Situated Engineering Learning:
Bridging Engineering Education Research
and the Learning Sciences

ADITYA JOHRI AND BARBARA M. OLDS
Virginia Tech, U. S. National Science Foundation

BACKGROUND
The field of engineering education research has seen substantial growth in the last five years but it often lacks theoretical and empirical work on engineering learning that could be supplied by the learning sciences. In addition, the learning sciences have focused very little on engineering learning to date.

PURPOSE
This article summarizes prior work in the learning sciences and discusses one perspective—situative learning—in depth. Situativity refers to the central role of context, including the physical and social aspects of the environment, on learning. Furthermore, it emphasizes the socially and culturally negotiated nature of thought and action of persons in interaction. The aim of the article is to provide a foundation for future work on engineering learning and to suggest ways in which the learning sciences and engineering education research communities might work to their mutual benefit.

SCOPE/METHOD
The article begins with a brief discussion of recent developments in engineering education research. After an initial overview of the field of learning sciences, situative learning is discussed and three analytical aspects of the perspective are outlined: social and material context, activities and interactions, and participation and identity. Relevant expert commentaries are interspersed throughout the article. The article concludes with an exploration of the potential for contributions from the learning sciences to understanding engineering learning.

CONCLUSION
There are many areas of mutual benefit for engineering education and the learning sciences and many potential areas of collaborative research that can contribute not only to engineering learning but to the learning sciences.

KEYWORDS
engineering learning, learning sciences, situative learning

INTRODUCTION
In recent years, there has been a concern about the need to develop a better understanding of how people learn engineering. Previous efforts to improve engineering education
have often followed an ad-hoc path without a systematic understanding of how learning occurs and without the development of a body of knowledge upon which to build. To help redress this situation, we review scholarship on learning broadly and engineering learning specifically with the aim to build a framework that can guide future research on engineering learning. This article complements other articles in this issue (Adams et al., 2011; Borrego & Bernhard, 2011; Litzinger, Hadgraft, Lattuca, & Newstetter, 2011) that also focus on learning.

We begin with a brief review of the history of engineering education research. We then review research on learning more generally and survey the field of learning sciences. As an exemplar, we focus on one dominant perspective on learning in that field, situativity, and draw some implications of this perspective for research on engineering learning. Next, we discuss how learning sciences and engineering learning can mutually inform each other, in particular what engineering education researchers can learn from scholarship in the learning sciences and what fundamental contributions engineering can make to research on learning. Interspersed throughout the article are research commentaries we have invited from six established and emerging international scholars in the learning sciences. Our hope is that the engineering learning community will see common ground and common questions in these commentaries and increase their familiarity with the learning sciences. Finally, we end with a short discussion and conclusion section that summarizes the key points of the article as well as outlines some areas for development.

From the perspective of engineering education, two significant differences exist between engineering learning and research in the learning sciences. First, learning sciences researchers have traditionally focused primarily on issues related to K-12 education; even though research on K-12 is on the rise within the engineering education community, such studies are still quite limited compared to those focusing on undergraduate teaching and learning. Still, fundamental ideas about learning apply irrespective of the targeted user population and will be useful for engineering learning research. Second, learning sciences research has not focused much on engineering disciplines. As a result, in some sense this is a great opportunity for engineering educators to make a significant contribution to the field. As we argue, a movement parallel to the rise of situative learning in the learning sciences is on the rise within engineering education; more and more scholars are engaged in research on engineering learning, and engineers and engineering have become the focus of novel and exciting research on learning.

Our thesis is that the learning sciences and engineering learning potentially have much in common, though the two communities have not interacted extensively up to now. We are not arguing that collaboration with the learning sciences is the only direction in which engineering education research should go, nor that there has been no collaboration between the two communities until now, but rather that such collaboration is important and promising and has been underexplored. Before we can examine the present state of research on engineering learning, it will be helpful to briefly discuss some of its historical path.

ENGINEERING EDUCATION RESEARCH

Although much of the history presented here is focused on developments in the U.S., engineering education research is clearly a global enterprise, as indicated by the
contributors to this article, this issue of JEE, other journals focused on engineering education in many countries, and mechanisms such as the Research on Engineering Education Symposia that connect scholars with an interest in engineering education from around the globe. The article by Borrego and Bernhard in this issue discusses in some detail the emergence of engineering education research as an internationally connected field of inquiry (Borrego & Bernhard, 2011). In addition, engineering education research has been fortunate to have more mature models in science and mathematics education from which it has learned much about the formation of a discipline. For example, Peter Fensham’s (2004) work on the evolution of science education as a research field has influenced engineering education researchers as they consider the identity of their new discipline.

Much of the early research in engineering education focused, understandably, on curriculum and instruction, the majority of it conducted by faculty whose professional training was in an engineering discipline and who were responding to what they observed in their engineering classrooms. John Heywood’s 2005 compendium contains much of this history from a broad international perspective and summarizes ongoing lines of engineering education research with chapters on topics such as Concepts and Principles; Learning Strategies and Learning Styles; Human Development; Problem Solving; Design; and Assessment and Evaluation (Heywood, 2005). Some examples of the types of “effective learning experiences” highlighted in Heywood’s book are also enumerated in the article by Litzinger et al. in this issue (2011). However, there are relatively few examples from the learning sciences per se, an indication perhaps of both the relatively recent emergence of the learning sciences and their even more recent adoption within the engineering learning community.

Pea and Collins (2008) identify four waves of science education reform activity over the past half century and argue that the reforms are building towards a “cumulative improvement of science education as a learning enterprise” (p. 3). They identify these waves as the post-Sputnik focus on curriculum reform in the 1950s and 1960s, the focus on cognitive science studies of learners’ reasoning in science in the 1970s and 1980s, the standards movement in the late 1980s and 1990s, and the current focus on a systemic approach to designing learning environments. Their metaphor of waves of reform is apt for understanding developments in the field of engineering education over the past century. In a 2005 guest editorial for a special issue of JEE intended to “review the current state of scholarship in key areas of engineering education,” Felder, Sheppard, and Smith take a similar approach to describing the waves of change in engineering education research. They argue that from the 1960s to the 1980s “engineering education journals and conferences remained focused on the mechanics of classroom instruction with little regard for the science of education and little evidence of rigorous scholarship” (p. 9). In the 1980s and 1990s, they continue, “scholarship in engineering education began to move toward a new level of maturity and sophistication.”1 They

1Before the time period covered by Felder, Sheppard, and Smith (2005), similar waves were present, as identified by Seely (1999), of which the wave of engineering science has had the strongest hold on engineering education. This movement was pioneered by engineers who moved to the U.S. from Europe and developed a stronghold in American engineering colleges in the years immediately after World War II. Interestingly, in his article Seely (1999) highlights that the actual intentions of reform seekers did not materialize as envisioned in the reforms that were implemented and argues that this gap between vision and implementation in practice is persistent across waves of reform.
conclude that going forward, engineering education will require “research guided by theories grounded in cognitive science and educational psychology and subjected to the same rigorous assessment and evaluation that characterize first-rate disciplinary research” (p. 9). They also argue for partnerships among psychologists, social scientists, and engineering educators. Reform towards research has gained significant momentum in the past decade and it is within this context that this paper and this issue are framed.

Clearly, engineering education research is a field of increasing prominence, global reach, and theoretical grounding. We applaud the multiplicity of approaches taken and the partnerships that are being developed. In the remainder of this paper, we hope to make the case for the value of partnerships and collaborations between the learning sciences and engineering learning.

AN INTRODUCTION TO LEARNING

Over the past couple of centuries, scholars from a wide range of disciplines including philosophy, psychology, anthropology, and sociology have spent considerable time trying to answer questions related to learning such as: How does cognitive development take place? How do we grow from a child with rudimentary abilities and knowledge into a highly skillful adult? How are humans able to engage in highly complex activities? Some scholars whose work has had a major influence on research on learning include Lev Vygotsky (1962, 1978), Jean Piaget (1952, 1964), John Dewey (1896, 1934), Harold Garfinkel (1967), William James (1890/1950), George Herbert Mead (1934/1962), Gregory Bateson (1978), Michel Polanyi (1967) and Jerome Bruner (1960, 1990). Core ideas of these scholars adopted by learning researchers in their intellectual and methodological trajectory include Vygotsky’s socio-cultural learning and zone of proximal development, Piaget’s genetic epistemology, Dewey’s transactional account, James’s pragmatism and realism, Polanyi’s tacit knowledge, and Garfinkel’s ethnomethodology. These ideas have not only shaped theoretical development of the field of learning but have also influenced the design of learning environments including our schools and curricula. Many central ideas that we take for granted in educational practice, such as the progression of child development through specific stages and the value of group work and collaborative learning, can be traced back to these influential scholars.

Greeno, Collins, and Resnick (1996), provide a useful classification of research on learning that occurred over the twentieth century and divide the work into three broad areas: behaviorist, cognitive, and situative. Behaviorism, a movement associated primarily with its most prolific and controversial scholar, B. F. Skinner, “took the position that knowing could be characterized only in terms of observable connections between stimuli and responses” (Greeno, Collins & Resnick, 1996, p. 16). For behaviorists, learning was the formation, strengthening, or weakening of those connections

2There are many other aspects of learning as well, for instance, biological where muscle memory is critical; neuroscience research is shedding more light on these issues and their relationships with social aspects of learning (Meltzoff et al., 2009; also see Tomasello, 1999, and Tomasello & Call, 1997; to learn more about the promise and perils of neuroscience research for education see commentary by Schwartz and Tsang).
through reinforcement. In other words, if a certain signal, such as ringing a bell, could induce a particular action, such as taking a break from working on the computer, learning had taken place. Furthermore, for behaviorists the mind (or brain) was a black box and they were content with forgoing understanding how the mind works. On the other hand, for the cognitive scientists an understanding of how the mind works was central to their approach to learning as they were particularly interested in how information was represented and processed by humans. Knowledge was seen as a structure consisting of different concepts, and learning was the acquisition of abilities such as reasoning, planning, solving problems, and comprehending language (Anderson, 1981, 1976; Newell & Simon, 1972). Unlike the behaviorists, for whom external motivation was the driver for learning, the cognitive perspective was interested in turning extrinsic motivation into intrinsic motivation. The cognitive movement got a particular boost with the advent of computation and computers as these devices incorporated many of the conceptual features of cognition emphasized by cognitive scientists and also allowed them to model their own conceptions of learning. A central attempt was to use the computer as a representation of how the mind works and to be able to understand learning by developing the brain. The third perspective, situative, views knowledge “as distributed among people and their environments, including objects, artifacts, tools, books, and the communities of which they are a part” (Greeno, Collins & Resnick, 1996, p. 17). In this view, learning is seen as meaningful participation in a community of practice with an understanding of “the constraints and affordances of social practices and of the material and technological systems of environments” (p. 17). As can be seen, the situative movement differs significantly from the other perspectives in its emphasis on the role of the environment on an individual’s conception of knowing and how they learn; knowledge is not something an individual possesses or stores in the brain but is present in all that they do. Clancey (1997b) succinctly summarizes the situative perspective and how it differs from the cognitive perspective when he argues, “The idea that knowledge is a possession of an individual is as limited as the idea that culture is going to the opera. Culture is pervasive; we are participating in a culture and shaping it by everything we do. Knowledge is pervasive in all our capabilities to participate in our society; it is not merely beliefs and theories describing what we do” (p. 271).

A further discussion of these ideas, including their implications for design of learning environments, is available in Greeno, Collins, and Resnick (1996) and has been summarized in Table 1 (also see Derry & Steinkuehler, 2003 for a short summary of the ideas). In addition, a series of articles and debates that appeared in the journals Educational Researcher and Cognitive Science do an excellent job of summarizing various perspectives associated with situativity and concerns cognitive scientists have with the concept (Brown, Collins, & Duguid, 1989; Greeno, 1989, 1997; Norman, 1993a; Vera & Simon, 1993). Brief historical discussions of situated cognition can also be found in Bruner (1990) and Clancey (1997a, 2009). Recently, many scholars have argued for research that bridges the cognitive and situative perspectives on learning (Greeno & van de Sande, 2007; Vosniadou, 2007). These efforts are driven by a need to overcome what some see as a dichotomy between the acquisition (learning is something we acquire, the cognitive perspective) and participation (learning is participating, the situative perspective) metaphors (Sfard, 1998). Cognitive scientists argue that if all learning is situated and participatory, then how do we account for transfer (Bransford & Schwartz, 1999)? The situativists answer this
criticism by arguing that we apply what we know in a new activity based on features common to that activity and previous activities and by reframing the learning contexts (Engle, 2006). Still, this answer does not satisfy all conditions of transfer, such as a novel domain or situation, and remains a critical challenge for the situative perspective. Arguing that both acquisition and participation metaphors can provide useful guidance for research, some scholars have proposed a third metaphor “knowledge creation” as a way to provide a better overall framework, consisting of all three metaphors, to advance our understanding of learning (Paavola, Lipponen, & Hakkarainen, 2004). Another thorny issue between the proponents and opponents of the situative perspective is the question of whether individuals learn or learning is a

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Guidelines for Curricula Design

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characteristic of an activity system (Salomon & Perkins, 1998). Although situativity scholars argue that situativity does not preclude learning from occurring at an individual level, empirical studies of situated activity have primarily dealt with a group-level analysis.

A Brief Note on Critical Perspectives on Learning

Before moving on to the next section, we want to briefly introduce the critical perspective on learning which has shaped the thinking of learning researchers and is not captured by any of the ideas discussed so far. Critical theorists argue for a re-examination of the current state of affairs regarding how we teach (design of instruction), what we teach (design of curriculum), and how we have reached the status quo (scrutiny of existing power relations that shape learning). “Schools, in these perspectives, are seen merely as instructional sites. That they are also cultural and political sites is ignored, as is the notion that they represent arenas of contestation and struggle among differentially empowered cultural and economic groups” (Giroux, 1983, p. 3). Critical theorists argue that fundamental change towards a more equitable society and learning can occur only by looking at things from a fresh perspective. In its most extreme form, some critical theorists argue for complete separation from the establishment or the modern enterprise which is significantly reflected in current educational settings.

In addition to the critical lens they bring to educational thinking, critical theorists also espouse a participatory and reflective view of research. “The interface between theory and practice...is at a point where these various groups come together and raise the fundamental question of how they may enlighten each other, and how through such an exchange (of theoretical positions) a mode of practice might emerge in which all groups may benefit” (Giroux, 1983, p. 240). One research method that takes these concerns into account is action research, “Action research is simply a form of self-reflective enquiry undertaken by participants in social situations in order to improve the rationality and justice of their own practice, their understanding of these practices, and the situations in which the practices are carried out” (Carr & Kemmis, 1986, p. 162). Though a detailed discussion of critical theory and action research is beyond the scope of this article, we urge interested readers to explore it further in the works cited previously and through Reason and Bradbury (2008) and Whyte, Greenwood, & Lazes (1989), among others. Action research is also discussed by Case and Light (2011) in their article in this issue.

THE LEARNING SCIENCES

Since the late 80s and early 90s many scholars interested in learning issues have coalesced around an emerging field called the Learning Sciences. In addition to the traditional scholarly disciplines, the learning sciences include scholars who self-identify with artificial intelligence, cognitive science, computer science, organizational science, educational sciences, information sciences, linguistics, and neurosciences. The institutionalization of the field had its beginnings in the first conference in the field (the International Conference of the Learning Sciences) and the subsequent journal, the Journal of the Learning Sciences, which published its first issue in 1991. The Institute for Learning Sciences was opened at Northwestern University in 1989 followed by the first doctoral program in learning sciences. The International Society for the Learning Sciences
was officially established in 2002 and in addition to its largely U.S.-based members, the leadership has made significant efforts to attract members from all over the world. Subsequent conferences of the society have been held in Taiwan, Greece, the Netherlands, and Chicago. In recent years the community has become increasingly international with scholars from Europe and Asia playing a significant leadership role in the society and its journals. Still, the majority of research we review here comes from U.S. scholars and follows a tradition of examining learning within K-12 settings. Recent work that examines higher education settings has started to emerge in Europe and has been reviewed in the Case and Light (2011) paper in this issue, particularly under the section on phenomenography (e.g., Bruce, Pham, & Stoodley, 2004; Carstensen & Bernhard, 2009; Ebenezer & Fraser, 2001, Swarat, Light, Park, & Drane, in press).

Overall, learning sciences researchers study learning in diverse contexts using a variety of methodologies ranging from ethnographic field studies to lab-based investigations. In addition to theoretical development, scholars apply their findings to design novel learning environments. Although the contributions of scholars in the field have been wide ranging, some topics relevant for engineering education that have been studied include learning by analogy, scientific reasoning and discourse, apprenticeship, intentional learning, collaboration, transfer, design, imitation, guided discovery, anchored instruction, and modeling (e.g., Barron, 2003; Bereiter & Scardamalia, 1989; Brown & Campione, 1994; CTGV, 2000). Learning science scholars have developed and tested new models of instruction including problem and project-based learning (Barron et al., 1998), case-based reasoning (Kolodner et al., 2003), and adaptive expertise (Hatano & Inagaki, 1986). The study of collaboration in both face-to-face small groups (Barron, 2000) and computer-mediated settings (Rummel & Spada, 2005) has received significant attention by learning sciences researchers. Another area that has garnered much interest from the learning sciences community is how the use of technology shapes learning. This has included investigating the role of scientific visualizations, simulations, and modeling for teaching science and mathematics (Gordin & Pea, 1995; Roschelle, 1992; Roschelle & Pea, 2002).

In addition to content-agnostic principles of learning, disciplinary research on science and mathematics learning forms a core contribution of scholars (Cobb, Yackel, & McClain, 2000; diSessa, 1982; Saxe & Guberman, 1998). Many scholars have written on learning in the disciplines such as physics (Chi & VanLehn, 1991; diSessa, 1982; Etkin et al., 2010), chemistry (Kozma, Chin, Russell, & Marx, 2000), and mathematics (Boaler & Greeno, 2000; Sfard & McClain, 2002), which are of special interest to engineering educators. Engineering education researchers have been fortunate to have existing models and theories to borrow from in related fields such as science education and mathematics education. These models have helped engineering education researchers think about questions related to the identity of the field as well as borrow theoretical and methodological

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1Although, as with most fields and disciplines, it is hard to come up with a definition of learning sciences, the official society’s Web site (www.isls.org) lists its mission as: “Learning Sciences (LS) investigations include fundamental inquiries on how people learn alone and in collaborative ways, as well as on how learning may be effectively facilitated by different social and organizational settings and new learning environment designs, particularly those incorporating information and communication technologies (ICT), as in computer supported collaborative learning (CSCL).” Another perspective is available in Nathan & Alibali (2010).
models. Several examples of how learning research in the disciplines has shaped engineering education can be cited. Perhaps the most viral of these has been the development of concept inventories in a variety of engineering topics. As described in the article by Litzinger, Lattuca, Hadgraft, and Newstetter (2011) in this issue the Force Concept Inventory (FCI) developed by Hestenes and Hake has been influential in the development of multiple inventories in engineering topics. According to Streveler et al., “learning conceptual knowledge in engineering science is a critical element in the development of competence and expertise in engineering. To date, however, research on conceptual learning in engineering science has been limited” (Streveler, Litzinger, Miller, & Steif, 2008, p. 279). They demonstrate the synthesis not only of an idea (concept inventories) that grew out of physics but also the way in which fundamental research by cognitive psychologists can inform engineering learning research. In the area of mathematics education, one area of research that has gained some traction in engineering is model eliciting activities (MEAs). MEAs use open-ended case studies to simulate authentic, real-world problems that small teams of students address (Hamilton, Lesh, Lester, & Brilleslyper, 2008; Yildirim, Besterfield-Sacre, & Shuman, 2009; Zawojewski, Diefes-Dux, & Bowman, 2008). Originally designed to observe the development of middle school student problem-solving competencies and the growth of mathematical cognition, it soon became apparent that MEAs provided a methodology to help students become better problem solvers “Lesh, 2003”.

In addition to theoretical development, learning sciences scholars have also explored innovative ways of undertaking research such as design-based research, founded on the idea of design experiments (Brown, 1992; Collins, 1992; Design-Based Research Collective (DBRC), 2003), and methodological approaches such as interaction analysis (Jordan & Henderson, 1995) and video analysis (Derry et al., 2010) form a core contribution of the field. Learning sciences scholars have also made significant efforts to bridge the gap between learning research and educational practice (Bransford, Derry, Berliner, Hammerness, & Beckett, 2005; CTGV, 1997) through the design of learning environments.

Of course, like most academic disciplinary fields, the learning sciences community itself has a dynamic identity often in a state of flux. In recent years several community members have questioned the purpose, membership, and role of the organization in several forums and have directed their research resources towards sense-making around the community through interactive symposia (Evans et al., 2010) and reflective and summative reviews (Nathan & Alibali, 2010). For a further understanding of the work in the field, we refer readers to The Cambridge Handbook of the Learning Sciences (2005). It is also important to mention that the National Research Council’s report How People Learn (2000) was largely the product of a collaboration among learning scientists. Several recent review articles do an excellent job of providing a background of the field and laying out future directions for research (Bransford et al., 2006; Clancey, 2009; Sawyer & Greeno, 2009). For instance, an emerging trend within the field is an emphasis on “learning outside of school” given the research on after-school settings, museums, digital media, community programs, and gaming (JLS, 2009, editor’s note) and Bransford et al. (2006) argue that the next decade will see a synergy between neuroscience accounts of learning and research in formal and informal learning.4

4Other venues for this research include the Journal of the Learning Sciences, International Journal of Computer–Supported Collaborative Learning, Cognition and Instruction, Educational Psychology, Mind Culture and Activity, and journals of the American Educational Research Association (AERA) and the European Association for Research on Learning and Instruction (EARLI), among others.
THE SITUATIVE PERSPECTIVE ON LEARNING

As introduced above, one significant change in research on learning over the past couple of decades is a move towards examining learning as a situated activity. The situative perspective is broad and owes a debt to many scholars and ideas. Its seeds can be traced back to the works of Dewey (1934). This perspective has been referred to as situated cognition (Brown, Collins, & Duguid, 1989; Greeno, 1989), situated learning (Lave, 1991; Lave and Wenger, 1991), situated action (Suchman 1987/2007), socio-cultural psychology (Rogoff, 1990; Wertsch, 1993), activity theory (Engeström, 1987), and distributed cognition (Hutchins, 1995). Greeno (2006) refers to the perspective as situative and/or situativity, as opposed to situated learning, to prevent the misconception that only some action, cognition, or learning is situated. He argues, as do others (Lave, 1988; Suchman, 1987), that all action, cognition, and learning is situated, whether in informal settings or formal school settings. The situative perspective views human knowledge as arising conceptually through dynamic construction and/or reinterpretation within a specific social context (Clancey, 2009). Furthermore, knowledge is socially reproduced and learning occurs through participation in meaningful activities that are part of a community of practice (Lave & Wenger, 1991), participation which is mutually constituted through and reflects our thinking and literacy skills (Gee, 1997). According to Sawyer and Greeno (2009) the core commitment of the situative perspective is, “to analyze performance and transformation of activity systems that usually comprise multiple people and a variety of technological artifacts (p. 348).” In other words, a central aim of the situated perspective is to understand learning as situated in a complex web of social organization rather than as a shift in mental structures of a learner.5

We believe that a broader and deeper understanding of the situative perspective can provide valuable lessons for engineering educators particularly in their efforts to develop theoretical insights into engineering learning. To facilitate this process, we next outline and discuss three analytical aspects of situative learning. First, we will look at the importance of the social and material context on learning. Second, we will examine the role of activities and interactions in situated learning. Finally, we will explore the ideas of participation and identity in relation to situativity. After discussing each concept in detail, we will explore their significance for engineering learning and how they can help inform future research. In addition, we have invited a group of international contributors to speak to these ideas in more depth in their commentaries.

Social and Material Context

From a situated learning perspective, all learning takes place within some social and material context. Humans are constantly surrounded by other people and by objects and artifacts. Tools mediate all our activities including learning processes and therefore the role and use of tools is important to understand. Tools not only have a physical dimension

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5In addition to the scholars cited above, readers can refer to the following edited volumes for in-depth work on this topic: Perspectives on Socially Shared Cognition (Resnick, Levine & Teasley, 1993), Handbook of Situated Cognition (Robbins & Aydede, 2009), Mind, Culture & Activity (Cole, Engeström & Vasquez, 1997), Everyday Cognition (Rogoff & Lave, 1984), Perspectives on Activity Theory (Engeström, Miettinen & Pumain, 1999), Communication and Cognition at Work (Engeström & Middleton, 1998), Cultural Psychology (Cole, 1990), Sociocultural Studies of Mind (Wertsch, Río, & Alvarez. (Eds.), 1995), Distributed Cognition (Salomon, 1993), and Situated Cognition: Social, Semiotic, and Psychological Perspectives (Kirschnner & Whiton, 1997).
but also allow us to represent symbols and manipulate those symbols. In Commentary 1, Estrid Sørensen from Aarhus University in Denmark discusses her work on the materiality of learning and some possible implications for engineering education.

**Commentary 1: The Materiality of Learning, Estrid Sørensen, School of Education, Aarhus University and Humboldt University**

Intense discussions have unfolded over the last decades concerning the place of agency. Scholars of Science and Technology Studies have shown how materials can come to act—often on human beings. A classic study is Latour’s description of a hotel manager, who in vain keeps telling his guests to hand over the keys when they leave the hotel (Latour 1992). Frustrated, he attaches to each key a heavy weight, whereby he, in Latour’s terms, delegates the agency involved in telling guests to hand over the keys to the weights. The agency of the weights turns out to be more successful than the hotel manager’s agency: the guests now actually return their keys!

Latour’s Actor-Network Theory is more sophisticated than emphasizing the agency of things. Important is the approach to humans as well as nonhumans as hybrids (Latour, 1993). The key weights were not entirely nonhuman since the hotel manager’s human agency was folded into them. The agency of the weights was a hybrid effect of the interrelation of hotel manager and weights. Likewise, the docility of the guests dutifully leaving the keys on the reception desk was not purely human. It was a hybrid result of the heavy weights and the guests’ distaste for carrying weight around.

Engineering education is probably one of the most material-saturated disciplines. For this reason, from an Actor-Network Theory perspective, even the overview of materiality in this article falls short of the possibilities of materiality since materials are only accounted for as a context for learning. Learning itself is seen as a purely human endeavor. This oversight is not surprising since other than in their role as tools and scaffolds materials are hardly to be found in learning theory. How can we understand the specificities of learning engineering if we fail to take into account the hybrid postures engineering students have to develop as a result of the interaction of their bodies and the variety of apparatuses involved in the craft of engineering? How can we understand collaboration between learners of engineering if we ignore that these collaborations unfold around material things? How much would there be left of learning engineering if all nonhuman things were left out?

With such questions and such an approach, I set off to reconsider situated learning theory (Sørensen, 2009). The basic point in this endeavor is to conceptualize learning not as a product of social interaction, but as a hybrid, socio-material process. Through classroom observations I learned that different forms of knowledge emerged when different materials were involved. The size, similarity and stability of the blackboard, the textbook and the layout of the classroom contributed to a form of knowledge that implied that knowledge was located in the heads of children, in the classroom situation, and in the book. Compared to this, a much more fluid, processual knowledge emerged when the
students engaged with a 3D virtual environment, a blog, and the Internet. It was revealed that learning differed when different materials were involved, and thus the evaluation of what was learned and the relevance of the learned varied. These findings emphasize not only the socio-material character of learning, but also learning’s translocal character: because materials, such as a book and a blog have different extensions, the space of learning is sometimes bounded to a geographically small area, the situation, and sometimes it is extended and fluctuating. Accordingly, the understanding of learning as a socio-material process also affects our concepts of the spatial and temporal dimensions of learning.

Materiality is evident not just in physical objects or tools, but in representations as well. In this manner, language becomes part of our ecology of learning, of our social and literacy practices (Gee, 1992, 2003). From a situative perspective, representations get their meanings from their use, “representations are as representations do” (Dourish, 2001),” in contrast to the cognitive perspective where representations are useful in terms of information processing. Representations are not just about disciplinary knowledge but about other people as well. Our impressions of others are central to how we interact with them and often, especially when digital materiality is involved, these impressions are formed from interpretation of digital cues of others. In summary, the socio-material context is central to understanding and designing learning from a situative perspective. Representations have been a strong focus of research within the learning sciences and have played an especially strong role in our understanding of science and mathematics practices (Danish & Enyedy, 2006; Greeno & Hall, 1997; Hall, 1996; Lee & Sherin,
Mediation and representational abilities have been shown to be central in learning science and mathematics, especially for expertise development (Pea, 1993b). Wolff-Michael Roth’s work explores the importance of inscriptions in Commentary 2.

Activities and Interactions

Context is meaningless for learning if a learner is not engaged in interactions and activity—context is in the doing and being and is not a static environment (McDermott, 1999). According to the situative perspective, learning is doing (Greeno, 2005) and it is through situated engagement in motivated action (Goodwin, 2000), using tools, and in interaction with others, that we learn some of our most essential skills. For instance, a child first acquires language through its use with parents. Clancey (1997b) has conceptualized an activity as a participation framework, “an encompassing fabric of ways of interacting that shapes what people do (p. 266).” Activities are intentional actions and they serve as a background for human actions such as deliberation, planning, description, and so on. They are critical sense-making units as our interpretations of actions or artifacts, our perceptions and interpretations are situated within specific activities; an interruption has a different meaning when we are engaged in finishing a publication compared to when we are watching television. The concept of activity is also a central tenet of activity theory, a theoretical line of inquiry that has developed from ideas first stated by Lev Vygotsky7 (1978, 1962) and expanded by Leont’ev (1978), Luria (1976), and, more recently, Wertsch (1998) (also see commentary by Roth). According to this view, we are motivated to engage in activities in part by our need to transform an object into a desired outcome.8 Engeström (1987) calls activity, “the smallest and most simple unit that still preserves the essential unity and integral quality behind any human activity” (p. 81). Overall, mediation by tools and engagement in activities (that include social interaction) are essential for learning and require paying attention to the micro-foundation of interaction. Interpretation embedded in action and interaction is also the underlying notion behind the social constructivist view of the world which advocates understanding the fabric of interaction that has emerged over time through reciprocal roles played by actors (Berger & Luckmann, 1966).

Commentary 2: Inscriptions: A Cultural-Historical Activity Theoretic Approach to Scientific Representation, Wolff-Michael Roth, University of Victoria

We live in a visual culture. It is therefore perhaps not surprising that one of the pervasive features of science, engineering, and technology is their use of visual representations in the form of graphs (Figure 1), photographs, drawings, diagrams, tables, or equations (Roth, 2003). On average, research shows that there are around two visual representations per research article in the sciences. In fact, the history of imagery in the sciences suggests that without visuals, the sciences, engineering, and technology would not be what they are today. The visual representations, the

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7Vygotsky (1978) essentially argued that all higher order psychological functions, including learning, first emerge on a social or interpersonal plane and are then internalized (move to an intra-personal plane). This transition occurs in interaction with others who are at a higher plane than us and through mediation by tools (artifacts, language).

8Ideally, the activities are motivated at a higher socio-historical level, an idea better captured by the participation metaphor of the community of practice perspective (also see Commentary 2 by Roth).
history of the sciences, and the cultural ways of communicating within and about science are but different sides of the same phenomenon. Visual representations also are important in teaching: There is not a day in science teaching at all ages where students would not see the instructor use some visual representation; and there are as many visuals in school textbooks, though the relative frequencies of the different representations used differs between scientific journals and textbooks.

In psychology, the use of visual representations in the sciences (engineering, technology, etc.) tends to be theorized in terms of mental representations (images). That is, no distinction is made between what scientists and science students make available to each other in face-to-face interactions or in written media (journals, books, Web pages, chalkboards, read-outs from instruments) and the unobservable processes of the mind. Thus, although the professor in Figure 1 only can be seen and heard articulating words (“and when you, when you adiabatically dEmagnetize it …”), producing gestures, employing intonation and other speech variations, and moving and orienting his body, psychologists try to study thought patterns that are not directly observable. But the students in the physics course do learn how to use the diagram and how to communicate with it from this lecture; and they do so without knowing psychology.

A very different approach has been proposed in the concept of inscription (Latour, 1987). This term refers to every external representation other than text used in the sciences, including graphs, photographs, micrographs, X-ray images, diagrams, drawings, maps, equations, tables, and so on. Because they are external, cultural-historical forms, they can be studied anthropologically. Rather than concerning themselves with unobservable mental structures, anthropologists do not attribute any special quality to the minds of inscription users but simply follow how inscriptions are gathered, used, transformed, combined, and sent around in the scientific culture and how these inscription-related processes change over different time scales (including historical). It is only when there remains something unexplained that we seek recourse to unobservable cognitive structures. Thus, rather than trying to get into the mind the professor (Figure 1), we study what he makes available to his students, which is precisely what to think and how to think with the diagram he is presenting to them in the lecture. His gestures already prefigure where there will be a horizontal line in the diagram, and they articulate thought as it unfolds and before it is fixed on the board. The gesture is part of cognition and it is from it that the students learn to think about graphs. Research on inscriptions has shown the tremendous social-interactive work that is involved in the use of inscriptions and their organizational (coordinating, mediating, integrating) effects in scientific use, the coordination of people, and in the learning of science.

The anthropological approach is consistent with the work of the Russian developmental psychologist Lev Vygotsky (1997), whose work is widely used in the educational sciences and whose work directs us how to think about cognition and development. Two core issues from his theory about the functioning of mind are important to the study of knowing and learning the use of inscriptions. First, any higher-order cognitive function is the result of social interactions. That is, the students watching and listening to the professor (Figure 1) learn how to use and talk about the graph not by going into his mind or by trying to guess what is going
on inside, but by carefully attending to what the professor makes public in and through his communication. They further learn to use inscriptions while doing assignments, a form of communication with the professor, or by communicating with others over and about inscriptions. Second, Vygotsky suggests that speaking and thinking are two separate but mutually influencing processes that themselves are always developing. Speaking and thinking are combined into a superordinate process that I think of as communication. Thus, the professor in Figure 1 does not engage in a memory dump, an externalization of mental structure, but his speech develops together with his thought, both subordinated to the communicative process. This process also includes all the other communicative modes that we may witness in the lecture, each being a one-sided expression of communication and therefore thought. In this way, we can actually understand how and why this professor incorrectly presented the topic of cooling by adiabatic demagnetization in two consecutive lectures, only to catch his error later, while looking at a series of equations and then correcting himself in a third attempt at presenting the curves in Figure 1.

Participation and Identity

A third element of the situative learning perspective at a more macro level than activities and interactions are the practices they make up. Meaningful participation in practices is a central concept within the situative perspective especially in the work of Lave and Wenger (1991) (Wenger, 1999) on situated learning and legitimate peripheral participation and ideas that preceded those such as cognitive apprenticeship (Brown, Collins & Duguid, 1989). According to this concept, all actions and activities are guided towards a larger goal and learning is about understanding that larger goal and aligning actions with that. We are all embedded in different communities of practice as graduate students, faculty, or as parents, and learning to participate in those communities is central to situated learning. Whatever we need to do to make sense and participate meaningfully is learning. The idea of a community of practice, and legitimate peripheral participation in that community, underscores the highly contextual nature of human learning. Furthermore, as we learn to participate we undergo an identity transformation (Holland, Lachicotte, Skinner, & Cain, 1998; Lave & Wenger, 1991). The identities we develop or reflect play a significant role in our learning trajectory (Eckert, 1989). In Commentary 3, Indigo Esmonde of the University of Toronto discusses issues related to identity in engineering. Rogoff (1990, 1995, 2003) studied children-parent and child-care interactions to examine learning of social skills. Guided participation and communities of learners ideas came from there. This work is also finding support from recent work in neuroscience (Meltzoff, Kuhl, Movellan, & Sejnowski, 2009). Scientists are realizing that social aspects play a critical role although delineating which ones is not an easy task. Vygotsky’s influence is also central to work by cultural psychologists and particularly activity theory.

Commentary 3: Becoming an Engineer: Identity, Equity and Learning, Indigo Esmonde University of Toronto

From a sociocultural perspective, learning is conceptualized as a process of becoming a particular type of person. During the process of learning, people develop what have been called practice-linked identities: “identities that people
come to take on, construct, and embrace that are linked to participation in particular social and cultural practices” (Nasir & Hand, 2008, p. 147). As any individual participates in a variety of practices, they develop several practice-linked identities, and through their participation, they also develop repertoires of practice, ways of engaging in activities that are related to their past forms of participation (Gutierrez & Rogoff, 2003). Prospective and practicing engineers develop repertoires and practice-linked identities associated with multiple contexts of learning, including K-12 or university courses, workplace education contexts, and any daily working contexts in which learning routinely takes place. While these varied identities are not unrelated, each practice-linked identity is integral to the context in which it emerges.

In analyzing opportunities to learn in engineering education, learning contexts should be interrogated to discover the ways in which these contexts allow participants to develop engineering-related identities. This is an equity issue if identity development is supported for some participants, and not others. Key questions include: how does the structure of the (engineering) practice influence access to knowledge about engineering, practices of engineering, and engineering identities? Similarly, how do interpersonal interactions within these spaces influence access to knowledge, practices, and identities?

The structure of the practice is key to understanding whether participants have equitable access to participation. For example, Nasir and Hand (2008) investigated opportunities to learn for students in high school basketball teams and mathematics classes. They argued that the teams offered more opportunities for students to engage in the practice of basketball, more opportunities for self expression, and offered each student the chance to take on an integral role in the team. Professional and educational contexts in which engineering practices are learned can be similarly analyzed. Interpersonal interactions should also be considered. In a given context, one's own identity influences one's opportunities to engage with the practice, but so do the identities of others. In a study of a high school mathematics classroom, I demonstrated that the presence or absence of a student considered ‘expert’ in any cooperative group influences the opportunities to learn for all other group members (Esmonde, 2009).

Although so far I have been describing issues of identity and equity as if they are solely related to the practice, it is critical to consider how people’s pre-existing identities, especially those related to broad social categories such as race, class, gender, and so on, influence the nature of their practice-linked identities (through, for example, influencing opportunities for participation). These social identities may interact with practice-linked identities in overt ways, such as programs designed to encourage women’s participation in science and engineering fields, or more subtle ways. As Gutierrez and Rogoff (2003) point out, “people do not just choose to move in and out of different practices, taking on new and equal participation in cultural communities” (p. 21).

For the field of engineering education, then, the challenge is two-fold. It is imperative to consider how contexts of learning can support the development of positive engineering identities. This cannot be done without considering the repertoires of practice that different social groups bring to these contexts.
The Situative Perspective and Engineering Learning

We believe that the situative perspective offers many useful avenues for research on engineering learning given three distinguishing characteristics of engineering learning: use of representations, alignment with professional practices, and the emphasis on design. The first element of engineering which is central to engineering learning and practice is the use of representations. Like many other practitioners, engineers are surrounded by tools and the purpose of many of these tools is to lead to representations that can help guide the work of engineers. Graphs, charts, visuals, are all examples of representations that engineers use on a regular basis. As a matter of fact, scholars have suggested that engineering can be seen as a discipline that teaches students how to convert one form of representation into another (McCracken & Newstetter, 2001). For instance, many problems that engineering students work on, and that a practitioner faces, are expressed as text that needs to be converted into another symbol system, often visual. A free body diagram is a prime example of such a conversion (also see Roth’s Commentary 2 on inscriptions). Increasingly, the role of producing representations is being played by digital technology leading to an era of production and exchange of representations which is unprecedented in human history. The use of tools is also leading to collaboration among engineers, aided by representations, that is swiftly but decisively reinventing engineering cognition (Pea, 1985) and practice, akin to the change brought about by the first wave of information technology use in manufacturing (Zuboff, 1989) and now being fostered by digital environments and large scale cyberinfrastructure (see Commentary 4 by Madhavan). The role of technological tools, particularly digital tools, is extremely under-theorized in engineering education and a perspective of representational mediation can prove useful to develop a deeper understanding of technology use and design. The potential exists not only for changing how we teach and learn, but our research practices themselves.

Commentary 4: The Role of Cyberinfrastructure in Engineering Education, Krishna P.C. Madhavan, Purdue University

The growth of the Internet as the fabric for exchanging information ranging from commercial services to scientific insights has fundamentally changed our daily lives. High-speed networks enable connecting together tools for data collection, data aggregation, scientific analyses, and visualization. More importantly, these technologies, also known as cyberinfrastructure, are powerful at connecting people in unprecedented ways leading to community formation. Large-scale engineering cyber-environments such as nanoHUB.org, the George E. Brown Jr. Network for Earthquake Engineering, the Earth System Grid, and the Cancer Biomedical Informatics Grid are effectively blurring the line between engineering practice, research, and learning.

Cyberinfrastructure serves two roles in the context of engineering education. In its more well-known role, cyberinfrastructure serves to deliver cutting-edge content to a large community of learners. In this role, cyberinfrastructure enables cyberlearning defined as “learning that is mediated by networked computing and communications technology” (NSFTFC, 2008). In its second role, cyberinfrastructure plays the role of enabling fundamental research within the field of engineering education.

In its first role, cyberinfrastructure facilitates the delivery of information in novel forms. Many learning environments routinely incorporate online lectures,
interactive animations, podcasts, and game-based paradigms to name a few flavors of cyberinfrastructure use. Even environments such as YouTube™ and iTunes™ may be viewed as cyberlearning platforms. If theory, experimentation, and modeling & simulations mark three primary pillars of engineering, cyberinfrastructure can play a critical role in enabling students to understand the variety of approaches available through each. For example, projects such as the iLab Network allow students real-time access to remote instruments through a cyber-environment. iLab allows students to perform experiments, build on existing knowledge, predict results, and explore. Similarly, cyber-environments such as nanoHUB, provide learners with access to highly sophisticated computational resources transparently. This allows students to explore and model new problem spaces that were not previously possible. While a non-trivial technical endeavor, one very viable approach that is currently being explored is to link such remote instruments with modeling and simulation environments thus enabling students to understand the interconnected nature of engineering problem solving.

The National Academy of Engineering (NAE) identified the grand challenge of “advancing personalized learning” (NAE, 2008). Cyber-environments, by their innate ability to be instrumented fully, provide us with an opportunity to personalize learning environments. For example, nanoHUB is beginning to explore the notion of user flow informatics, which attempts to understand patterns of tool and resource usage within the HUB environment. Software available within the cyber-environment acts as a sensor in identifying the preferences and bottlenecks faced by each learner. This deep insight, when fed back into the cyber-environment, allows educators to receive real-time insights into student performance and provides appropriate learning pathways. Indeed, they help in understanding the efficacy of the learning material also. In combination with currently available research on intelligent tutors and growing knowledge of how people learn, cyber-environments have real promise for delivering on the dream of personalized learning.

The second role of cyberinfrastructure in acting as a platform for facilitating research is a more challenging issue. The National Science Foundation (NSF) Atkins Report (Atkins, 2003) outlines the need for a cyberinfrastructure. In the field of engineering education research both within and outside the U.S., cyberinfrastructure is just beginning to gain traction as a platform for facilitating research.

The emergence of engineering education as a problem space of rigorous research puts into sharp relief the need for educational researchers to utilize tools that other engineering disciplines use on a day-to-day basis. Knowledge production in the field of engineering education is vibrant, highly distributed, and fragmented. It has every characteristic of a complex virtual community. Much progress needs to be made in fully leveraging cyberinfrastructure to accelerate the transition of data to knowledge in engineering education, and many efforts that are currently underway. For example, research leveraging large-scale data in combination with well established visual analytic methods in the field of social network analysis is beginning to provide new insights into the state of knowledge within engineering education research (Madhavan et al., 2010). While this application shows the power of cyberinfrastructure in studying the emergence of engineering education.
research, it is just one of the many facets of cyberinfrastructure use in research. The holy grail of cyberinfrastructure use continues to be the development of environments that transparently transition between engineering practice, research, and education.

A second critical aspect of engineering and engineering learning is its close association with professional practice. A majority of engineers pursue the profession to be able to work as engineers. Therefore, an inherently large aspect of their training is learning to become a part of the community of practice of professional engineers. This includes developing an identity as an engineer in numerous ways and forms. Professional practice is also collaborative in nature and therefore learning to work as part of groups and teams is essential to engineering learning. Of course, work settings have played a crucial role in informing early work in the field (Scribner, 1997a, 1997b; Wenger, 1998) and this is one aspect of engineering learning which we believe has been studied extensively by scholars in aligned disciplines such as technical communication (Winsor, 1996), science education (Lemke, 1997), technology studies (Bucciarelli, 1994), architecture (Schon, 1983), engineering studies (John, 2010a), and also learning scientists (Hall & Stevens, 1995; Stevens, 2000). Yet, the disjuncture between school-engineering and work-engineering remains intact and significant efforts are needed to bridge this gap. Engineers in the workplace often say that even technical skills are easier to learn on the job as compared to formal training. They often complain that very little of what they learn in school is of any use to them. There is an issue of situated learning and transfer. Recent work has started to capture this tension (Stevens, O’Connor, Garrison, Jocuns, & Amos, 2008). There has to be effort that links research with practice on an ongoing basis as the environment for work and learning changes rapidly.

A final element of engineering learning that is unique compared to mathematics and science learning is design. Engineers are by definition designers. Engineering design thinking and learning are central to the development of an engineer (Dym, Agogino, Eris, Frey & Leifer, 2005). Yet, design has its own unique ways of developing cognitive and situated skill requirements. It requires skills with materials, ability to work collaboratively, and the ability to become part of a community of practice. Models of teaching design therefore differ from teaching engineering science-based content to students. Design is also a useful metaphor to think about engineering learning research that can lead to innovations. Design-based research (a descendent of work on design experiments) is a useful paradigm that can be adopted by engineering learning researchers. It also highlights that ideas from core engineering disciplines can be used to improve engineering learning if applied with the right understanding of context. Iris Tabak of Ben Gurion University of the Negev discusses design research in Commentary 5.

Commentary 5: Design-based Research Methods and Engineering Education, Iris Tabak, Ben Gurion University of the Negev

Engineering education faces unprecedented challenges. Engineering educators are called upon to help learners develop analytic, communication, and

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9See Lemke (1997) for more comprehensive discussion of the disjuncture between school practices and professional practices and the effort that must be made to integrate students’ school and professional trajectories. The discussion is highly applicable to engineering learning given the professional and applied nature of our practices.
teamwork skills, while meeting ever increasing content demands and cultivating independent learners. Although innovative teaching methods with documented success exist, there is still much that we do not know about how to achieve these goals. Thus, it is necessary to simultaneously develop novel approaches to learning and instruction, examine how they can be adopted, and ascertain whether and how they are achieving their intended aims (Streveler & Smith, 2006). Design-based research methods (DBRM) offer a productive means to accomplish this.

Roughly, design-based research methods are an iterative cycle of design, enactment, and empirical study of an innovation in a naturalistic setting (Design Based Research Collective, 2003). DBRM are especially useful when there is dissatisfaction with extant circumstances, but desirable alternatives exist only as a vision. Thus, it is necessary to design an innovation as a tangible first approximation of this vision.

DBRM incorporates pedagogical and curricular design knowledge, as well as cognitive and sociocultural learning theories in the design of this innovation. The design attends to varied aspects: activities, curricular sequences, teacher guidance, classroom social organization, and cohesion with local practices. This broad conceptualization of learning environments is key to successful implementation in non-research settings. This design is then enacted in actual classrooms.

Once the design is enacted, concrete tangibility replaces ethereal ideation and the approach can now be scrutinized. DBRM draws on both quantitative and qualitative measures to identify whether and how learning occurs. Emphasis is placed on deriving process models that describe how different facets of the design contribute to microlongitudinal changes in knowledge and practice of both learners and teachers. For example, pre/post tests might be used to measure changes in conceptual understanding, and open-ended observations might be used to document how a particular conception is articulated in successively better ways through interactions between peers, materials, and teachers.

Designs that operate in real-world settings are complex, multifaceted, and interact with existing contextual factors. In some cases, making a design work in a particular setting necessitates changes to the design. This is why DBRM involves an iterative process within as well as between enactments. Empirical study enables designers to understand the strengths and weaknesses of their original designs, and to incorporate efficacious elements that emerged through an enactment as purposeful elements of subsequent redesign (Tabak, 2004). As the design is refined and evidence in support of the design accrues, an effort is made to articulate the design at both a principled and a concrete level in order to assist in dissemination. The empirical aspect of DBRM also produces new insights on the nature of learning particular topics and skills.

Design-based research methods can offer a way for engineering educators to achieve the fields’ ambitious goals in an evidence-based way that advances both theory and practice (e.g., Carstensen & Bernhard, 2007). DBRM, like all methods, needs to develop and change. In particular, future endeavors should consider how to better integrate large-scale quantitative measures with process measures, and how to obtain process data in a more cost-effective way.
Corresponding to the three characteristics of engineering we have outlined, we believe that the three elements of situated learning we have identified can make a significant contribution to furthering our understanding of engineering learning in unique ways, similar to its role in biomedical engineering education (Harris, Bransford, & Brophy, 2002). These connections have already started to manifest themselves in recent articles in engineering education publications. For instance, Paretti (2009) uses the situated learning approach, in conjunction with activity theory, to examine communication practices in a capstone design class. Pierrakos, Beam, Constantz, Johri, & Anderson (2009) use emerging literature on situated identities to investigate the different pathways and experiences of students who persist with engineering versus those who switch out of engineering. Similar examination of identity has also been done by Stevens et al. (2008). Gill, Sharp, Mills, and Franzway (2008) build on anthropological investigations of the workplace and the communities of practice literature to draw attention to gender issues in professional engineering settings. They find that the positive self image women had in school was not maintained in the workplace given a lack of women role models in immediately higher up positions in the office hierarchy. In an upcoming article Johri (in press) introduces the concept of “sociomaterial bricolage” to capture the essence of engineering work practices on global teams. Software engineers in his study make do with whatever resources are available to them to develop work practices that span geographic dispersion, this ability to “make do,” he argues, is the essence of most engineering work. In relation to digital technology, Johri and Lohani (2008) draw on guided participation and communities of practice frameworks to examine the role of representations in large engineering classes. They argue that a content-transfer model of technology use undercuts the benefits that are available with digital technology, particularly pen-based technology, to engage students in mutual construction of engineering representations. These studies illustrate welcome progress but we believe that enormous potential still exists to make significant theoretical contributions (Johri, 2010) and with that aim in mind we have outlined some potential research ideas in Table 2.

**CONVERGENCE AND GROWTH: A SCIENCE OF ENGINEERING LEARNING AND BEYOND**

As we suggest earlier, there is significant potential for engineering learning research to build on research on learning undertaken by the learning science community. We show how one theoretical idea, situativity, can shape research on engineering learning. As the field of engineering education research has matured, more alliances are being forged between that community and the community of the learning sciences, which, as discussed above, has traditionally focused more on K-12 issues. This is evidenced in a number of ways including the inclusion of learning scientists on the faculty of engineering education programs at both Virginia Tech and Purdue; the acceptance of a workshop on engineering education and the learning sciences for the summer 2010 meeting of the International Society for the Learning Sciences; and increasing collaborations between engineering researchers and learning scientists. We believe that knowledge does not have to flow in just one direction and that the fields can benefit each other mutually. For engineering learning scholars, one of the measures of success in the future will be the ways in which they shape other fields and disciplines such as learning sciences (Shulman, 2005). There is significant development, for instance, on cyberlearning in engineering education which has the potential...
This article focuses primarily on the situative perspective on learning as we believe that in the short and medium terms, it offers the best body of knowledge and alignment with engineering education to build a science of engineering learning. Yet, we recognize that it is only one perspective and many other viable options exist. For instance, recent scholarship suggests that future educational research and practice is likely to be shaped significantly by recent developments in brain sciences and neuroscience (Bransford et al; 2006; also see Commentary 6 by Schwartz and Tsang). Interestingly, initial work in the area demonstrates what has been the prevalent idea in situative theory that, "human children readily learn through social interactions with other people" (Meltzoff et al., 2009, p. 285). The social basis for cognition once again points out the tough road ahead in reconciling the social and the individual in learning. Furthermore, as Commentary 6 shows, for any new

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field that draws on significantly new instruments and methods there is a large gap that needs to be overcome between deterministic adoption of a method and its often situated and long term effect on actual scientific practices. The approach taken by Bransford et al. (2006), and the Learning in Formal and Information Environments (LIFE) Science of Learning Center, is one way of overcoming this gap (also see their chapter in the Cambridge Handbook of the Learning Sciences). The scholars engaged with that center argue that the next decade of learning sciences will see a convergence between informal learning, formal learning, and implicit learning and the brain. This synergistic integration will follow the major changes that learning research has undergone from drawing on findings from studies conducted only in the laboratory to studies conducted in complex setting such as a classroom (p. 210).

Commentary 6: How Could Neuroscience Have Practical Applications for Engineering Education?, Dan Schwartz and Jessica Tsang, Stanford University

Cognitive neuroscience is a small branch of neuroscience that examines the relations between intelligent behavior and brain functioning. Educators often wonder if cognitive neuroscience will provide practical benefits for improving instruction. We briefly review three possibilities: direct instructional applications, clinical treatments, and theoretical re-orientations.

There is substantial interest in direct translations of neuroscience to the classroom, or brain-based education. Succeeding will require better bridges between the basic science of brain research and the applied aims of educational research. Physics and engineering have had centuries to build their bridges. In neuroscience, a study might demonstrate a brain region is necessary for mathematics by disrupting its function and noting a decrement in numerical processing. Educators, however, would be more interested in whether strengthening this region improves numerical processing. Another brain study might inch closer to educational goals by showing that basic rewards stimulate plasticity in the target region. However, educators would ask whether rewards negatively impact students' interest in mathematics, for example, by undermining their intrinsic motivation. We need to build win-win collaborations where the search for necessary mechanisms and the design of sufficient conditions for learning can complement one another.

In the context of clinical populations, excitement over practical applications has a stronger basis, where the need to improve a specific dysfunction legitimates unusual treatments. Working with clinical populations is a strong suit for neuroscience, understanding a dysfunction advances the science while successful remediation provides important causal evidence. Although tangential to most engineering students, clinical approaches will be important for helping younger students who might otherwise never make it to an engineering program. For example, by measuring electrical brain activity, one can identify infants at risk for dyslexia before language has developed. Thus, remediation can start before the child has already started to fall behind. (See Gabrieli (2009) for a synthesis of the literature.)

Most immediately, we believe neuroscience can spark theoretical re-orientations. There is nothing as practical as a good theory. We are not recommending that engineering educators study neurotransmitters to become better teachers. Rather, neuroscience provides broad models and generative analogies that
can influence how people think about learning. One example is the finding that there are brain networks involved in any school task. For example, we have discovered that determining the midpoint between -3 and 3, for example, activates a different network from deciding which digit is greater. Networks displace the common folk model that learning is like strengthening a muscle, and assessment is a test of mental strength. Intellectual growth is more like learning to dance, and a goal of instruction is to help students coordinate the different evolutionary functions of the brain into a new culturally mediated dance. The simple switch from learning-as-strengthening to learning-as-coordinating has generative possibilities for the design of instruction, and is an example of the broad theoretical shifts that neuroscience will precipitate in the behavioral sciences.

To accelerate educationally relevant theoretical contributions, we have two recommendations. (1) In addition to examining the biological basis of individual brain differences, research should focus on how context and experience affect brain function and behavior. This is the piece of learning that educators can influence, and such a shift in focus would welcome social and cultural theories that emphasize contextual factors. (2) Research should choose problems relevant to enduring questions in education, for example, “What is the value of hands-on activities?” or “What are the unique consequences of discovery versus being told?”

Neuroscience will influence education through theory, remediation for clinical cases, and eventually, practical applications for everyday students. The most high-impact work will develop when researchers from different traditions distance themselves from their “routine expertise” to create a new but shared set of goals.

CONCLUSION

The age that we live in has variously been characterized as the information age, the knowledge economy, the network society, and/or the global era. Irrespective of the nomenclature, the core idea that remains constant is that we live in a rapidly changing environment where our ability to learn fast and reinvent ourselves is key for survival and growth (Bransford, 2007). Furthermore, complexity of human social and engineered life has never been higher. This significantly affects our ability to make sense of the world around us and to act intelligently. This change is reflected in the professional life of engineers where they have to work with novel technologies, with a diversity of people around the world, as part of highly interdisciplinary teams, and on projects that are complex both in scale and expertise. What engineers need is adaptive expertise which allows them to be both innovative and efficient at what they do. From an educator’s viewpoint, this is the world we inherit and need to prepare our students to enter. Therefore, it is imperative that we reflect on the skill development we need to facilitate and design implementable learning environments for our students. This forms the core agenda for the emerging discipline of engineering education (Haghigi, 2005).

In this paper, we have laid out a broad theoretical agenda to serve as a toolkit for understanding and designing learning. Throughout the paper we have introduced several
scholars and their ideas with the intention to spark an interest in readers so that they will be motivated to learn more. We hope that readers will engage more with the ideas of situative learning, lifelong learning, informal learning, and personalized learning (one of the key challenges identified in NAE’s grand challenges for engineering). Almost three decades ago Becker (1972) argued, somewhat controversially, that a school is a lousy place to learn anything and we need to rethink and retool our conception and implementation of schools. We now have the tools and technology and need to engage a broad audience to bring about an innovation in how we organize our resources to make engineering learning and education available to a larger number of students and help them to engage in it successfully. Lemke (1997) captures the problem faced by engineering education scholars quite aptly when he states that: “Schools are communities of practice that do not preach what they practice. They teach about practices of other communities, for example, about the practices of science and mathematics, but say very little about the practices of schooling” (Lemke, 1997; p. 52-53). It is time we made an effort to investigate our practices closely with the aim to innovate.

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**AUTHORS**

Aditya Johri is assistant professor of Engineering Education and director of toolsLAB (Technology, Open Organizing, and Learning Sciences laboratory) at Virginia Tech, Blacksburg, VA 24061; ajohri@vt.edu.

Barbara M. Olds is senior advisor to the Directorate for Education and Human Resources (EHR) of the U. S. National Science Foundation, 4201 Wilson Blvd., Arlington, VA 22230; bolds@nsf.gov.