors and teacher educators and in their study of what happened with those groups during a period of dramatic curricular transition. Drawing on qualitative data collection methods, including transcripts of audiotaped group discussions and interviews over two years, they identified a series of critical events, which allowed contradictory outcomes and involved conflicts and dissonance "at the edge of chaos" (p. 1279). They showed that these events were pivotal to the group's learning and led to the group's self-organization. In a different, but somewhat consistent effort to challenge and transform traditional notions of professional learning, Nielsen et al. (2010) developed and studied a bi-monthly conversational community of cooperating teachers and teacher educators who met over two years. The authors conceptualized the collective as an "open-ended, diverse, and emergent phenomenon, attentive to a variety of futures through self-examination and reflection on current practices" (p. 839). They reported that their sensitivity to complexity science prompted them to pay attention throughout the life of the group to local action initiation and direction, feedback loops, disequilibrium as potentially generative, and nested layers of systems. As the authors noted, earlier work they did using complexity theory to describe teacher education practice (Clarke et al., 2005) prompted them to "invite chaos and trust complexity" (p. 845) as part of the applied research process.

The defining feature of the studies in this third category—and their major contribution—is that they do not use complexity

theory only to produce deeper and richer descriptions of practice in teacher education. Rather, drawing on salient concepts from complexity theory, they actually transform particular aspects of teacher education, and they also describe and analyze those transformations. In this sense, they reflect Davis and Sumara's (2006) assertion that complexity thinking has evolved into a pragmatics of transformation based on the conviction that "transformations of learning systems cannot be understood in linear or mechanical terms" (p. 130). Rather, as Davis and Sumara argued, complexity thinking that focuses on simultaneities rather than discontinuities has the capacity to guide "observational-descriptive work *and* to inform pragmatic concerns" (p. 154). This, they suggested, distinguishes complexity from most of the discourses borrowed from other domains and applied to education.

The studies we have sorted into the three categories above show that ideas and concepts from complexity theory can be very useful for understanding teacher education from the perspective of complex and self-organizing, multilevel systems. From this perspective, teachers' learning and their practice (not to mention the learning of their eventual students) are influenced by multiple forces, which cannot be neatly predicted nor assumed to occur in a single way. As we have alluded in the above discussion, however, deeper and richer descriptions of practice are not enough. Rather, we need more empirical research on teacher education, informed by complexity theory, that gets at the persistent issues and problems that trouble teacher education with the aim of developing a complex explanatory theory of initial teacher education. As we point out in the section that follows, there are significant epistemological, ontological, and methodological challenges that must be overcome if the promise of complexity theory for teacher education research is to be realized. We take these up below.

THE CHALLENGES OF RESEARCH ON TEACHER EDUCATION GUIDED BY COMPLEXITY THEORY

Although many scholars in education and the social sciences have found complexity theory promising on a conceptual and descriptive level, there are multiple challenges involved in using it to guide the development and conduct of empirical studies that go beyond retrospective description (e.g., Horn, 2008; Morrison, 2008; Radford, 2006). This may explain why we have few such studies in teacher education and few explicit methodological discussions about complexity theory and research on teacher education. In this section of this article, we propose that complexity theory integrated with critical realism, which we introduce below, offers a theoretical frame for teacher education research that is sufficiently robust to

take up the most important challenges.

To begin to address the many theoretical challenges involved in using complexity theory as a framework for research on teacher education, we have integrated key ideas from complexity theory with critical realism, a philosophy that connects aspects of the natural and social worlds at the level of deep causal mechanisms (Bhaskar, 1987; Sayer, 1992). A major tenet of critical realism is that, although reality is not fixed nor immediately accessible, there are some aspects of reality that exist beyond our knowledge and conceptions of them; one key aspect of reality is the causal mechanisms that produce empirically observable events (Danermark, Ekstrom, Jakobsen, & Karlsson, 1997).

To integrate complexity theory and critical realism, we have drawn on the work of several scholars who have taken up this task in sociology (Byrne, 1998, 2001; Reed & Harvey, 1992; Walby, 2007). In line with them, we reject both reductionist *and* postmodernist versions of complexity, instead identifying critical realism as the ontological underpinning of complexity most consistent with the important questions posed by teacher education research. Byrne (2001) described this approach as the "synthesis of critical realism as a philosophical ontology and complexity theory as a scientific ontology proposed by Reed and Harvey (1992)" (p. 62). In Byrne's chapter titled "The Reality of the Complex, the Complexity of the Real" (p. 35), he clarified the realist position by asserting, "The essential elements in realism are the assertions that that which we observe in the world is real and that it is the product of complex and contingent causal mechanisms which may not be directly accessible to us" (pp. 37-38). Byrne suggested that the appeal of this perspective on complexity is that it allows us to deal with two critical problems of sociological theory—a way to relate macro and micro issues without being aggregative or reductionist and a way to describe the agency–structure relationship that accounts for human agency by acknowledging that human beings sometimes have the capacity to initiate certain causal sequences.

In Project RITE, we have applied and developed for teacher education the integration of complexity theory with critical realism as an animating research perspective. In the remainder of this article, for the sake of brevity, we use the abbreviation, CT-CR to refer to the application, development, and implications of complexity theory integrated with critical realism as a platform for teacher education research that offers a way to address many of the central challenges involved in using complexity theory as a framework for empirical research in education. We see CT-CR as a research perspective, not a specific research tool or method or a full-blown research

agenda with a prescribed set of questions and approaches. Rather than restricting research in teacher education, we see CT-CR as an opening and broadening perspective that invites new questions, methods, and combinations of research tools. We explore the meaning and potential contribution of CT-CR in the discussion below.

A number of scholars have questioned the usefulness of complexity theory in guiding education research. In the discussion that follows, we draw on Morrison's (2008) philosophical analysis of key challenges, focusing on three that are especially relevant to research on teacher education: (a) the criticism that complexity theory yields primarily post hoc descriptions with limited potential for prospective studies that inform teacher education practice or policy; (b) the assertion that, given its rejection of linear notions of cause and effect, complexity theory cannot provide causal explanations about teacher education and, thus, cannot drive the improvement of practice and policy in teacher education; and, (c) the charge that complexity theory is amoral and value-free, not attending to power inequalities and, thus, inconsistent with education as a normative enterprise. In order for research from a complexity perspective to be generative and salient to the current challenges of teacher education, these three issues must be taken up.

GETTING BEYOND POST HOC DESCRIPTIONS

As our brief overview in the previous section has shown, much of the existing empirical research on teacher education that works from a complexity lens can be characterized as post hoc description. Morrison (2008) was explicit that this is a deficit of complexity theory as a guiding frame for education research: "One can see the hidden hand of complexity theory—the ghost in the machine—working in the present and past only; this limits its prospective utility" (p. 26). Morrison also suggested that this kind of work tends to leap unjustifiably from description (what is) to prescription (what should be in the future). He concluded that, given complexity theory's premise that unpredictability is unavoidable, it undermines its own power because it cannot offer guarantees regarding prescriptions for future contexts.

There are two challenges to complexity theory as a framework for research on teacher education intertwined in Morrison's critique, and both of these must be addressed if the promise of complexity theory for teacher education research is to be fulfilled. One has to do with the capacity of complexity theory to inform research prospectively rather than providing a lens that is only good for descriptions of past events, and the other has to do with complexity theory's capacity to "guarantee . . .

prescriptions" for the future. The first challenge is not so difficult to address. In fact, as we noted, a small number of studies in teacher education has already used complexity theory prospectively in that it has informed both the transformation of processes and structures in teacher education as well as empirical study of those transformations (e.g., Nielson et al., 2010; Zellermayer & Margolin, 2005). As we noted, Davis and Sumara (2006) make this point explicitly, demonstrating with examples that complexity theory can guide both descriptive work *and* transformative work through a "pragmatics of transformation" (p. 130).

Morrison's second concern is that, given complexity theory's own premises about unpredictability, it cannot guarantee prescriptions for the future. This challenge is more difficult to address. It seems to imply that the goal of education research *should* be producing generalizable information about linear causes and effects, a supposition that would indeed render complexity theory inadequate as an education theory because it cannot offer guarantees about how things will work in the future. However, this is only a weakness if, consistent with positivist premises, one assumes in the first place that the point of education scholarship is to "prescribe" specific behaviors and strategies and to "guarantee" their effect on future contexts. We would argue here that the questions Morrison raises can be addressed by acknowledging the value of education research that concentrates on local contexts. As Byrne (1998) pointed out, because critical realism linked with complexity theory assumes that the character of reality is nonlinear, it is "absolutely concerned with the implications of local context(s) expressed in terms of time and space" (p. 47).

From this perspective, the contribution of teacher education research informed by CT-CR can be conceptualized in part in terms of the theories it generates about how things happen —given particular initial conditions and based on the local particulars of specific circumstances—rather than the production of generalizable correlations between processes and outcomes. Erickson (1986) made this point in his now-classic discussion of qualitative research on teaching:

> Each instance of a classroom is seen as its own unique system, which nonetheless displays universal properties of teaching. These properties are manifested in the concrete, however, not in the abstract . . . The task of the analyst is to uncover the different layers of universality and particularity that are confronted in the specific case at hand—what is broadly universal, what generalizes to other similar situations, what is unique to the given instance . . . The primary concern of interpretive research is

> particularizability, rather than generalizability. One discovers universals as manifested concretely and specifically. (p. 130)

Some of the goals of teacher education research informed by CT-CR need to be understood in terms that are more like the interpretive goals described by Erickson 25 years ago than the current dominant goals of generating prescriptions with guaranteed outcomes.

In a review of complexity theory and education research, Radford (2006) made this point quite well, although he was talking about school research rather than teacher education research. Below, we insert "teacher education programs" and "teacher education" for Radford's "schools" and "schooling" to apply his point to teacher education research informed by CT-CR:

> Educational research, if not identifying "key factors" that contribute to "effective [teacher education]" in general, and thus necessarily containing a prescriptive role, might have a task that is realist in its conceptualization. That task is to describe and explain how individual [teacher education programs] adapt to changing conditions. Research is interested in how, at the local and short term level, the complexity of factors and interconnections that constitute [teacher education programs] come together to function successfully in a given environment. (p. 185)

Following Radford, we would suggest that part of the task of research informed by CT-CR is describing and explaining how the complexity of factors, levels, interconnections, and systems that constitute teacher education function in different local conditions and under differing circumstances to contribute insights about the particular that are also useful beyond the local context and beyond a single moment in time. In the final sections of this article, we propose a new set of questions for teacher education research that speak to these goals, and we propose some new methods of data collection and analysis that researchers can use to address these questions.

THE PLACE OF EXPLANATION IN COMPLEXITY STUDIES OF TEACHER EDUCATION

A second major theoretical challenge involved in conducting complexity research in teacher education has to do with complexity's rejection of positivism and linear causality. Along these lines, Morrison (2008) argued, "[Al]though complexity theory provides a sharp and timely critique of positivism, one

cannot overlook the contribution that positivism makes to many improvements in everyday life . . . Indeed one could ask about the nature of explanation if causal connections are no longer acceptable" (p. 28). What Morrison's critique points to is what anyone who has spent any time in schools or in teacher education contexts already knows: in our day-to-day work as educators, we crave explanation. In today's increasingly diverse global society, with its exceedingly high expectations for teachers and students, we want to be able to explain whether and how teachers learn to teach in ways that enhance the learning of all students, and we want to know whether and how certain kinds of social, intellectual, and organizational contexts support that learning. What Morrison's critique does not consider is that rejecting the notions of causality that are integral to positivism is *not* the same as rejecting the notion of "cause" itself and is *not* the same as rejecting the possibility of causal explanations that are not linear and not reductionist. In this section, we take up these questions by considering the nature and place of causal explanation in complexity studies of teacher education, and particularly in studies animated by CT-CR.

David Byrne (1998) is helpful here because he explicitly connected complexity theory in the social sciences (including education) with models of contingent and multiple causation. To explain realism and complex causation, Byrne used a 1930s study by F. C. S Bradbury of the cause of tuberculosis (TB) in the Tyneside region of the United Kingdom. In introducing the study, Bradbury pointed out that everyone already knew that the TB bacillus caused TB and that virtually everyone in Tyneside had been exposed to the bacillus at that time. Thus, instead of asking what caused TB, Bradbury asked why most people at the time did *not* contract the disease. He eventually concluded that TB was the product of the interaction of multiple complex factors: poor housing conditions and overcrowding, which spread the disease; insufficient food (especially milk), which let the disease take hold; and being Irish, which at that historical moment, meant less previous generational exposure to TB (Byrne, 1998, pp. 38–39).

Byrne (1998) suggested that Bradbury's multiple, contingent, and complex explanation was far superior to the then commonplace explanation that TB was "caused" by the exposure of a susceptible individual to the TB bacillus. But, Byrne also pointed out that even this explanation is not enough currently (pp. 38–39). To illustrate, he argued that in order to explain the reoccurrence of TB in New York City in the late 20th century, we need a complex contingent explanation related to AIDS as a complex social product, poverty, homelessness, and lack of housing, health care, and fire protection in poor urban areas with large numbers of

immigrants. Byrne used this example to make an argument about realism and complex causality, which involves interactions among systems at different levels, and has important implications for how we understand agency.

In our effort to investigate the application of complexity theory to teacher education research, we use this example from Byrne to emphasize that rejecting linear notions of cause and effect is not the same as rejecting the idea that things have causes or rejecting the search for causal mechanisms as an aim of research. Understanding cause as complex, multiple, and contingent is quite consistent with focusing on the particulars of local contexts, which we referred to in the previous section. CT-CR seems to us to be a particularly appropriate theoretical framework for teacher education research because it gives us a way to focus on the initial conditions, contexts, and circumstances within which learning emerges in open systems and proposes that, under certain circumstances, it may be possible for agents to initiate certain causal sequences, a point we take up below.

In the extant research that connects complexity theory and teacher education, we found virtually nothing about explanation or causality beyond rejection of linear models of cause and effect. Rather, much of the complexity research in teacher education has more affinity with post-modernist perspectives (e.g., Cilliers, 1998; Davis & Sumara, 2006) than with attempts to develop explanatory theories about how the learning of teacher candidates emerges in certain contexts and under certain conditions. Here, Opfer and Pedder's (2011) review of research on teachers' professional learning, to which we referred previously, is an exception. Although they did not connect complexity theory to critical realism per se, as we do, their perspective is consistent with our approach. They argued that the goal of research on professional learning should be the development of an explanatory theory of teacher learning as a complex system based on patterns of interaction within and between levels of activity. In doing so, they rejected invariant models of teacher learning that assume that structures and systems repeat themselves in the same forms and, instead, adopt a "mechanism" or "process" logic of explanation.

Opfer and Pedder called for research that examines how the "generative mechanisms" (p. 394) of teacher learning occur under varying conditions and circumstances and in differing contexts. In teacher education research, CT-CR focuses on "causal" or "generative" mechanisms, which may be extremely valuable in understanding teacher education as a complex system. One goal of this kind of work is to develop explanatory theories of teacher candidates' learning during the critical period of initial teacher education by seeking complex,

contingent, and multiple causes while at the same time avoiding being reductionist, linear, or piecemeal. This perspective also allows us to address questions about the responsibility and agency of teacher educators, even given complexity's recognition of unpredictability and connectedness.

Morrison (2008) challenged, "Where does responsibility lie in a shared ethical, epistemological, and ontological web?" (p. 29). What we suggest here is that acknowledging unpredictability does not require that teacher educators abdicate their responsibility for making normative decisions about preferred knowledge and experiences for teacher candidates. Instead, it requires that they have more complex and contingent notions of agency and responsibility that depend on deep understanding of the local (e.g., initial conditions, sequences, and transformative events) linked to larger understanding of processes and outcomes at various systems levels that are widely variable but not inexplicable. In this way, as Byrne (1998) put it, complexity theory can serve as the basis of an "engaged science," *not* founded in "the assertion of an absolute knowledge as the basis for social programs, but rather in a humility about the complexity of the world coupled with a hopeful belief in the potential of human beings for doing something about it" (p. 45). From this perspective, human agency and responsibility are not abdicated, but treated with the appropriate appreciation of uncertainty, complexity, and unpredictability. This understanding of human agency and responsibility is a central feature of CT-CR as we are proposing it here as a platform for teacher education research.

MORALS, VALUES, AND POWER IN COMPLEXITY THEORIES OF TEACHER EDUCATION

Finally, we take up challenges to the capacity of complexity theory as a theoretical framework for research on teacher education that have to do with morals, values, and power. Morrison (2008) argued that because complexity theory primarily describes, it is neutral and amoral, while education is normative. For this reason, he concluded that complexity theory is inadequate (or, at best, incomplete) as a theory of education. Morrison also suggested that complexity theory "under-theorizes power" (p. 28) and does little to address powerlessness in society.

The claim that complexity theory is incapable of dealing with values and power differences is a serious challenge to teacher education research guided by complexity theory. Many teacher education scholars and practitioners, ourselves included, have long characterized teacher education as a moral, ethical, values-centered, and political enterprise with serious

implications for social justice (e.g., Cochran-Smith, 1999, 2010; Hansen, 2008; King, 2008; Ladson-Billings, 1999; Villegas & Lucas, 2001; Zeichner, 2010). We address these challenges to complexity theory as a framework for teacher education research in two ways.

First, it is important to note again that CT-CR, as we are developing it here as a platform for research on teacher education, seeks explanatory theories focused on interactions across levels of systems. This approach supports the examination of interactions among actors and structures, and thus allows for examination of ideologies and values. Tilly (2008) called researchers who do this kind of sociological analysis "linkers" because they analyze the articulation between larger structures and processes and the lives of people. He characterized this as "relational realism," which

> concentrates on connections among people and social sites—for example, households, neighborhoods, associations, firms, or organized occupations. It sees those connections as concatenating, aggregating, and disaggregating rapidly, forming organizational structures at the same time as they shape individual behavior. (p. 7)

When research on teacher education is animated by CT-CR, it links the emergent practices of teacher candidates in differing circumstances and contexts to larger social structures and processes. This has the potential to provide valuable new insights about policy and practice.

Second, we look to the work of sociologist, Sylvia Walby (2007), who used complexity theory to reconceptualize the traditional notion of social systems. She suggested that a social system cannot be regarded as a hierarchy wherein some subsystems are nested within others. Rather, she argued, that each social system (e.g., economy, polity, and civil society) and each set of social relations (e.g., gender, ethnicity, and class) takes all other systems as its environment. Consistent with critical realist approaches to complexity theory, Walby concentrated on the multiple intersectionalities of social systems of inequality, including inequalities based on class, gender, and ethnicity. She emphasized that these systems of inequality are overlapping, but "non-nested" and "non-saturating" (meaning, for example, that although gender interacts with class, it is not contained within class relations, and neither gender nor class fully accounts for the institutional domain of the other; p. 460). Walby suggested that her approach to understanding social systems opens up the theoretical agenda (and we would add here, the research agenda), which was closed by traditional systems thinking: "This allows the possibility of

analysis of multiple simultaneous complex inequalities, while retaining concepts of social structure and system" (p. 460).

As we noted, CT-CR is generally consistent with efforts in the social sciences to develop social mechanism-type explanations of social processes and is also compatible with the idea that multiple social systems of inequality intersect with one another and with the environment. With CT-CR as a platform for research on teacher education, it is possible to conduct analyses of complex social inequalities in relation to teacher educators' and teacher candidates' practices and students' learning. This allows us to see systems in new ways that reveal interconnected inequities in new ways.

We make one final point here in response to Morrison's (2008) challenge that complexity as a theory of education does not tell us how to act. We are not sure that any education theory tells us how to act. Even humanities-oriented research, which explicitly takes up issues related to ethics and justice, does not tell us what to do. Rather, this kind of scholarship is intended to "problematize unrecognized assumptions, implications, and consequences" and "foster dissonance and discomfort" with conventional practice and policy alternatives (American Educational Research Association, 2009, p. 482). Perhaps this means that the appropriate thing to expect from CT-CR studies of teacher education is not that they tell us what to do, but that they show us where to look and what processes to trace as teacher candidates learn to enact practice that enhances the learning of all students, including those not well-served by the current system.

In the preceding section of this article, we have discussed the challenges involved in engaging in teacher education research guided by complexity theory. Along these lines, we have suggested that integrating complexity theory with critical realism provides a platform that addresses central theoretical dilemmas and generates new questions about some of the most persistent problems in initial teacher education. Building on our discussion of these challenges, in the next section of this article, we explore the promise of teacher education research guided by CT-CR.

THE PROMISE OF RESEARCH ON TEACHER EDUCATION GUIDED BY COMPLEXITY THEORY

To explore the promise of CT-CR, we enumerate some of the new empirical questions this platform allows, and we describe several innovative methods of data collection and analysis that are appropriate for these new lines of inquiry. These illustrate how a CT-CR framework changes what we ask, how we look for answers, and what it is possible to know. These new questions

and methods may be of particular interest to other researchers who are interested in engaging in empirical research on teacher education from the perspective of complexity, especially given the dearth of explicit discussions about these issues.

In the previous sections, we have suggested that CT-CR offers an alternative view of social structures and processes that may help us work on some of the persistent problems of teacher education. As we showed, previous research using complexity theory as a lens for teacher education provides a language and a lens for looking at teacher education as a complex system rather than a complicated process. This work is valuable in showing us how complexity theory can account for events and outcomes that remain hidden by other theoretical frameworks. For example, CT-CR expects unintended consequences and variability in outcomes, helping to provide explanations that can account for "multifinality" (apparently very similar experiences that, under some circumstances and for some persons, lead to notably dissimilar outcomes) and "equifinality" (apparently very different experiences that, under some circumstances and for some persons, lead to notably similar outcomes; George & Bennett, 2005).

POSING EMPIRICAL QUESTIONS FROM A COMPLEXITY PERSPECTIVE

Teacher education is haunted by some persistent problems, which leave it vulnerable to manipulation and reform by political and social forces and unable to instigate powerful change. Teacher education research has grown out of a need to find answers to these problems. Chief among them in the current international political climate is ensuring high-quality teaching and learning for all students. This is the general problem we take up here.

We have argued that reductionist, linear approaches have not yielded the answers we need to understand how teacher candidates learn to teach. In this section, we suggest four clusters of questions that result from our use of CT-CR to rethink how we can ensure high-quality teaching and learning for all students. We focus on the teacher education program level, although this is not the only part of the teacher education system that can be interrogated. One way our discussion of CT-CR may be helpful to other researchers is in terms of the new questions it poses for study.

In the past, we have looked at teacher education as a complicated process, pulling it apart to investigate its pieces. With CT-CR, however, we take a holistic view, including the interactions and relationships that occur because the system is

more than the sum of its parts. Our first group of questions is about the teacher education program system itself: *What are the elements and interactions in a teacher education program system? How does a teacher education program function as a system?* We pose these questions not to isolate the parts, but to build a rich picture of the system's function. Subquestions aid this process: *Who communicates with whom? How is key information shared? How do system elements interact? What is the overall network structure of the system? How did the system get to be like this? What is its history? How does the system learn/grow/adapt/change? What is the nature of the interactions that occur? What feedback loops can be observed? How are effects amplified or diminished? How do participants in various roles within teacher education, who are complex systems themselves, function in the system?* Our answers to these questions will always be limited by our perspective on the system, but the questions direct us to key parts of system functions that we might not have previously considered as influences on ensuring high-quality teaching and learning. Comparing the range and variation of systems across teacher education program types, pathways, and contexts may help us to understand the differing learning opportunities for teacher candidates that emerge from teacher education program systems and, ultimately, what this means for the learning opportunities and outcomes of students.

As we have discussed, complex systems are self-organising. This means that their change and growth occurs as a bottom-up emergent process, rather than as a top-down directed process. The CT-CR framework gives us insights about how teacher education responds to the policy environments in which it is embedded. A linear view of policy implementation might trace the impacts of a policy chronologically, from its promulgation to evidence of its impact. On the other hand, CT-CR suggests that the introduction of new policy into a teacher education program may initiate the process of self-organisation, which is fundamentally nonlinear and tends to produce unintended consequences. To investigate this, we might ask several questions: *How does the introduction of new policy requirements create disequilibrium in the function of a particular teacher education program? What emerges from the system in terms of learning opportunities for teacher candidates and the students they teach? How is this emergence different in programs and pathways of various types? How do patterns of interaction, relationships, and system elements grow and change, or resist growth and change in response to new policy? What are the effects of this growth and change on teacher candidates and student learning? What aspects of the policy or its implementation are amplified by the system's function, and which aspects are suppressed or diminished? What unexpected outcomes for teacher candidates and*

students can be observed?

Many complex systems have other complex systems embedded within them, but they also have open and ambiguous boundaries. This means that systems are sensitive to their environments and exchange information with neighboring systems. This results in different types of relationships between systems. If an element of a system is also part of another system, the two systems are mutually constitutive. Other systems may interact at their boundaries but contain distinct elements. This insight is very powerful for investigating the relationship between teacher education and high-quality teaching and learning for all students. In many situations, teacher education is assumed to exist as an entity that is separated by both time and space from the contexts in which teacher candidates work with students. This makes researching the relationships between the two problematic. Rather than conceptualizing teacher education and student learning as two distinct boxes that might be joined by an arrow, complexity theory suggests that these systems overlap at their boundaries. This re-conceptualisation is a rich source of questions for investigation: *How do teacher education program systems interact with schools as systems? To what extent are elements of teacher education program systems mutually constituted with elements of school systems? How does information flow between and within these systems? How did the interactions between systems get to be as they are? How does the history of interactions shape what can emerge from the systems in terms of teacher candidate learning? What role do individuals as systems play in these emerging patterns of interaction? What learning opportunities for teacher candidates emerge from the boundary between the systems? What evidence is there of amplification and suppression of teaching practices in the interaction between the systems?* There is range and variation in school system interactions with teacher education programs and pathways. Important questions include the following: *What learning opportunities for teacher candidates emerge from different types of interactions and relationships? To what extent are teacher candidates' abilities to enact teaching that enables learning for all students influenced by different school system/teacher education system interactions and relationships? How do these influence students' learning opportunities and outcomes?* Examining the boundaries between systems to answer these questions shifts the focus from individual teacher candidates to powerful system processes where useful, and previously unexplored, explanations may be found.

Complexity theory suggests that system functioning is determined by initial conditions and by ongoing limits on its activities, often referred to as *enabling constraints*. Positive

and negative feedback loops prompt adjustments in the system and may lead to small events having large consequences or large events having small consequences. Previous research has compared the effectiveness of different routes into teaching, examining the program elements and learning opportunities in each. From the perspective of teacher education programs as *systems*, however, we need instead to understand the initial conditions and limits within which a system is working and to examine the recursive and nonlinear interactions within the system to trace the effects of feedback and other mediating factors on teacher candidates' practice. In examining how a teacher education program system functions to ensure quality teaching and learning for all students, we could ask several questions: *What initial conditions, interactions, feedback loops, and other mediators are associated with the emergence of teaching practices that enhance student learning?* Of as much interest is the inverse of this question: *What initial conditions, interactions, feedback loops, and other mediators are associated with the non-emergence of such practice?* Then we could ask more questions: *What are the key causal processes or generative mechanisms that account for both "multifinality" and "equifinality"?*

As we have suggested, Walby (2007) argued that a complex system has as its environment all other systems. From the perspective of CT-CR, the teacher education system, at all levels, is regarded as intersecting with all other systems including, importantly, social systems such as gender, race, and class. In traditional frameworks for teacher education research, gender, race, and class are often characterized as variables and treated as characteristics of individuals. The notion of teacher education program systems intersecting with gender, race, and class as complex social systems opens up questions that address "multiple intersecting social inequalities" (Walby, 2007): *How do social inequalities based on gender, race, and class shape the initial conditions and enabling constraints that frame teacher candidate learning opportunities in teacher education programs? How are system elements and interactions influenced by social inequalities?* Teacher candidates' gender, race, and class may contribute to the way that elements in the teacher education system construct a view of them as learners and teachers. This suggests questions: *What role do systems of social inequalities play in feedback loops within teacher education program systems? How does a teacher education program's self-organization and emergence intersect with multiple social inequalities as systems?* Social inequalities as complex social systems affect all levels of the teacher education system. As well as influencing the functioning of the teacher education system, they are also part of the curriculum of teacher education. This leads to questions: *How can a teacher*

education program system, which is itself intersected by multiple systems of social inequality, help teacher candidates develop a critical and applied understanding of those systems?

The questions we have enumerated here are intended to be suggestive—the beginnings of an empirical research agenda in teacher education, guided by CT-CR, which may be of interest to other researchers and practitioners in teacher education. What these questions show is that insights from CT-CR prompt us to look in new places for solutions, give us new ways to consider how things might be related, and generate a new body of evidence that builds toward an explanatory theory of teacher learning during the critical initial teacher education period. Posing questions derived from CT-CR opens up new avenues for inquiry. To pursue these avenues, however, new questions may need to be examined using some new research methods, which we consider in the next section.

METHODS OF DATA COLLECTION/ANALYSIS FROM A COMPLEXITY PERSPECTIVE

As others have noted, complexity theory does not offer a package of methods for data gathering and analysis. Indeed, a number of theorists have emphasized that complexity theory is not method, but methodology (e.g., Haynes, 2008; Schneider & Somers, 2006). Nevertheless, a CT-CR framework suggests important emphases for research methods and designs. As we noted above, a central aspect of complex systems is the interactions, interrelationships, and interdependencies of elements rather than discrete elements or disconnected parts of a process. Methods of data collection and analysis in CT-CR studies of teacher education thus need to account for and foreground relationships, interactions, and processes across levels within the system with particular attention to system boundaries and to the spaces where systems interact and co-evolve. This does not necessarily mean new research designs or methods of data collection and analysis, but it may mean that we need to borrow methods from other social science fields, make modifications to existing methods, and combine methods in new ways.

As we have noted, there has been little empirical research on initial teacher education—from a complexity lens—that goes beyond description of selected teacher education events, courses, communities, or contexts. We turned to empirical research in areas other than teacher education for ideas about research designs and methods consistent with CT-CR. By way of illustration, we suggest three promising possibilities for data collection and analysis in teacher education research informed by CT-CR, one from organizational studies, one from health care, and one from political science. We suggest that these

tools and strategies can be used in combination with each other and/or with other existing qualitative, quantitative, and mixed methods approaches to lead to promising new lines of research in teacher education.

System Mapping

Many researchers now believe that organizations cannot be adequately understood nor effectively led unless they are regarded as complex and flexible systems that operate, not in terms of the simple relationships between the discrete pieces of a system, but in terms of the dynamic connectivities between and among elements and structures that continuously change over time (Kowch, 2012; Schneider & Somers, 2006). This approach allows for the consideration of numerous contingency and mitigating factors that shape how organizations pose and solve problems, how they respond to and reinterpret policies, as well as how individuals are influenced by structures but also feed back into those structures in ways that influence future organizational arrangements (Haynes, 2008).

Working from this perspective in education, some studies of organizational change, leadership, and school reform have used data collection and analysis methods derived from social network theory, systems theory, and related concepts to trace interactions between and among the elements and structures of the system. For example, Kowch (2012) blended network analysis and cross-case coding of interview data to study the content and capability of school district networks to organize their interests and accomplish their objectives in a shared service network involving a large urban and a smaller rural school district. Along somewhat similar lines, Davis, Sumara, and D'Amour (2012) used the idea of complex learning systems to study how three differently networked school districts conceptualized and operationalized funded school reform initiatives and, thus, produced quite different outcomes.

Our suggestion here is that in initial teacher education research informed by CT-CR, salient ideas derived from complex network and systems theories can be used to develop a suite of tools for what we refer to as *system mapping*, which lays out the general landscape of a complex system, including its major elements and structures, its interdependencies and overlapping areas, and its ambiguous borders. System mapping has potential as both a data collection tool and a data analysis approach in teacher education research. As a data collection tool, for example, the various actors and agents within a particular initial teacher education program might be asked to complete a highly specified diagramming or mapping task, representing their experiences with the various elements and

structures of the system and how these interact with one another to influence the learning of teacher candidates. As a data analysis tool, on the other hand, system mapping might be used by researchers along with other data sources (e.g., interviews, documents, and archival data), as a way to represent and compare the patterns of interaction among two or more differing initial teacher education programs or pathways and the learning opportunities they made possible. System mapping would help identify how and to what extent particular initial teacher education programs/pathways functioned as complex systems, similarities and differences in the ways various actors and agents within programs conceptualized the relative value and role of various system elements, and what various actors saw as the boundaries of the system. System mapping could also be used to suggest possible directions for tracing key processes and/or causal mechanisms involved in teacher candidates' learning, which we return to below.

By way of example, in our own research using the CT-CR framework, the Project RITE research team is currently using system mapping as a tool for both data collection and data analysis in a study about the perceptions of teacher candidates, university-based teacher educators, school-based cooperating teachers and principals, and national-level policymakers regarding the influences and interconnections of the various elements and structures of initial teacher education, regarded as a complex system (Ell, Cochran-Smith, Grudnoff, Ludlow, & Hill, 2013). As a data collection tool, we are using system mapping to gather constituents' perceptions of the presence, strength, and interaction of system elements in terms of how they influence teacher candidates' enactment of patterns of practice that enhance all students' learning. As a data analysis tool, we are using analytic procedures derived from concept mapping and consensus brand mapping to reveal similarities and differences in the perceptions across constituent groups. We are also using cluster analysis and multidimensional scaling to reveal some of the underlying connections in constituents' perceptions of the power and influence of the elements in a complex teacher education system. These analyses are beginning to lay the groundwork for the development of a complex explanation of how the pieces and parts of teacher education systems are interconnected.

Extended Case Studies

A second research method, the extended case study, has been used in a number of social science areas, including health care. According to Anderson, Crabtree, Steele, and McDaniel (2005), the field of health care has been plagued by the persistent failure to make genuine change in practice despite wide-scale

efforts to improve practitioners' knowledge. One response has been to shift the focus of improvement from individual physicians to health care practice environments and organizations, using case study designs to investigate. Anderson and colleagues argued, however, that traditional case study designs have wrongly assumed that health care organizations are rational and stable mechanisms with predictable causes and effects that can be broken into bits for study and improvement. Instead, they suggest that "extended" case study designs, informed by complexity science, offer new and uniquely-suited tools for the study of health care organizations as complex adaptive systems wherein relationships are critical and nonlinear, dynamics are unpredictable, and interdependencies exist across the boundaries and levels of the system.

Anderson et al. (2005) proposed multiple extensions of traditional case study designs for the health care field, many of which are relevant to the study of teacher education. For example, they pointed out that case studies have traditionally "bound the case" and then studied phenomenon within the boundaries. In contrast, with extended case study designs, there is an intentional focus on the ideas, actions, and interdependencies that occur at and across boundaries. Similarly, in traditional case studies, Anderson and colleagues suggested that the focus has been on roles and formal organizational positions (the "boxes" in traditional organizational flow charts with lines connecting them). In contrast, with extended case studies, there is more emphasis on interrelationships, flows, and exchanges (the "lines" that connect the boxes in organizational flow charts, rather than the boxes themselves). In addition, Anderson and colleagues suggested that it is important to focus on "nonlinearities," particularly situations in which small events have large outcomes, and large events have small outcomes; they also called for an intentional focus on the "unexpected" by using multiple methods and perspectives, attending to outliers, and examining situations in which improvisation and creativity occur, rather than focusing on situations structured by rules.

Case study designs are very common in teacher education research. Extended case studies, informed by perspectives consistent with CT-CR and with some of the features described by Anderson and colleagues, could easily be adapted to research teacher education and would have the capacity to shift the focus away from the knowledge and skill of individual teacher candidates and toward the ways that individuals' experiences and performances are shaped by complex practice environments and organizations. These new approaches would help us study systems as integrated wholes rather than pieces and help us focus on the positioning of individual teacher

candidates and school students as systems relative to the teacher education system.

Process Tracing

The third research method we propose here for teacher education guided by CT-CR is process tracing. A number of researchers in political science (e.g., Collier, 2011; George & Bennett, 2005), sociology (e.g., Marsh, 1982; Tilly, 2008), and other social sciences (Hedstrom & Ylikoski, 2010) have worked in recent years on ways to uncover the complex causes of social processes. The emphasis in this work is on identifying and understanding the multiple, contingent, and complex causes of particular outcomes within and across cases, with a focus on mechanism- and process-based explanations. As we noted earlier, this approach to causality focuses on initial conditions, complex sequences, and varying combinations of events and mechanisms that "concatenate into processes having explicable but variable overall outcomes" (Tilly, 2008, p. 9).

Along these lines, political sociologists, George and Bennett (2005), have taken the lead in developing the method of process tracing in within-case and cross-case study research. They pointed out that Hall noted as early as 1979, that process tracing was valuable, given the increasing recognition by social scientists that the causes of social processes are complex: "Process tracing is a methodology well suited to testing theories in a world marked by multiple interaction effects, where it is difficult to explain outcomes in terms of two or three independent variables—precisely the world that more and more social scientists believe we confront" (Hall in George & Bennett, 2005, p. 206). George and Bennett described the method of process tracing as follows:

> [Process tracing] attempts to trace the links between possible causes and observed outcomes. In process-tracing the researcher examines histories, archival documents, interview transcripts, and other sources to see whether the causal process a theory hypothesizes or implies in a case is in fact evident in the sequence and values of the intervening variables in that case. (p. 6)

As a method in history, political science, and political sociology, process tracing involves the careful description of data at multiple time points in order to analyze trajectories of cause. Process tracing involves "find[ing] the conditions under which specified outcomes occur, and the mechanisms through which they occur" (George & Bennett, 2005, p. 31). Process tracing can contribute both to describing political and social phenomena and to evaluating causal claims. With multiple

cases, the repertoire of causal paths that lead to given outcomes can be charted along with the conditions under which those outcomes occur.

Research on initial teacher education needs explanatory theories that help us understand why some teacher candidates (and the beginning teachers they become) enact practices that support the learning of all students, including those underserved by the current arrangements of schooling, and why others do not do so. With teacher education research informed by CT-CR, process tracing has the potential to contribute to the development of explanatory theories. Coupled with traditional qualitative data collection tools, which allow for the identification of initial conditions, contexts, and cultures, process tracing can be used to track the key causal processes and mechanisms that support, constrain, amplify, or diminish teacher candidates' enactment of classroom practices that enhance students' learning.

CONCLUSION: COMPLEXITY THEORY AND TEACHER EDUCATION RESEARCH

In this article, we have argued that we need teacher education research that is guided and informed by theoretical frameworks with a holistic view of teacher education and with the goal of enhancing learning for all students. CT-CR is attractive to teacher education researchers because it offers a theoretical framework that preserves wholes, privileges interactions and interdependencies, and expects surprising outcomes. There are challenges that arise, however, when moving from using complexity theory as a metaphorical tool or a descriptive lens to using complexity theory to frame empirical research prospectively. While, in a certain sense, these challenges are intrinsic to complexity theory, we have suggested here that CT-CR—complexity theory integrated with the critical realism and developed and applied for teacher education research—affords both the rich, holistic view of teacher education that we need and the power to allow the development of explanatory theory.

As we have argued, adopting CT-CR as a frame for empirical research changes not only the questions we ask and the ways we seek answers to those questions but also the nature of what we might find. To use CT-CR is to abandon the idea that there will be one cause or one explanation at the end of a piece of research. As outlined above, this does not mean that there are no causes or no explanations in teacher education. Research that offers no explanations of cause will not serve teacher education well. Rather, what we are suggesting here is that empirical research informed by CT-CR may yield explanations of a different nature from the explanations offered by other

paradigms. Complex and contingent causal mechanisms revealed by empirical work from the perspective of CT-CR might consist of elements from several levels of a system, describe interactions within and between levels and systems, focus on patterns that emerge from different system levels, and contain elements of the system's past functioning. Evidence for cause or explanation could be drawn from a range of sources and perspectives, rich, deep, detailed, highly particular, and local. From this deep understanding of particular circumstances may come explanatory theory about general teacher education.

Using CT-CR to understand how teacher education relates to student learning involves new perspectives at all stages of the research process, including new perspectives about what the results of research mean and how they can be used. For policymakers, this may mean rethinking what counts as valuable evidence and developing a more nuanced understanding of how system change might be instigated and maintained. CT-CR may provide some unexpected implications for teacher educators, with both distant and local influences implicated in teacher learning. Change may be needed in unexpected places. In posing new questions and suggesting some allied methods, we have begun to tease out what using CT-CR means for researchers in teacher education; at every turn, we find challenges to our common ways of thinking. In these challenges, however, lie the promise of CT-CR—new understanding about teacher education and its connections to student learning.

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