Change Knowledge

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Paper Type: This is an empirical study along two lines of investigation around the phenomenon of “change knowledge” in transforming engineering education: (1) a study of how successful change agents, “changemakers”, talk about change – their experience-based beliefs, assumptions, and mental models of how change in STEM education happens, and (2) that study, itself, as a change initiative in “radically transparent research”, as a mechanism for transforming engineering education. The abstract below represents an abbreviated version of the full paper. This paper contributes to this special volume in two significant ways:

* Advancing knowledge: Explores new approaches to understanding mechanisms for transforming engineering education by broadening and deepening the knowledge base on how change happens from a socio-cognitive and situated perspective.
* Models for initiating change: Provides a working example of an alternative model for connecting educational research and practice that leverages participatory and action research methodologies, and challenges approaches to dissemination as a theory of change (from transmission of evidence-based practices to engagement in a relational and collaborative meaning making process)

Background & Problem Statement

This special issue on change underscores the collective view that engineering education in the United States, along with higher education on the whole, is a complex system in need of transformation in order to meet the rapidly changing realities of our global existence (Duderstadt, 2008; Holly, 2009; Jamieson & Lohmann, 2008, Adams & Felder, 2008). Prior attempts to change undergraduate STEM education have had only temporary local impact (Dancy & Henderson, 2008; Henderson et al., 2011; Eiseman & Fairweather, 1996; Fairweather, 2009; Kezar, 2001; Seymour, 2012), a dismal success rate but one comparable to change attempts in higher education and non-educational organizations as a whole (Boyce, 2003). Fullan, Cuttress, and Kilcher (2005) claim some of this is due to a lack of "change knowledge," a concept that is parallel to “pedagogical content knowledge” (Grossman et al., 2009; Shulman, 1986) and refers to the tacit dimensions of contextualized knowledge such as typical barriers and enablers that may be experienced, relevant goals, and common misconceptions and ineffective habits of mind that may limit change or further development as a change agent.

The problem is compounded by a lack of effective mechanisms for communicating engineering education change knowledge that has potential to transform educational practice. Traditional dissemination approaches such as peer-reviewed and archival publications are ineffective (Foertsch et al., 1997; Froyd, Layne & Watson, 2006; Marder, McCullough & Perakis, 2001) in part due to their focus on the “telling” and not the “doing” (Ballantyne, Bain, & Packer, 1997), making it difficult to transfer findings to other contexts. Alternative approaches, such as peripheral participation (Lave & Wenger, 1991) in a community of practice for engineering education changemakers are an essential element for sustained organizational change but are often discouraged in existing incentive structures (Senge et al., 1999; Kezar, 2001; Boyce, 2003), so any attempts to engage potential change agents must be extremely low-cost in terms of start-up effort required from participants.

## Purpose

This paper introduces and empirically investigates two ideas for advancing knowledge on mechanisms for transforming engineering education and models for initiating change: “change knowledge” and “radically transparent research”. We take two different but complementary lenses to the question*: What is it that successful changemakers in engineering education know, and how can exposing that knowledge help us collectively make sense of that change knowledge and apply it in our own practice?*

For the first lens, we summarize existing *change knowledge* elicited from interviews with *“changemakers,”* experienced *change agents* who have impacted engineering education at institutional, national or international scales. We focus on how their experiences shaped their intentions, identities, beliefs, values, assumptions, and mental models, and explain the theories used to understand the mechanisms by which changemakers work.

For the second lens, we introduce the technique of *“radically transparent research”* (RTR) as a way to enable others to participate in the uncovering of engineering education change knowledge. Based on the working methods of open source communities (Chua & Dziallas, 2012), RTR "makes thinking visible" (Collins et al., 1991) by opening everything from raw data to process artifacts to public viewing and participation. The medium thus becomes the message, with RTR becoming a change initiative of its own aimed at capacity-building in the engineering education community.

Theoretical Frameworks

In this section we briefly summarize the theoretical lenses used for framing our research questions, designing our study, and sensitizing our lenses for collaboratively interpreting the data.

**Change knowledge: the type of learning-in-action we are exploring**

"Change knowledge" refers to the assumptions, beliefs, and values individuals hold about the process of change and key drivers and strategies for success in change initiatives. The concept of change knowledge is situated in research that seeks to understand and guide the sustainability and continual improvement of diverse engineering education systems (SCNEERC, 2006). Educational systems are a complex web of functions and structures bounded in particular contexts (Banathy, 1992; 1996). Change knowledge takes a perspective of that system that focuses less on the observable "tip of the iceberg" (Senge et al., 1998) such as vision statements, organizational policies, and formal disciplinary work structures, and more on the less visible, internalized, tacit, and human-centered dimensions of the beliefs and values of the individuals within the system that shape that system. It moves the lens from investigating the artifact being changed (or targeted for a change) to the human agent that seeks to initiative a change.

Drawing on Fullan (2007, 2008) and Kezar and Eckel (2002a), we assert that systemic change involves sensemaking, a process of situated cognition (Brown et al., 1989; Greeno, 1998) by which individuals make sense of their roles, approaches, identities, and philosophies about educational transformation within a given community of practice. Among other things, a person's change knowledge includes their assumptions about the system in which they work, such as their views about the nature of engineering and the purpose and practice of engineering education, and their hypotheses on how to work within that system to avoid barriers and ultimately enable the transformation they seek. If a person applies the change knowledge they have, we call them a change agent.

**Transformative learning theory: how we frame and make sense of change knowledge**

While discussing their work, change agents frequently use the word "transformation" in three ways: as an outcome, as an experience, and as a particular way of knowing and being.

*As an outcome*, "transformation" refers to radical departures from current practice that are facilitated as self-organizing processes of expansion, divergence, and discovery within an organization (Carlisle & McMillan, 2006), standing in contrast to more incremental and convergent processes that preserve the current hierarchy. This type of transformation involves challenging current beliefs and practices to make way for innovations at the “edge of chaos” (Axelrod & Cohen, 2000) and may thus be complicated by the dominance of instrumental thinking (Jackson, 2001). A change agent's understanding of the power dynamics of a system are likely to affect the strategies they use to organize and initiate change efforts.

*The notion of "transformation" as an experience*, whether deliberately created or inadvertently encountered, may be explored with the theories of transformational learning (Mezirow, 2000; Kegan & Lahey, 2009; Taylor, 2000) and transformative learning partnerships (Baxter Magolda & King, 2004). These theories emphasize interactions between interpersonal, intrapersonal, and epistemological development in their examination of learning processes triggered by a disorienting life event or dilemma (Taylor, 2000) that causes an adult to bring his or her unexamined beliefs, assumptions, and frames of reference into question (Mezirow, 1997). Through critical self-reflection and discourse with others on what had previously been taken for granted, the transformed person finds their way to a broader and more holistic perspective they can use to find meaning and take actions in a specific context. The biographies of change agents often speak to this sort of developmental arc (e.g., Algert & Watson, 2005; Burton, Schlemer & Vanasupa, 2012).

*As a way of knowing and bei*ng, talking about “transformation” is a way of making visible the mental models change agents hold about transforming education systems (Seymour, 2001). These mental models are likely to be intertwined with their identity as a change agent (see Dall’Alba, 2010). Kegan and Lahey (2009) argue that leaders of a transformation must have the capacity to transform themselves; a change initiative is as much about transforming the world outside of us as it is about developing a self-transforming mind and changing ourselves from within (see also Algert & Watson, 2005). The self-identities of change agents may shift in response to changes in their mental models of the system they work within (Burton, Schlemer, & Vanasupa, 2012). By being comfortable with contradictions and multiple perspectives, a mature change agent shows others by example how to examine their current frames of reference and form new ones that allow them to function within a system that differs radically from their former practice.

**Active and participatory research: radical transparency's role in change knowledge sensemaking**

In traditional laboratory research, the aim is to sit at an objective distance from phenomena, describing it without disturbing it. While this may be fitting for researching involving technical phenomena, it is not suited to working with the dynamics of a human system, such as engineering education, that we deliberately want to change (Reason & Torbert, 2001; Torbert, 1981). To borrow a farm metaphor, "weighing the pig does not make it grow." The RTR approach (Chua & Dziallas, 2012; Chua, in review) is to invite the neighborhood to feed the pig. Instead of analyzing de-identified data behind closed doors, researchers assign copyright of an interview transcript to their interviewees, then publicly analyze the fully-identified versions of those transcripts after interviewees have edited and voluntarily released their own data online under a Creative Commons license (http://creativecommons.org). The general public is invited to observe and contribute to the process of discourse analysis, leading to collaborative sensemaking that draws from multiple perspectives that would not otherwise be available.

RTR is consistent with action research (Reason & Torbert, 2001), participatory research (Kemmis & McTaggart, 2000; McIntyre, 2008), and the concepts of legitimate peripheral participation (Lave & Wenger, 1991), situated cognition (Brown, Collins, & DuGuid, 1989), and cognitive apprenticeships (Collins et al., 1991; Collins et al., 1987). It may support transformative learning and learning partnerships (Mezirow, 2000; Baxter Magolda & King, 2004), high-leverage and potentially transformative system interventions (Meadows, 2008), and iterative cycles linking research and practice through critical reflection (Arbaugh et al., 2010). Pioneering such a process will naturally involve extensive discussions with human subjects review boards. We anticipate that our experiences can inform policies for research that sits at the boundary of research and practice.

Study Procedures

The empirical foundations of this paper draw upon interviews conducted by Vanasupa and Herter between 2008-2008 with eight engineering education "changemakers" who had made an impact that exceeded institutional, regional, or national boundaries. Subjects were selected via a combination of convenience and snowball sampling until interviewees varied in terms of context (academia, government, and industry) and goals for change (policy, process, and pedagogy in engineering education). Interviews lasted between 45 and 90 minutes and were transcribed. The interview protocol was designed to elicit motivations and inspirations, assumptions about how transformational change occurs, and oral histories of experiences an interviewee deemed significant to his or her journey as a "changemaker." We used a semi-structured, narrative-style protocol with only four questions and ample opportunities for follow-up:

1. What do you see as your greatest accomplishment?
2. What caused you to come to that point of view?
3. What caused or inspired you to pursue this [transformation]?
4. [A causal loop diagram was presented to interviewees as an artifact to elicit personal theories of change.] What do you think of this diagram - what causal links look relevant, and what do you think is missing?

Adams was recruited to the project after data collection, and soon invited Mondisa, Chua, Siddiqui, Denick, and Sambamurthy to participate in the analysis of interview data. It quickly became apparent that providing our subjects with anonymity would be an issue; each "changemaker" had made such a prominent impact in their field that a simple Internet search quickly identified them. Since none of the interviewees had discussed confidential or personally sensitive information, we saw this as an opportunity to pilot a radically transparent research process (Chua & Dziallas, 2012; Chua, in review) as described earlier in this paper. At the time of this writing, all interviewees are in the process of voluntarily making an identifiable version of their interview transcripts publicly available, in some cases with minor modifications to the transcript to correct errors and deal with any information they perceive as risky.

Analysis has followed an inductive thematic process where patterns, themes, and categories of analysis are emerging out of the data rather than imposed prior to data collection and analysis (Patton, 2002). This has involved a version of the constant comparison technique where inductive category coding is combined with simultaneously comparing observations across cases to identify and analyze group themes around different perspectives (Lincoln & Guba, 1985). The frameworks presented in the previous section are used as sensitizing concepts (Patton, 2002) to guide collaborative perspective taking – moving back and forth between logical constructions and the actual data in a search for meaningful patterns. Hypotheses are being generated as an iterative process of continual refinement where initial observations are continuously critiqued as new dimensions and relationships emerge. For example, our early analyses revealed the diversity in perspectives (and our level of sensitivity for those perspectives) within the research collaboration. As such, we spent the first six months of data analysis collectively reviewing, annotating, and challenging our assumptions that were guiding our interpretation of the transcripts. Over time we have been developing a common perspective and a set of categories about how the changemakers interviewed experienced a process of change and the relationships among these categories as emerging themes about change knowledge.

Example Findings

The following examples illustrate the kinds of change knowledge emerging from the data. We anticipate finalizing the analysis process by October at the latest.

**Changemakers have a comprehensive vision regarding the system they seek to change and specifically identify transforming the way people think, as compared to what people do, as critical for success.** They have developed an awareness of the fear people associate with letting go of practices that have worked well in the past, and are able to help others overcome that fear by guiding them through a sensemaking process as part of their initiation into a change initiative. Through naming a new participant's existing practices in a way that links to the change vision, they shift the framing of the change initiative from “letting go of prior ways of thinking” into a trajectory that participants see themselves as already aligned with.

**Changemakers describe their accomplishments with humility, citing the collaborative process of change over the leadership of an individual.**  This speaks to a “different kind of leadership” that focuses on facilitating ways to find a shared vision, being able to “see the way” and help others “see the way”, and understanding how this fits together and relates to them so they can walk a parallel path. Changemakers focus on relationship-building over information dissemination.

**Changemakers aren't interested in fighting.**The stereotype of a change agent as a “rebel against the system” is inaccurate. On the contrary, changemakers recognize they have limited time and resources, and don't want to spend those resources on places and people who will be unwilling to change. They develop an ability to assess the opportunity cost of a situation and walk away if it's too high, and try to find their own spaces in the existing infrastructure if they have the chance to do so.

Contributions

In this section we summarize the contributions of this paper to this special volume. First, we discuss the theoretical implications for advancing knowledge on the mechanisms for transforming engineering education by (1) making visible how transforming engineering education is a learning process that involves revealing what actors within a change initiative understand about change and themselves as change agents, (2) taking a critical first step in drafting a socio-cognitive framework of “change knowledge”, the values, beliefs, assumptions, and mental models individuals hold regarding the goals and process of successful transformative change, and (3) broadening a repertoire of professional development frameworks to include shifts in thinking about the goals and process of change. Second, we discuss the practical implications for initiating transformative change by (1) presenting an alternative model, radically transparent research, for connecting educational research and practice that leverages participatory action research methodologies and a relational dissemination model (as compared to a transactional dissemination model), (2) illustrating the value of sharing personal narratives around change as a way to engage in change discourse and support critical reflection and transformative learning, and (3) providing insights for improving the impact of professional development experiences.

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References

[Note: In the process of chopping down the proposal to about 2000 words we messed up our references – this will be resolved in the full paper.]

Arbaugh, F., Herbel-Eisenmann, B., Ramirez, N., Knuth, E., Kranendonk, H., & Quander, J. R. (2010). *Linking Research & Practice: The NCTM research agenda conference report.* Washington, DC: National Council of Teachers of Mathematics.

Axelrod, R., & Cohen, M. D. (2000). Harnessing Complexity: Organizational Implications of a Scientific Frontier. New York, NY: Basic Books.

Ballantyne, R., Bain, J. and Packer, J. (1997). *Reflecting on University Teaching Academics’ Stories*. Canberra, ACT: Australian Government Publishing Service, Committee for the Advancement of University Teaching.

Banathy, B. (1992). *A Systems View of Education: Concepts and Principles for Effective Practice*. Englewood Cliffs, New Jersey: Educational Technology Publications.

Banathy, B. H. (1996). *Designing Social Systems in a Changing World*. New York, NY: Plenum Press.

Banathy, B. H., & Jenlink, P. M. (2004). Systems Inquiry and its Application in Education. In D. H. Jonassen (Ed.), *Handbook of Research for Educational Communications and Technology* (pp. 37-57). Mahwah, NJ: Lawrence Erlbaum Associates.

Baxter Magolda, M. and King, P. (2004). *Learning partnerships: Theory and models to education for self-authorship*. Stylus Publishing.

Baxter-Magolda, Marcia B. (1999). “Creating Contexts for Learning and Self-Authorship: Constructive-Developmental Pedagogy.” Edited by J. M. Braxton. First Edition ed. Nashville: Vanderbilt University Press.

Bower, G., & Morrow, D. (1990). “Mental models in narrative comprehension.” *Science*, 247(4938), 44-48.

Boyce, M. (2003). Organizational Learning Is Essential to Achieving and Sustaining Change in Higher Education. *Innovative Higher Education*, *28*(2), 119–136. doi:10.1023/B:IHIE.0000006287.69207.00

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Burton, R., Schlemer, L., & Vanasupa, L. (2012). Transformational Innovation: Reflections on How to Foster it in Engineering Education Systems\*. International Journal of Engineering Education, 28(2), 275-285.

Burton, R., Schlemer, L., & Vanasupa, L. (2012). Transformational Innovation: Reﬂections on How to Foster it in Engineering Education Systems. *International Journal of Engineering Education*, *28*(2), 275–285.

Carlisle, Y., & McMillan, E. (2006). Innovation in Organizations from a Complex Adaptive Systems Perspective. *Emergence: Complexity & Organization*, *8*(1), 2–9.

Chua, M. and Dziallas, S. (2012). “Work in progress – from sage on the stage to guide on the side: creating an open compendium of teaching transformation stories.” Unpublished.

Chua, M. (in review). Radically transparent research: Exposing the discourse of our practice. Submitted to the annual EPIC (Ethnographic Praxis in Industry Conference), Savannah GA, October.

Collins, A., Brown, J. S., & Holum, A. (1991). Cognitive apprenticeship: Making thinking visible. *American Educator*, *6*, 38–46.

Collins, A., Brown, J. S., & Newman, S. E. (1987). *Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics* (Research Report No. 403). Center for the Study of Reading Technical Reports. Champaign, IL: University of Illinois at Urbana-Champaign.

Dall’Alba, G. (2009). *Learning to be Professionals. Innovation and Change in Professional Development*. Dordrecht: Springer.

Dancy, M., & Henderson, C. (2008). Barriers and promises in STEM reform. <http://www7.nationalacademies.org/bose/Dancy_Henderson_CommissionedPaper.pdf>, Retrieved March, 1, 2009.

Dowd, A.C., & V. P. Tong. (2007). “Accountability, Assessment and the Scholarship of “Best Practice”.” In *Higher Education: Handbook of Theory and Research* ed. J. C. Smart: Springer.

Duderstadt, J. (2008). Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education. Ann Arbor, MI: The Millennium Project.

Eckel, P. D., & Kezar, A. (2003). *Taking the reins: Institutional transformation in higher education*. Westport, CT: Praeger Publishers.

Eiseman, J., & Fairweather, J. (1996). *Evaluation of the National Science Foundation Undergraduate Course and Curriculum Development Program: Final Report*. Washington, D.C.: SRI International.

Eiseman, J., & Fairweather, J. (1996). Evaluation of the National Science Foundation Undergraduate Course and Curriculum Development Program: Final Report. Washington, D.C.: SRI International.

Fairweather (2009) Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education: A Status Report for The National Academies National Research Council Board of Science Education.

Fairweather (2009). Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education: A Status Report for The National Academies National Research Council Board of Science Education.

Foertsch, J., Millar, S. B., Squire, L., & Gunter, R. (1997). *Persuading professors: A study of the dissemination of educational reform in research institutions*. Madison: University of Wisconsin Madison, LEAD Center.

Froyd, J., Layne, J., and Watson, K. (2006). “Issues regarding change in engineering education.” Proceedings of the Annual FIE Conference.

Fullan, M., Cuttress, C., & Kilcher, A. (2005). Eight Forces for Leaders of Change: Presence of the Core Concepts Does Not Guarantee Success, but their Absence Ensures Failure. *Journal of Staff Development*, *26*(4), 54–64.

Gess‐Newsome, J., Southerland, S. A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. *American Educational Research Journal, 40*(3), 731‐767.

Greeno, J. G. (1998). "The Situativity of Knowing, Learning, and Research." American Psychologist **53**(1): 5-26.

Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. Journal of Research in Science Teaching, 48(8), 952–984. doi:10.1002/tea.20439

Holley, K. A. (2009). Interdisciplinary Strategies as Transformative Change in Higher Education. *Innovative Higher Education*, *34*(5), 331–344. doi:10.1007/s10755-009-9121-4

Jackson, M. C. (2001). Critical Systems Thinking and Practice. *European Journal of Operational Research, 128*(2), 233-244. 10.1016/S0377-2217(00)00067-9

Jamieson, L. H., & Lohmann, J. R. (2008). *Creating a Culture for Scholarly and Systematic Innovation in Engineering*. Washington, D.C.: American Society for Engineering Education.

Kegan, R., & Lahey, L. L. (2009). Immunity to Change: How to Overcome It and Unlock the Potential in Yourself and Your Organization. Boston, MA: Harvard Business School Publishing.

Kemmis, S., & R. McTaggart. (2000). “Participatory action research.” In *Handbook of Qualitative Research*, ed. N. K. Denzin & Y. S. Lincoln. Thousand Oaks: Sage Publications.

Kezar, A. (2001). Understanding and facilitating organizational change in the 21st century. *ASHE-ERIC Higher Education Report*, *28*(4).

Kezar, A. J. (2001). Understanding and facilitating organizational change in the 21st century: recent research and conceptualizations. *ASHE‐ERIC Higher Education Report, 28*(4), 1‐162.

Kezar, A., & Eckel, P. (2002a). Examining the institutional transformation process: The importance of sensemaking, interrelated strategies, and balance. *Research in Higher Education, 43*(3), 295‐328.

Kezar, A., & Eckel, P. D. (2002b). The effect of institutional culture on change strategies in higher education: Universal principles or culturally responsive concepts? *The Journal of Higher Education, 73*(4), 435‐460.

Lave, J. And Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge, MA: Cambridge University Press.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, CA; London: Sage Publications.

Marder, C., McCullough, J. and Perakis, S. (2001). Evaluation of the National Science Foundation’s Undergraduate Faculty Enhancement (UFE) Program. SRI International.

McIntyre, A. (2008). *Participatory Action Research*. Thousand Oaks, CA: Sage Publications, Inc.

Meadows, D. (2008). *Thinking in Systems: A Primer*. White River Junction, VT: Chelsea Green Publishing.

Mezirow, J. (1997). Transformative Learning: Theory to Practice. *New Directions for Adult and Continuing Education*, *1997*(74), 5–12. doi:10.1002/ace.7401

Mezirow, J. (2000). *Learning as Transformation: Critical Perspectives on a Theory in Progress*. Jossey-Bass.

Mezirow, J. (2000). Learning to Think Like an Adult: Core Concepts of Transformation Theory. In J. Mezirow & Associates (Eds.), *Learning as Transformation: Critical Perspectives on a Theory in Progress* (pp. 3–33). San Francisco, CA: Jossey-Bass.

Patton, M. (2002). *Qualitative Evaluation and Research Methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Reason, P. & Torbert, W. (2001). “The action turn: Toward a transformational social science.” *Concepts and Transformation*, 6(1), 1-37.

Reason, P., & W. R. Torbert. (2001). “The action turn: Toward a transformational social science.” *Concepts and Transformation,* 6 (1):1-37.

Senge, P., Kleiner, A., Roberts, C., Ross, R., Ross, G., & Smith, B. (1999). *The Dance of Change: The Challenges to Sustaining Momentum in Learning Organizations*. New York: Currency Doubleday.

Seymour, E. (2001). Tracking the Processes of Change in US Undergraduate Education in Science, Mathematics, Engineering, and Technology. *Science Education* 86**:**79-105.

Shulman, L. S. (1986). Those who can understand: Knowledge growth in teaching. *Educational Researcher* 15(2), 4-14.

Taylor, E. W. (2000). Analyzing Research on Transformative Learning Theory. In J. Mezirow & Associates (Eds.), *Learning as Transformation: Critical Perspectives on a Theory in Progress*. San Francisco, CA: Jossey-Bass.

The Steering Committee for the National Engineering Education Research Colloquies (SCNEERC) (2006). “Special Report: The Research Agenda for the New Discipline of Engineering Education.” *Journal of Engineering Education*, 95(4), pp. 259-261.

Torbert, W. R. (1981). “Why educational research has been so uneducational: the case for a new model of social science based on collaborative inquiry.” In P. Reason & J. Rowan (Eds.), *Human Inquiry.* Boston: John Wiley and Sons.

Walther, J. (2008). A complex systems approach to engineering competence. Dissertation: University of Queensland.

Wertsch, J. V. (1985). *Vygotsky and the Social Formation of Mind*. paperback ed. Cambridge: Harvard University Press.