Hartzler, R., & Blair, R. (Eds.) (2019). *Emerging issues in mathematics pathways: Case studies, scans of the field, and recommendations*. Austin, TX: Charles A. Dana Center at The University of Texas at Austin.

Available at **www.dcmathpathways.org/learn-about/emerging-issues-mathematics-pathways**

Chapter 6

Higher Education as a Complex Adaptive System:

Considerations for Leadership and Scale

Jeremy Martin
The Charles A. Dana Center
The University of Texas at Austin

Abstract

As state policies, economic pressures, and enrollment declines increase pressure on higher education systems to rapidly improve student outcomes in mathematics, many institutions have transformed the way they do business and have adopted mathematics pathways at scale. At the same time, many systems of higher education have struggled to move from piloting mathematics pathways to implementing reforms at a scale that supports every student's success in postsecondary mathematics. Drawing on complexity science, this chapter presents a conceptual framework for leaders at all levels of higher education systems to design change strategies to adopt mathematics pathways principles at scale. How leaders think about the systems that they work in has material consequences for designing, implementing, and sustaining scaling strategies. The chapter offers a framework and recommendations for understanding higher education as a complex adaptive system and the role of strategic leadership in designing, implementing, and sustaining reforms at scale.

Introduction

After decades of innovation and research on improving student success in postsecondary mathematics, a convincing body of evidence has emerged about high-leverage strategies that ensures students have equitable access to and success in mathematics. As a result, many states and higher education systems have begun adopting mathematics pathways principles for all students by transforming policies, practices, and cultural norms anchored in system-level student success strategies. Today, leaders of higher education systems are leveraging what has been learned from the collective efforts of system-level mathematics pathways reforms. By sharing promising practices, research, and strategies, faculty, staff, and administrative leaders are contributing to transformational changes in policies and practices at a scale that support all students.

Despite the successes, many states and systems struggle to integrate mathematics pathways with the myriad student success initiatives that exist across many academic and administrative departments. A substantial body of literature has amassed around policy implementation and the problem of scaling. Programs that begin as pilot projects with the intent of "scaling up" rarely take root as a transformational change across a system. At the same time, policies mandated from system governance or legislatures are often underfunded and unenforceable, limiting the sustainability needed for broad and deep implementation.

This chapter draws on the field of complexity science as a lens for examining the relationship between systems transformation and scale. Using the mathematics pathways movement in higher education systems as a case study, the chapter offers a framework for understanding transformational change in higher education and the role of strategic leadership in designing, implementing, and sustaining reforms at scale.

Higher Education as a Complex Adaptive System

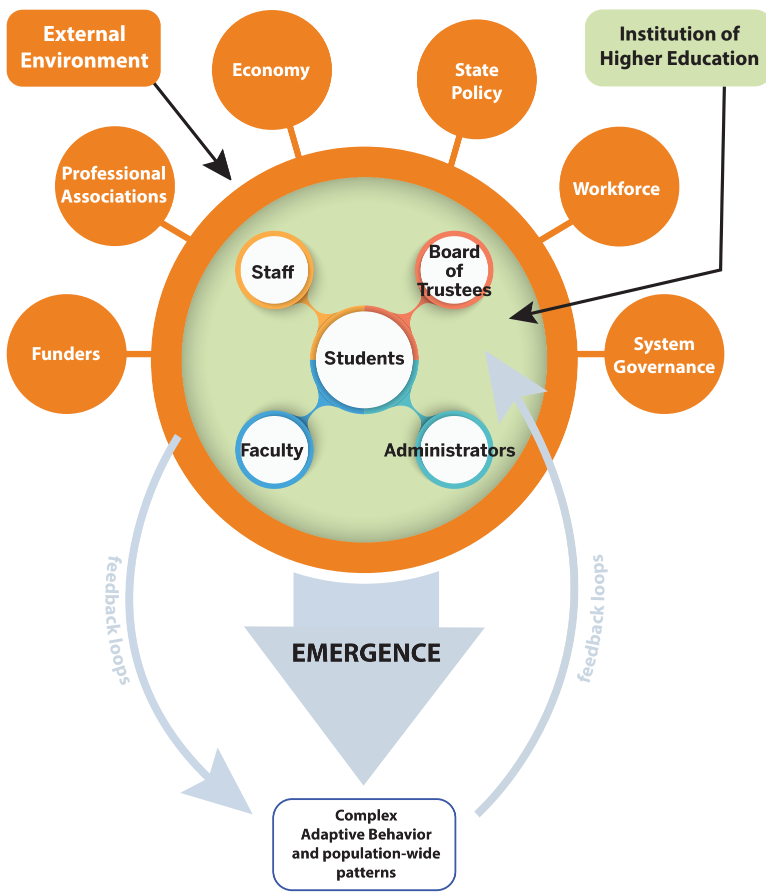
The term *system* refers to a set of connected parts that together form a complex whole. Systems are integral to the way we live our lives and undertake our work. While many such systems can be described as complicated, others are complex and adaptive. Automobiles, for example, characterize a system of highly specialized mechanical parts that work together to transport people between points. The automobile represents a highly complicated system, one that must function consistently based on a limited set of hierarchical rules such as accelerating, braking, and turning. In contrast, the traffic flows created by the sum of all automobiles moving between different points represents a *complex* and *adaptive* system. Traffic is complex because it sits at the intersection of many other complex systems, such as government policy, population shifts, and geography, to name a few. Traffic is also adaptive because its flow constantly changes as a dynamic function of the micro-level interactions of *both* automobiles with one another *and* automobiles nested within the larger systems that constitute transportation policy and infrastructure.

An emerging body of literature has begun to apply concepts and methodologies from the science of complex adaptive systems theory to understand the dynamics of change in human systems. Scholars and systems leaders have contributed to this research by using complex adaptive systems theory to better understand the dynamics of transformational change in higher education systems. Complexity science can offer a powerful conceptual framework for how leaders at all levels of higher education systems think about their roles in designing, participating in, and sustaining scaling strategies for mathematics pathways.

Complexity science has its origins in the natural sciences and mathematics. Meteorologists first formalized models of complex systems by creating computer simulations to model the interaction and coevolution of weather systems (Burnes, 2005). Research into complex adaptive systems seeks to understand how macro-level features of systems emerge from the self-organizing, micro-level interactions of individual agents within the system.

In the case of the meteorologists, the task is to understand how hurricanes emerge from the complex interaction of many dynamic weather systems to design better models and improve early warning alerts for affected areas. For leaders of education systems, the question becomes how to create a holistic understanding of the systems they seek to change and designing strategies that can harness the systems' collective energy to achieve broad, deep, and sustained scale.

Figure 1. Complex adaptive behavior and population-wide patterns



Higher education systems, like living organisms, must constantly adapt and evolve to ensure survival in response to ever-changing system dynamics. While a treatment of the technical features of complexity science is beyond the scope of this chapter, Figure 1 offers a simple visual model for understanding how institutions of higher education fit within a complex adaptive systems view. In this model, institutions of higher education can be understood as organizational systems made of diverse, active, interdependent agents (students, staff, faculty, and administrators) interacting and adapting on the basis of "knowledge, experience, feedback from the environment, local values, and formal system rules" (Keshavarz, Nutbeam, Rowling, & Khavarpour, 2010, p. 1468). At the same time, institutions of higher education are nested in a larger ecosystem of complex systems that dynamically exchange information and exert environmental pressures on one another. It is through the iterative feedback loops between the internal and external systems that the policies, practices, and cultural norms embodied by the institution emerge.

Leadership for Scale in Complex Adaptive Systems

While the application of complex adaptive systems theory in education settings is relatively new, research from this field has suggests design principles that higher education leaders can use to develop, implement, and evaluate scalable reforms (Frank, Muller, Schiller, & Riegle-Crumb, 2008; Maroulis, Guimerà, Petry, Stringer, Gomez, Amaral, & Wilensky, 2010); White & Levin, 2016). Since complex adaptive systems research focuses on systems that can evolve over time, research into these systems can trace the attributes, behaviors, and relationships that influence changes in individuals and which result in collective changes at the system level (Mandviwalla & Schuff, 2014). The mental models that leaders within higher education institutions use to understand systems and scale matter because they shape the tactics and strategies for achieving student success goals.

First, varied understandings of the term *scale* shape how leaders design reform strategies. "Unidimensional" definitions of scale, such as defining the success of a particular reform as the degree to which it spread across sites, are insufficient for capturing what is in essence a multidimensional change process. Instead, a complex systems view requires a complex understanding of scale. Coburn (2003) offers a reconceptualization of scale that accounts for the complex adaptive features of education systems:

> *Taking an external reform initiative to scale is a complex endeavor. It not only involves spreading reform to multiple teachers, schools, and districts . . . it also involves all of the challenges of implementing reform documented by decades of implementation research and of sustaining change in a multilevel system characterized by multiple shifting priorities. It is the simultaneity of these challenges, in all their complexity, that makes the problem of scale fundamentally multidimensional. (p. 3)*

Coburn argues that scale should be described along four axes: spread, depth, sustainability, and shift in reform ownership. *Spread* refers to the adoption of reform principles across different institutions. *Depth* refers to the quality and nature of reform to have consequential change in all classroom practice by altering the "beliefs, norms of social interaction, and pedagogical principles" of faculty, staff, and administrators (Coburn, 2003, p. 4). Since institutions are situated in and inextricably linked to a turbulent external environment, *sustainability* indicates the durability of a reform to persist over time in the face of a changing environment. Finally, *shift in reform ownership* highlights the need to design scaling strategies that create conditions for the authority and knowledge of a reform to transition from an external group to faculty, staff, and administrative leaders at all levels of an institution.

Just as higher education institutions and scaled reforms have complex adaptive systems features, leadership itself can be understood as a complex dynamic process (Hazy & Uhl-Bien, 2015; Lichtenstein & Plowman, 2009; Lichtenstein, Uhl-Bien, Marion, Seers, & Orton, 2006). Leadership is defined as an emergent event that occurs in the interactive spaces between people and ideas. In applying complexity science to leadership theory, researchers seek to understand the role of leadership in expediting and sustaining change processes, and creating conditions through which the interdependent actions of many individuals combine to create a system that is greater than the sum of its parts (Lichtenstein et al., 2006).

The most sustainable and adaptable systems are characterized by strong ties between the agents in a network. finding value and meaning in the information sharing that leads towards collective goals. Drath (2001) writes, "People construct reality through their interactions within worldviews . . . [they do it] when they explain things to one another, tell each other stories, create models and theories . . . and in general when they interact through thought, word, and action" (p. 136). Accordingly, leadership is not just the action of a single individual; rather, leaders emerge from the interactions between agents over time.

Boal and Schultz (2007) have characterized strategic leadership in complex adaptive systems in the following way:

> *In complex adaptive systems, strategic leaders affect organizational learning and adaptation . . . by telling stories and promoting dialogue in which an organization's past, present, and future coalesce: stories and dialogue about our history; stories and dialogue about who we are; stories and dialogue about who we can become. . . . Through the evolving process of storytelling, strategic leaders achieve innovation and change by demonstrating its legitimacy and consistency with the past. Maintaining this balance—between the past and future, between stability and disorder—allows organizations to evolve and learn. (pp. 426–427)*

Institutions of higher education are constructed from the interaction of students, staff, faculty, and administrators working towards the shared goal of student learning and success. Accordingly, strategic leaders can affect organizational learning and change by creating the conditions for all agents in the system to work together towards shared goal.

Mathematics Pathways in Complex Adaptive Systems

The Charles A. Dana Center coined an operational motto for scaling strategies built on the recognition of overlapping systems of power within and between institutions of higher education: "Faculty-driven, administrator-supported, policy-enabled, culturally-reinforced, and student-centered" (2018). This description of working at scale offers a touchstone for articulating specific actions across all levels of a higher education system and provides groundwork for key considerations of leadership in complex adaptive systems.

In the Dana Center's implementation work across many states and a variety of systems, one primary challenge to scaling continues to be aligning mathematics pathways between institutions of higher education. The success of students who transfer between institutions of higher education offers one powerful example for understanding the intersection between mathematics pathways reforms and complex systems theories.

More than 40 percent of all undergraduates enroll in two-year institutions and at least 80 percent of these students intend to transfer and earn a bachelor's degree (Jenkins & Fink, 2015). Based on the most recently available federal data, at least 35 percent of all undergraduate students transferred at least once from 2004 to 2009 (Government Accountability Office, 2017). Despite the high student mobility rates between institutions, very few transfer-intending students ever complete a degree. Jenkins and Fink (2016) estimate that only one-third of transfer-intending students ever matriculate to a fouryear university, and less than 15 percent earn a bachelor's degree.

These data suggest that one feature of many students' experience of higher education is navigating a web of diverse policies, practices, and curricula at a variety of institutions. While many, and sometimes all, mathematics courses will transfer between institutions, many courses may only count as elective credit and may not consistently or transparently apply towards a specific degree program. In many states and systems, programs of study that are similar have varied mathematics requirements. In higher education systems, the lack of coordination and coherence of mathematics course requirements across institutions presents challenges for students, advisors, and faculty when helping students enroll in courses that meet their needs as transfer students.

A small set of studies use complex adaptive systems theory as a framework for understanding the relationship between transfer institutions and the behaviors of agents within those systems that can promote or hinder transfer student success. Kisker (2007) uses systems theory to study the processes that promote community college and university transfer partnerships. Specifically, Kisker's research is based on the concept of "network embeddedness," meaning that "an institution's external and internal 'social networks' are the most influential factors shaping organizational behavior" (p. 285). Through a series of interviews with stakeholders at one university and nine community colleges, Kisker found that ongoing faculty involvement is critical for effective transfer partnerships. In addition, strong relationships between transfer partners are built on a history of trust and sustained by a culture that promotes communication and coordination.

Leaders can strategically frame ideas such as mathematics pathways in a way that honors an institution's mission and history and engages individuals at all levels of the system in processes that work towards cooperation instead of competition. Three principles derived from research on leadership in complex adaptive systems can be used to support the scaled adoption of mathematics pathways:

- Leaders must create conditions for stakeholders at all levels of an institution to self-organize and work together in mutually beneficial ways. The most robust and sustainable systems are made up of decentralized, yet tightly connected networks of agents. When these stakeholders at all levels of an institution are supported in their work, empowered to make decisions, and actively encouraged to work as a team, they use their collective wisdom to predict challenges and quickly adapt.
- Leaders should create meaningful feedback loops that allow for rapid iteration of ideas and strategies. Change represents the only constant feature of a complex adaptive system, and leaders understand this phenomenon well as it relates to institutions of higher education. Evolution is a process of "trial and error," not "trial and success." In order to design reforms that can sustain themselves through the ever-shifting currents of policy, economy, and social norms, leaders must actively encourage refinement and be willing to learn from mistakes.
- Third, a healthy institutional culture is a precondition for the success of any reform, especially reforms aimed at fundamentally changing policy and practice at scale. In complex adaptive systems, context matters. The trajectory of how change unfolds is highly sensitive to initial conditions. Effective leaders must have a grounded understanding of the conditions of their systems and a clear vision for the organizing principles

that will move the system to transformation. For example, how leaders think and speak about scale has material consequences for the success of a scaling strategy because the definition of what counts as “scale” shapes what counts as “success.” An institutional culture based on trust and open communication between stakeholders and grounded in an explicit commitment to equitable student success will create the conditions for sustainable change. Leaders are the arbiters of institutional culture and must consistently model the values, norms, and beliefs that they hope to see reflected in everyday practice.

While mathematics courses represent a small piece of most students’ postsecondary experiences, a rigorous, relevant, and aligned pathways experience can be crucial for their success. Leaders working to promote mathematics pathways principles within their institutions can draw on lessons from complex adaptive systems research to influence the strategies and approaches for scaling and sustaining reforms.

References

Boal, K. B., & Schultz, P. L. (2007). Storytelling, time, and evolution: The role of strategic leadership in complex adaptive systems. *The Leadership Quarterly, 18,* 411-428.

Burnes, B. (2005). Complexity theories and organizational change. *International Journal of Management Reviews, 7*(2), 73-90.

Charles A. Dana Center. (2018). *The Dana Center Mathematics Pathways Model*. Retrieved from https://dcmathpathways.org/dcmp/dana-center-mathematics-pathways-model

Coburn, C. E. (2003). Rethinking scale: Moving beyond numbers to deep and lasting change. *Educational Researcher, 32*(6), 3-12.

Drath, W. (2001). *The deep blue sea: Rethinking the source of leadership*. San Francisco, CA: Jossey-Bass & Center for Creative Leadership.

Frank, K. A., Muller, C., Schiller, K. S., Riegle-Crumb, C., Muller, A. S., Crosnoe, R., & Pearson, J. (2008). The social dynamics of mathematics course taking in high school. *American Journal of Sociology, 113*(6), 1645-1696.

Government Accountability Office. (2017). *Higher education: Students need more information to help reduce challenges in transferring college credits*. GAO-17-574. Retrieved from https://www.gao.gov/assets/690/686530.pdf

Hazy, J. K., & Uhl-Bien, M. (2015). Towards operationalizing complexity leadership: How generative, administrative and community-building leadership practices enact organizational outcomes. *Leadership, 11*(1), 79-104.

Jenkins, D., & Fink, J. (2015). *What we know about transfer*. New York, NY: Community College Research Center, Teachers College, Columbia University.

Jenkins, D., & Fink, J. (2016). *Tracking transfer: New measures of institutional and state effectiveness in helping community college students obtain bachelor's degrees*. New York, NY: Community College Research Center, Teachers College, Columbia University.

Keshavarz, N., Nutbeam, D., Rowling, L., & Khavarpour, F. (2010). Schools as social complex adaptive systems: A new way to understand the challenges of introducing the health promoting schools concept. *Social Science and Medicine, 70,* 1467-1474.

Kisker, K. B. (2007). Creating and sustaining community college–university transfer partnerships. *Community College Review, 34*(4), 282-301.

Lichtenstein, B. B., & Plowman, D. A. (2009). The leadership of emergence: A complex systems leadership theory of emergence at successive organizational levels. *The Leadership Quarterly, 20*, 617-630.

Lichtenstein, B. B., Uhl-Bien, M., Marion, R., Seers, A., & Orton, J. D. (2006). Complexity leadership theory: An interactive perspective on leading in complex adaptive systems. *Emergence, Complexity and Organization, 8*(4), 2-12.

Mandviwalla, M., & Schuff, D. (2014). Reimagining the higher education experience as a socially-enabled complex adaptive system. *Proceedings of the 2014 47th Hawaii International Conference on System Sciences* (pp. 4546-4555). Washington, DC: IEEE Computer Science Society.

Maroulis, S., Guimerà, R., Petry, H., Stringer, M. J., Gomez, L. M., Amaral, L. A. N., & Wilensky, U. (2010). Complex systems view of educational policy research. *Science, Education Forum, 330*, 38-39.

White, D. G., & Levin, J. A. (2016). Navigating the turbulent waters of school reform guided by complexity theory. *Complicity: An International Journal of Complexity and Education, 13*(1), 43-80.

About the author

Jeremy Martin is a senior policy analyst for the Charles A. Dana Center at The University of Texas at Austin. He has spent his career working in education systems to support students' access and success in achieving their academic and career goals. At the Dana Center, he conducts research, provides policy analysis, and develops resources for institutional leaders and state decision makers to improve student success in postsecondary mathematics. Jeremy supports scaling the Dana Center Mathematics Pathways (DCMP) by fostering a coordinated institutional and state policy environment that ensures the transfer and applicability of mathematics requirements for programs of study. Before joining the Dana Center, Jeremy was a public high school speech and debate teacher and led one of the nation's largest debate teams to broad competitive success at regional, state, and national competitions.