

# Laboratory Learning: Industry and University Research as Site for Situated and Distributed Cognition

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**Abstract:** In this symposium we present findings from qualitative studies of both university and industrial research laboratories, and their partnerships, to illuminate how learning takes place in these settings. Research laboratories are unique in providing a window on learning of content as well as learning to participate. Both kinds of learning are central to the functioning of the laboratory as an organization and to the growth of individual researchers within the laboratory. We highlight common themes across the different settings and showcase some of the differences that lead to different outcomes. We discuss institutional level as well as micro-interactional level issues related to learning. The three studies that make up this session examine biomedical engineering, interactive media research, and applied computer science.

## Introduction

For some decades, research laboratories have been sites for ethnographic studies of science and engineering practices (e.g. Bucciarelli 1994, Latour & Woolgar, 1986, Lynch, 1985) and for studies of the organization of work (Owen-Smith, 2001). Within the field of learning sciences, research laboratories have often served as sites for observational (Dunbar 1995) and ethnographic studies of cognition (See e.g., Hall, Wright & Wieckert, 2007; Ochs & Jacoby 1997). In this symposium, we build on this prior work by arguing that much can be gained from studies of such highly situated and advanced learning communities charged with discovery and knowledge development on the frontiers of science. We contend that studying learning situated in research labs makes good sense for several reasons. First, as sites for learning, laboratories often combine formal/informal, tacit/explicit, and other such dualities of learning into practice (Barab et al, 2003). Further, efforts in the K-12 arena to move from cookbook to inquiry-driven science, to bring greater parity between science as practiced by scientists and science as “practiced” by students could benefit from and perhaps made richer by findings on learning in these labs. But perhaps most importantly, research laboratories serve as the training grounds for the majority of STEM practitioners because such labs are where science and engineering graduate students conduct their Ph.D. research. These labs are also where science and engineering identity trajectories at the undergraduate level are often strengthened and career paths that include graduate school become a vision. Findings from numerous post-hoc survey studies of undergraduate research experiences attest to the positive impacts of working in a lab (Kremmer & Bringle, 1990; Morely, Havick, & May, 1998 July; Ryder, Leach, & Driver, 1999; Seymour, Hunter, Laursen, & Deantoni, 2004; Zydney, Bennett, Shahid, & Bauer, 2002), particularly for women and minorities (Conefrey, 2000; May, 1997; Morely et al., 1998 July). These findings have undoubtedly influenced the U.S. National Science Foundation’s push to create more opportunities for post-secondary students to participate in and be mentored through the Research Experience for Undergraduate (REU) program. However, apart from studies (e.g. Hall, Stevens & Torralba, 2002) there has been very little investigation of what actually happens in these labs from a learning perspective that could account for these positive effects. Thus, it is critically important to identify features of laboratory settings that are conducive to documented positive learning experiences and think seriously about how those features could be translated into designs for instructional settings. Moreover, with increased university-industry partnership, the relationship between university research labs and innovative work in the industry also needs to be examined. This symposium aims to bring important findings on lab-based learning to light for those purposes. The three studies presented here look at university research, research in the industry, and university-industry partnership.

## Learning in and through Situated Activity

Recent work in the field of learning sciences emphasizes the importance of learning in activity (Greeno, 2006). According to this perspective, students learn as they engage in meaningful activities where they are involved not only in the learning of content but in meaning-making activities that require them to put their content learning into perspective, gain conceptual understanding, and to become part of a community. This framework follows in the tradition of socio-cultural theories of learning (Rogoff, 2003; Vygotsky, 1978), the situated learning perspective (Lave & Wenger, 1990), and work in cognitive science that emphasizes that students come with preconceived notions, schemas, of the world around them and teaching and learning start from understanding their perspective (NRC, 2000). Learning theory relevant to research-based learning defines the students as active learners who are motivated by a desire for mastery (NRC, 2000). The theoretical

framework of the learner/researcher is based on the constructivist learning theory (Vygotsky, 1978) and pedagogies, including communities of practice (Wenger, 1998), in which the learners as “newcomers” are engaged into the practice of the “research” community under the direction and support from the faculty as the “old-timers” (Lave & Wenger, 1990). In addition, studies show that engaging students with authentic practices, in our case laboratory sites, is critical if they are to adopt an identity of a researcher (Edelson & Reiser, 2006; NRC, 2000). In this apprentice-style learning and teaching model, the learner/researcher works collaboratively with faculty, graduate students, and employers by relying on the mentors’ expertise and resources to cultivate initiative and take primary responsibility for the project (Collins, 2006). Furthermore, engaging such learners with authentic practices is critical for them to engage with different facets of being a researcher. As Mills (1959) remarked, “Only by conversations in which experienced thinkers exchange information about their actual ways of working can a useful sense of method and theory be imparted to the beginning student (p. 195).”

### Organizational and Institutional Aspects of Learning

From the standpoint of how learning is organized, ethnographic studies of labs can be an invaluable resource. Studies of research laboratories in organization theory are not new and since Tom Allen’s classic study of communication patterns within research laboratories, especially in regards to the role of proximity, several scholars have studied research labs. Industrial research laboratories have gotten their fair share of attention and PARC and Bell Labs have provided many case studies of failed and/or successful innovations. Owen-Smith calls lab ethnographies “the shop floor studies of the knowledge economy” since they shed light on the practices and organization of producing and developing knowledge and innovation, the primary concerns of the new economy. Theories from learning sciences, especially distributed cognition, emphasizes that the organization of an activity – the artifacts, the actors – is crucial for any system to work as a cognitive system. But other than a few field studies such as those of a navigation system on the ship or airline cockpits, we have few field studies that examine how a system at the scale of an organization is designed or assembled. The lack of studies that investigate the institutional aspects of learning systems has been highlighted by Jones et al. They argue that, “On its own, the availability for analysis of interaction related to other levels is not enough...you need a theoretical approach that explicitly takes the meso level into account, not just in terms of explanations but also to direct attention to those features of a setting that may remain invisible while attention is focused on macro or micro-level analysis (p. 40).” Therefore, studying a research laboratory comprehensively allows us to understand not just the interactions at the bench-top or in a conference room, but also how they relate to other aspects of the laboratory. This is critical if we are to examine the complexities of learning. Ethnographies of research settings are also related to the idea of a community of practice (Lave & Wenger, 1990; Wenger 1998). A research laboratory brings to light several the aspects of a community of practice due to its organization. There are peripheral and full members, many practices emerge within the lab, and there is an abundant use of artifacts in those practices. Yet, a community of practice account leaves many questions answered especially around the dynamics of organizing -- how do communities change over time, what affects do newcomers have on a community? In particular, one aspect that has been associated with CoPs but not really investigated in detail is the idea of “boundary crossing.” In current research laboratories several different kinds of boundaries can be characterized. Given the increase in interdisciplinary work, one critical boundary is that of disciplines. In addition, given the increased movement of research around the world research labs now have people with very different national and cultural backgrounds. What role does this diversity play and how do people work across their differences? Researchers, in addition to their research lab, often have relationships that span other institutions and research communities. What role do such networks play? At the institutional level the embeddedness of the CoP or the organization within a particular setting also shapes the learning – how people learn and what they need to learn in order to be innovative. So studying a larger system provides a better understanding of the relationships among different aspects. It also opens up the question of how do organizations learn and what does it mean for an organization to learn and the members of that organization to learn? Do more intelligent collectives shape individual learning and vice-versa?

### **Ethnographic Studies of Research & Innovation**

Here we report on investigations of learners and learning in industry and university-based laboratories and university-industry partnerships. Early ethnographic data revealed how learning trajectories intersected with the developmental trajectories of the diverse technological artifacts, problems, and the various social systems within the lab, and that learners and technology have evolving, relational trajectories. To capture these trajectories both cognitive-historical analyses of the problems, technology, models, and researchers and ethnographic analysis of the practices *in situ* were utilized. Ethnographic data collection techniques included participant observation and the generation of field notes during lab activity, meetings, and journal clubs, formal and informal interviewing of lab participants at all levels from the PI to the new undergraduate student, and artifact/document collection. These ethnographic activities were coupled with cognitive-historical analysis centering around the simulation devices developed in the labs. For this part of the analysis the customary range

of historical records (including grant proposals, drafts and published papers, artifacts, emails) were collected to recover how the salient representational, methodological, and reasoning practices had been developed and used by the researchers.

We frame the findings presented in the symposium in terms of a central issue that became salient to understanding the enactment of learning in these labs, that is, the necessity of forming relationships with other entities, both human and otherwise, within the lab and beyond the boundaries of the lab. We focus on the social dimension of these relationships as well as the cognitive dimension foregrounding how various processes of distributing cognition create a complex but supportive environment for both learning and teaching. In the first two studies we start with a proposal for a certain kind of relationship achieved at the end of laboratory learning trajectories that we refer to as “cognitive partnering” move on to impression formation as mediating the potential for laboratory learning, and end with the role and importance of building in the formation of relationships.

## **STUDY 1: BIOMEDICAL ENGINEERING IN THE UNIVERSITY**

The first study covered a span of six years during which a mixed methods approach to data collection and analysis were utilized to illuminate the cognitive and learning practices found in a Lab A, a vascular tissue engineering laboratory and Lab D, a neuroengineering laboratory. The former seeks to develop cardiovascular bio-substitutes, ultimately built from the cell up and readily available to patients suffering from heart disease. The major barriers being addressed in the lab are 1) developing strategies for endothelial cell sources and 2) developing certain mechanical properties in the bio-substitutes that can withstand the mechanical forces found the body. The intermediate problems that drive the research in this lab are producing “constructs” - living tissue that mimics properties of natural vessels - examining and enhancing their mechanical properties, and creating endothelial cell sources through mechanical manipulation of stem cells. In turn, Lab D studies dissociated cultures of 30 - 40 thousand mouse neurons by growing cell cultures on multi-electrode array (MEA) culture dishes, stimulating them with electrical impulses, and applying optical time-lapse microscopy and high-speed imaging to learn about distributed activity patterns and information processing in these cultured networks. Lab D often gives the cultured cells a “body”, either simulated or robotic and an environment in which to behave.

### **Building as Entree**

In the bioengineering laboratories, a very commonly taken up newcomer/learner activity is building which tends to drive research in both labs. Building affords immediate opportunities for rapid participation and the build-up of requisite knowledge. It can involve “wet” materials such as cells and collagen sleeves, *in silico* materials such as software or construction materials like wood frames and duct tape. It can involve the design and development of complex *in vitro* environments such as bioreactors where cells are conditioned or flow chambers where blood vessel forces are replicated for experimental purposes. Or it can involve the design of makeshift Home Depot supplied enclosures in which cell cultures are nurtured and protected. Building can take a long time and require very sophisticated skills and knowledge as in Lab D where a specially designed two-photon microscope was under construction for two years. Or it can be a short-term solution to controlling CO<sub>2</sub> in a cell culture chamber. With all this building going on as part of the investigative knowledge-making practices of the labs, learner/agents most often establish first footholds and a sense of place as builders. Designing and assembling different kinds of enclosures in Lab D and devices in Lab A is a kind of building knowledge that often falls to newcomers. A second semester freshman described how he designed and built a much-needed enclosure for a microscope and his account tells us several things about the social and work configurations in the lab and how they are constitutive of rich learning opportunities. The first notable feature is the democratic nature of work assignments. The lab needed an enclosure and the undergraduate who asked questions and expressed interest became the lead designer. This self-initiated move allowed the student to find a niche or foothold in the community---a place from where he could make a much-needed contribution. No one questioned whether he was qualified or had the required skills. Instead, they let him take over and then assisted him when he asked for help. This project offered a rich learning context in which the student could explore alone or with the assistance of a more knowledgeable lab member. As an agent in determining the contributions he would make, he claimed a context for his own learning about the “dish” or culture of neurons and what it takes to keep them alive, the materials and heating units, the physical structure itself. What is significant in this account of self-identified learning opportunities is that the nature of the problems under investigation in these interdisciplinary labs affords multiple opportunities for increasing legitimate peripheral participation (Lave & Wenger, 1991). Building affords an immediate and easy opportunity for membership in and contribution to the lab setting, which serves as first steps towards full membership. At the same time, the numerous jobs to be tackled or sub-problems to be addressed allows for students to become free agents of their learning, much more so than in a traditional apprenticeship situation where practices are relatively static and entry points much more prescribed. The wide open knowledge frontier and relatively flat hierarchy make for hospitable first beginnings for new lab members, even undergraduate students.

## Cognitive Partnering

In trying to understand the role of environment and learning, we follow up on Lave and Wenger's proposal for a "*decentering* of common notions of mastery and pedagogy" (Lave & Wenger, 1991) p. 94). Decentering for us means searching for mastery in varied forms and pedagogy as enacted through participation in situated activities and interactions. The particular argument we advance here is that participation as the vehicle for learning extends to interactions not just with people, but just as importantly, with *artifacts*. This argument relates to Lave and Wenger's notion of both, "absorbing and being absorbed in—the culture of practice" (p.95). We have observed that artifacts are critical to this process of being absorbed into the practices. It is our contention that research laboratories as instances of innovation communities are not well understood unless we consider learning as relational with respect to people and community as discussed in previous sections, *and* artifacts. We further contend that our understanding of such communities can extend the current notion of distributed cognitive systems as it relates to learning (Hutchins, 1996). We find that artifacts as part of the cognitive system in such communities afford evolving "*cognitive partnerships*." We use the notion of cognitive partnering to capture our observations that researchers come to understand the technology they design and construct as collaborators in research (Osbeck & Nersessian 2006). The design and construction of technology for simulation and experiment help the researchers define their questions and deepen their knowledge. When scientists use the technology, for instance to manipulate cells, what is important is not the final assay, which can be examined to test their original hypothesis. Rather, learning and knowledge innovation occur during the entire process of building and designing the technology. The model-systems such as construct, flow loop, or dish are not systems separated from the user but by their available inputs and outputs, but rather more like partners in that they support and promote creativity. One researcher aptly noted that their research involves "putting a thought into the benchtop to see if it works." From a distributed cognition standpoint, as an instantiated thought, a model-system is an embodied mental model – a tangible artifact with a meaning that evolves alongside the researchers' understanding. It thus serves as an important site of simulation – not just of some biological or mechanical process, but also of the researchers' knowledge.

Such partnerships are singular kinds of relationships formed with certain artifacts that are salient to the lab research agenda. These relationships are interesting in that they are both negotiable and changing through repeated and varied interactions manifesting in contrasting notions of representation and agency. Over time, learner understandings of lab artifacts are constructed, revised, enhanced and transformed by learning *through* and *with* those artifacts present in the community. Moreover, we have discerned developmental patterns enacted as changed understandings and uses of the artifacts both materially and cognitively. These dynamic relationships are critical to knowledge acquisition and deepening forms of participation. And of central importance to these cognitive relationships is their evolving nature (Nersessian et al., 2002). To get a better sense of these dynamic and developmental relationships, we offer in the symposium an extended example that starts with cells and then moves onto a lab designed device in which cells are embedded. This example derives from a yearlong series of interviews with A22, a newcomer to the tissue-engineering lab, who had worked as a mechanical engineer in the auto industry. She starts as a MA student but eventually switches to a PhD in bioengineering.

## **STUDY 2: INTERACTIVE MEDIA RESEARCH IN THE INDUSTRY**

The second study focused on an industrial R&D lab, TechLab, with offices in the U.S. and Asia, which does work in computer software and hardware related areas. TechLab has offices in two geographical locations. One office is located in a western state in the U.S. (TechLab U.S. or TLU) and covers the entire second floor of a building. The other office is located in Asia (TechLab Asia or TLA) and covers several floors of a large building. There are around 25 researchers at TLU and 70 researchers in TLA. In addition to the researchers, who were the primary informants, the U.S. lab also has technical support staff, visiting researchers, administrative staff, and interns. This research was conducted as a qualitative field study for a period of 5 months in which data collection methods included participant observation of the laboratory settings, interviews with researchers and managers, collection of archival materials available at the organization, and short surveys, primarily at the U.S. site.

## Learning as Mediated by Impression Formation and Interpersonal Relations

TechLab study focuses on how participants in a community of practice (CoP) form impressions of each other (Fiske, Lin, & Neuberg, 1999; Fiske & Neuberg, 1990) and how these impressions impact learning and knowledge sharing. One of the primary concerns we have is how to focus the analysis so that we are able to make a cogent case. Theoretically, we use the concept of "frames" (Goffman, 1974) to examine how impressions form and the role of practice in this process. Frames "organize experience" and are the basis for our interpretations of the lived world. In a sense our impressions of other people are interpretations that are socially constructed. The framework we have come up with to explain this process is this: Any organization or community of practice has several "practices" that are part of that community. These practices, we argue, are

interpretations that are commonly shared by members of the community. Practices in an organization consist of numerous interactions and practices frame how we interpret these interactions through what we are calling “practice frames.” Furthermore, what takes place within an interaction is an interpretation too, whether shared by people or not, and the frame participants employ for that interpretation is an “interactive frame.” So, participants’ impressions of others, who are part of an interaction, depend on how they interpret the practices and interactions since their understanding of what is going on is through a lens of practices and interaction.

Learning has been shown to be based on practice and one of core constituents of practice are other participants. Interpersonal relationships are known to form a critical component of learning (Vygotsky, 1978) but we still do not know about relationships in the world of work. To function effectively researchers in TechLab had to be supported in various ways. They needed new hardware and software; they needed assistance with traveling arrangements they needed help with finances and other matters considered to be “human resources” function such as health insurance and retirement. Therefore, surrounding the core CoP of the researchers were other communities. Overall these communities could be said to form a network of communities within which the individual members were networked through their relationships. People occupied positions in different overlapping communities although they identified primarily with one community. These positions represented their normative assignment with the organization but often went beyond that. For instance, a research “manager” not only managed one research group but formed ties with administration and often played a critical role as a knowledge broker between administration and researchers. Furthermore, practices of one community, for instance “brainstorming” by researchers, often overlapped with practices in other communities, such as the function and meetings of technical support staff. To brainstorm they often needed artifacts that were made available by the technical support staff. Furthermore, learning often took place across the CoP through the ties that stretched across two or more communities. For instance, the technical support and visual designers knew more about particular technologies – software and hardware – than the researchers and brought that to the table. The contractors and interns were often more experienced with certain topics and methodologies than the researchers. Looking at this dynamically, the newcomers to the organization, especially fulltime researchers, often brought expertise that was then shared with a particular group. Newcomers were often hired to bring in knowledge that was not there but for it to materialize and become embedded in the organization it needs to be shared and therefore making ties became critical. Overall, being an organizational membership involved participation in more than one overlapping community and members were “networked individuals (Castells, 1996; Wellman, 2002).” They were embedded in communities were themselves embedded in a large constellations of communities. Therefore, ties and networks that bridged different communities were critical for sharing knowledge across communities for learning. Work on distributed cognition and distributed intelligence has looked at the role played by artifacts that a person is surrounded but the role of other participants also needs in-depth examination. How do relationships form and how are they shaped? What role do they play in how and what people learn? More importantly, with more and more emphasis on collaborative learning it is critical to understand the role relationships might play in how people collaborate. Relationships can be investigated at different levels of analysis dyadic, group or team. All thinking and existence is relational as Cooley, and then Mead, tell us. Our development of symbols is a relational process and how we think of the other shapes who we think we are; who we are and how we act. If the self does not exist other than in relation to the ‘other’ then as educationalists we need to pay more attention to the ‘other.’

### **STUDY 3: APPLIED COMPUTER SCIENCE AS UNIVERSITY-INDUSTRY PARTNERSHIP**

The last study looks beyond research and industry and at their partnership (Fischer, Rohde, & Wulf 2007; Rohde et al. 2005). Beyond research is the next step, that of innovation and the critical issue here is – how do we prepare student to be innovative? We start with the observation that although engineering universities have a strong record in knowledge sharing with industries, ranging from cooperative research projects to student internship linked with the engineering curricula, computer science lab courses are not organized according to the model of engineering curricula but natural science curricula. This creates a gap in the learning of computer science graduates. The study is conducted in Germany where computer science faculties typically do not encourage entrepreneurship. So, even in IT-related start-ups often the founders do not have a background in computer science. To tackle some of these problems, we developed a new course in applied computer science teaching based on socio-cultural theories of learning. In the course we partnered with local start-up companies to create lab-based multi-cultural and multi-functional groups of students to work on authentic IT projects (see Figure 1). The course was accompanied by a series of lectures in which university lecturers and practitioners present entrepreneurship and media relevant topics. The results of the evaluation of the course show that both networking on a technical and a social level offer new opportunities for university level education. Especially the work on real-world problems, collaboration in teams together with partners from start-up companies were evaluated very positive. Following a first instance of the course the didactical design was modified considerably according to evaluation results. By a more precise selection of start-up partners, larger lab teams, coaching of the lab groups by tutors, and increased motivation to use the technical community-system, collaboration and

therefore the establishment of a common practice within the lab groups have been encouraged. This work builds on prior studies that have compared school and work worlds (e.g. see Stevens, 2000) to understand the similarities and differences in these settings. The work discussed in this study goes beyond that to look at how these two domains can learn from each other.

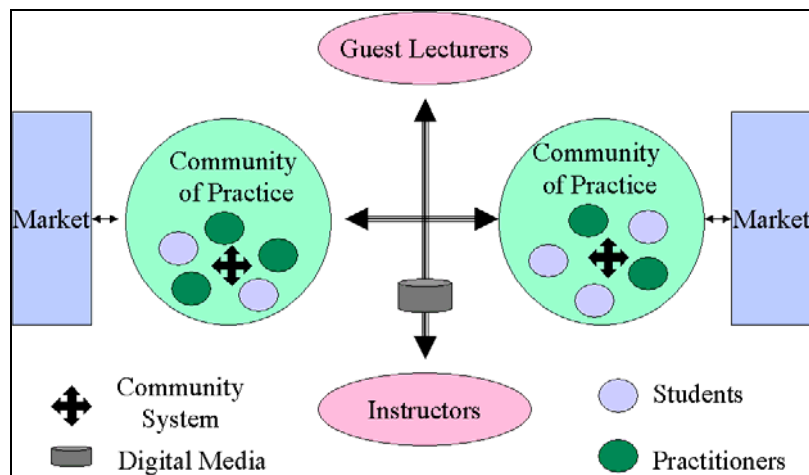


Figure 1. Design of the computer supported course “Entrepreneurship and New Media” (cf. Rohde et al. 2007)

We argue that universities can develop a core competency in providing community based learning and provide a critical resource for regional innovation. Traditionally, universities focus primarily on instructionist teaching. Such an understanding has been criticized from theoretical and practical points of view. We believe that *socio-cultural theories of learning* and the concepts of *communities of practice* (CoPs) and *social capital* hold considerable promise as a theoretical base for the repositioning of universities in the knowledge society. This case study indicates how approaches to community-based learning can be integrated into a curriculum of applied computer science. We also discuss the role these didactical concepts can play within a practice-oriented strategy of regional innovation.

Universities play an important role in the knowledge society (Brown & Duguid, 2000). Beyond their traditional role in research and education, they have the potential to exploit local knowledge in (regional) innovations and to provide opportunities for students to become lifelong learners. To realize these potentials, universities – specifically in the fields of applied sciences and engineering – will have to reinvent their conception of education by taking the importance of industrial practice and social networks into account. In this paper, we first describe a conceptual framework for community-based learning. We illustrate the framework by presenting our approaches to community-based learning. Empirical data evaluating the different courses indicate potentials and problem areas. Finally, we discuss lessons learned from our efforts to transform learning and to create new educational opportunities and experiences at our residential, research-based universities. Compared to approaches that try to extract the epistemology of CoPs and bring it into the classroom (Shaffer, 2004), the Siegen experiences indicate that educational institutions should cross the boundary toward industrial practice to an even wider extent. Supporting the enculturation of students into CoPs of companies offers occasions for mutual learning among residential universities and regional industries. So, besides students, regional industries and universities can learn. From the point of view of necessary personal resources, it should be noted that community-based strategies of learning are labor- and qualification-intense on the part of the universities. They require coaching students intensively; particularly if these strategies are taking place in cooperation with practice (Rohde et al., 2005). Our findings also suggest that the relationship between universities and regional industries will have to develop to a new level of intensity. Saxenian (1994) and other scholars in regional studies have already hinted at the importance of leading research universities for development in the high-tech domain (e.g., by educating a highly skilled workforce and attracting the support of high-tech companies). We stress the bi-directionality of this relationship in particular. Under a community-oriented learning paradigm, a university depends very much on its region to provide appropriate practices to nurture its different programs. In the Siegen region, however, the software and media industry lacks density, thus limiting the opportunity to address specific practices. With regard to political agendas for regional development, community-based learning offers interesting perspectives. The policy followed by the Siegen business development council points in an interesting direction. By supporting networks of practices that include the relevant actors of the university, the potentials of community-based learning are well exploited.

## Conclusion

In this symposium we present three field studies that investigate learning in the real world of research and innovation. The settings are university research lab, industrial research lab, and university-industry partnership. We highlight the variegated nature of learning beyond the classroom setting and examine the situated, distributed, and practice based models of how people learn.

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