Distributed mentoring:

Enrolling students in a virtual community of practice

By

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Abstract

This study examines *Distributed mentoring*, a theory of learning that argues that the interaction between a learner and a mentoring system, rather than a learner and an individual mentor, is the proper unit of analysis for analyzing mentoring. Building on previous theories of distributed mentoring (M. A. Hamilton & Hamilton, 2002; S. F. Hamilton & Hamilton, 2004), theories of distributed cognition and actor-network theory (Hutchins, 1995; Latour, 2005), epistemic frame theory (Shaffer, 2006b), and positive youth development (Larson, 2006), distributed mentoring offers a new theoretical and methodological approach to understand mentoring. It is a framework for understanding how actants in a learning environment coordinate to draw learners into a community of practice. Using qualitative research methods, this study examines distributed mentoring in the context of an engineering virtual internship called Nephrotex. Nephrotex is an epistemic game that simulates the training activity of a professional community of practice (Arastoopour et al., 2012; Lave & Wenger, 1991; Shaffer, 2006b). This study found that the mentoring strategies and goals in the internship were provided by, and distributed among, multiple human and non-human mentoring actants. Further, these mentoring actants coordinated their efforts by reinforcing and complementing each other to simulate an engineering community of practice, and that participants adopted key productive and reproductive activities characteristic of the community. The successful process of facilitating the participants' acting as members of a community of practice through distributed mentoring is proposed as a potential explanation for the utility of mentoring provided by distal figures in young people's lives.

Introduction

The benefit of having a mentor involved in the life of a young person has reached mythical status. Indeed, any young protagonist who is going to fulfill his or her destiny and save the universe at some point gets guidance from a mysterious father figure who takes an interest in helping our young hero reach full potential. This wise old mentor teaches the young hero what it takes to overcome the obstacles set up in the first act, as well as the new challenges awaiting in the second and third.

While not every young person is a hero in an epic saga, all young people face obstacles along their developmental paths. And not just in fiction, but also in real life are mentors proposed as valuable, and in the opinions of some, integral, figures in the lives of youth.

Mentors are commonly defined as non-parental adults who have a special caring relationship with young people. These relationships are theorized to contribute to young people's resilience (Rhodes, 1994, 2009) and positive youth development (Larson, 2006).

A "core requirement" for other aspects of positive youth development is the development of initiative which is only gained through experiencing motivation in the context of accomplishing tasks (Larson, 2000). Young people, and especially older adolescents, need the right combination of autonomy and guidance in order to feel motivated. The problem associated with adult guidance is that it can threaten a young person's perception of their ownership of their activity (i.e. their autonomy). As parents will tell you, adolescents don't like to be told what to do. In other words, there is what

Larson calls an “intentionality paradox,” in which an adult wants to promote intentionality in the youth, but by intervening, threatens the youth’s intentionality.

Mentors, by virtue of their role as non-parental figures who nonetheless have an interest in the young person’s development, have some leeway when it comes to giving guidance. This leeway does need to be earned however. Mentors, it is theorized, need to develop trust through a long-term record of mentoring that achieves the right balance of providing structure that focuses the young person on accomplishing increasingly challenging tasks—in other words, teaching— towards a goal, and preserving for the young person a sense of ownership over the activities. The consistency of a long-term relationship that consists of quality mentoring interactions characterized by mutuality is what mitigates the autonomy threat posed by an interaction with someone with more authority.

There are two problems with this solution to what Larson (2006) has called the intentionality paradox. The first is that these successful mentoring relationships are exceedingly rare. The second is that this concept of mentoring does not adequately reflect the reality that many young people receive mentoring from people who are not, strictly speaking, mentors at all. In fact, it is argued that for this reason that it is more useful to view mentoring as a function than as a role (S. F. Hamilton & Darling, 1996; S. F. Hamilton & Hamilton, 2004). Hamilton and Hamilton (2004) argue that the mentoring function can in fact be distributed among multiple distal figures in the young person’s life.

There are thus two views of mentoring. The first, more traditional and narrow view, held by Rhodes (2005), Larson (2006), and others (Karcher & Nakkula, 2010; Keller & Pryce, 2010a) is that mentoring is the type of support and guidance that is the exclusive province of a special figure who has a primary relationship in a young person’s life. The other, held by Hamilton and Hamilton (2004), is a view in which mentoring can be viewed as a particular type of guidance that can be provided by distal figures. In the first case, actions may be termed "mentoring" when they are provided by a mentor, while in the second view, actions can be considered "mentoring" when they consist of particular strategies of guidance for particular types of cognitive or developmental purposes. This study takes the latter view, and extends it to consider mentoring actions that come from an expanded possible set of sources.

Mentoring from non-mentors, sometimes referred to as distal mentoring or instrumental mentoring (S. F. Hamilton & Hamilton, 2004) often occurs in the context of settings like workplaces. In these structured settings, multiple people offer guidance meant to help the young person participate in the relevant activities associated with those particular settings. In other words, young people encounter mentoring in the context of communities of practice (Halpern, 2010).

Communities of practice are groups of people who have established a particular way of working together of time (Lave & Wenger, 1991). They share a type of work, a particular language and set of resources for doing that work, and modes of interaction by which they do the work together. Newcomers to a community of practice learn by engaging in that community's activity through a process called legitimate peripheral participation. This process involves at first working alongside full members of the community on tasks that are less integral to community's success, but eventually, as expertise is gained, participating in more important activities in the community.

Most importantly, legitimate peripheral participation is a theory of learning based on membership. By framing learning as a social practice rather than an internal process, Lave and Wenger argue that learning “implies not only a relation to social communities –it implies becoming a full participant, a member, a kind of person” and that even further, learning “is itself an evolving form of membership” (1991, p. 53).

Quality mentoring involves working together on accomplishing tasks together in joint activities, while fostering the young person’s learning and development (Halpern, 2010; S. F. Hamilton & Hamilton, 2004; Larson, 2006). These dual mentoring goals can happen even without the benefit of a long-term quasi-parental relationship, particularly in the context of participating in communities of practice, like workplaces, and simulations of workplaces like practica and apprenticeships (S. F. Hamilton & Hamilton, 2004). As one of the main purposes of a mentoring is to facilitate learning, and learning can be thought of as a form of membership, perhaps the reason why distributed mentoring can work is that gaining membership in a community of practice approximates, or at least appropriately stands in for, the value of a long term relationship. This is the hypothesis that this dissertation investigates.

Communities of practice have established particular settings for newcomers to learn to participate in them. These settings, which include practica and apprenticeships, introduce the learner to the practice in "simulated, partial, or protected form” (Schön, 1987, p. 38). Apprenticeships, in particular, have been touted as useful developmental settings for adolescents (Halpern, 2010). Apprenticeships for youth provide learning settings where young people participate in the practices of a community under the supervision of a mentor. In these types of apprenticeship experiences, young people work on challenging longer-term projects with multiple stages. The mentor provides structure, feedback, guidance, and reflection on the process to help the young person achieve the apprenticeship's tasks, but also to promote their development of important competencies that will help them in their lives (Halpern, 2010).

This study examines one such type of apprenticeship, called Nephrotex. Nephrotex is a virtual internship offered as a first–year design course for undergraduate engineering students. In it, students work as engineers for a fictional engineering firm called Nephrotex to design prototype kidney dialysis devices. Along the way, they complete research and design tasks facilitated by various employees and resources.

Virtual internships like Nephrotex have also been referred to as epistemic games, because they aim to teach young people the ways of thinking that characterize particular professional communities of practice, called epistemic frames (Shaffer, 2006b). Epistemic frame theory (Shaffer, 2006b, 2010; Shaffer et al., 2009) argues that professional expertise involves making diverse and dynamic connections between different forms of professional skills and actions, guided by a set of norms and epistemological practices that are particular to that professional community of practice. Epistemic frame theory suggests that "thinking as an engineer" means acting like an engineer, and knowing about engineering topics. These engineering skills and bodies of knowledge are marshaled in the service of matters important to an engineer, a set of professional values. And engineering tasks are accomplished and problems are solved guided by a particular engineering epistemology—by making decisions and justifying actions as an engineer does. Finally, thinking like an engineer means seeing oneself as the type of person who does all of these things, or possessing an engineering identity. An epistemic frame, then, is a way of operationalizing the shared repertoire of a community of practice, and an epistemic game like Nephrotex is a setting for teaching that epistemic frame by facilitating participation in a community of practice.

This dissertation looks for quality mentoring in an epistemic game. It looks for mentoring from all sources and then looks to see how that mentoring may be distributed among those sources. Finding a distributed mentoring environment, it then attempts to explain how that distributed mentoring created a community of practice. Finally, it asks whether the interns in Nephrotex became members of that community.

Dissertation Overview

In this chapter I have thus far described the problem that this study addresses, and explained the ways it attempts to find answers. While the remainder of this dissertation will describe the study in much greater detail, a brief summary of each of the chapters may provide a helpful overview for the reader. In the next chapter, *Theory*, I establish the theoretical framework for the study, including a treatment of the mentoring literature, and present the research questions. In the third chapter, *Methods*, I describe the settings and participants of the Nephrotex, the game's structure, the data collection and collection processes, data coding, and data analysis methods used to answer the research questions. In the fourth chapter, *Results*, I report the qualitative results and connect them back to the research questions. In the fifth chapter, *Discussion*, I make conclusions based on the results and describe their potential ramifications. In this section I also describe the limitations of the study and suggest areas for future research.

Theory

T1. Engagement

Psychological researchers have obtained abundant evidence that humans have a motivational system that mobilizes development (Csikszentmihalyi & Larson, 1984; Deci & Ryan, 2000). A basic finding of this research is that people are most motivated to take on challenges when they experience ownership of what they are doing: when they perceive themselves as agents of their actions (Deci & Ryan, 2000; Skinner, Zimmer-Gembeck, Connell, Eccles, & Wellborn, 1998). One of the key insights of recent work on positive youth development is that young people are able to be—and should be—agents of their own development. Young people are most effectively producers of their own growth when they feel their actions to be their own (Larson, 2006). Studies have suggested that teachers and parents who support adolescents' autonomy contribute to self-deterministic behavior (Skinner et al., 1998; Soenens & Vansteenkiste, 2005), and that this is especially important in the transition to adolescence (Eccles et al., 1993).

Perhaps one of the most common public perceptions of today's youth is that they are disaffected, bored, and care little for school or adult responsibility. Some studies suggest that boredom is verging on epidemic levels. For example, Larson (2000) points to his and his colleagues study that collected a random selection of self-reports of 16,000 moments in the daily lives of a representative sample of White middle and working-class youth, in which youth reported being bored 27% of the time.

Larson argues that the development of initiative, which is "the ability to be motivated from within to direct attention and effort toward a challenging goal," is a "core requirement" for other components of positive development (2000, p. 170). According to Larson (2000), initiative consists of three elements. It first involves intrinsic motivation, or wanting to be doing an activity and being invested in it. Second, this intrinsic motivation must be experienced in a "concerted engagement with the environment," which involves the "exertion of constructive attention in a field of action involving the types of constraints, rules, challenge, and complexity that characterize external reality" (Larson, 2000, p. 172). In other words, the activity that the youth choose to invest themselves in must be challenging in a way authentic to the real world. Third, this investment of concentration in challenging, authentic activity must be goal-driven in a way that requires the youth persevere through setbacks and obstacles over time. Put most succinctly, Larson describes initiative as "the devotion of cumulative effort over time to achieve a goal" (2000, p. 172).

T1.1 Challenge

To promote positive youth development, then, adults should support young people's feelings of agency. This conclusion, however, leads to what Larson calls the "intentionality paradox" (2006): how can adults intentionally help youth without diminishing the youth's own feeling of intentionality? The dilemma is that adults providing too much direction can lead to loss of youth ownership, whereas providing too little direction can mean that youth are not being challenged to grow and develop.

This paradox is illustrated by the primary settings of adolescent life. For example, school accounts for roughly 25-30% of adolescents waking hours on average (Larson, 2000), but during school hours students report high levels of boredom and fewer occasions for self-directed activity. Unstructured time with friends accounts for the majority of the remainder of adolescent waking hours. Here, the story flip-flops. In their free time, young people report high levels of self-directed activity, but low levels of concentration and feeling challenged.

T.1.2 Solutions

According to Larson (2006), a key nuance to young people's need to perceive that they own their activity is that what is important is not that the youth have autonomy, but rather that they *perceive* they have it. Adults interested in providing guidance and structure for young people should therefore work to promote the *perception of ownership*.

Whether their authority is a threat to young people's autonomy or not, it is argued that teachers and parents are not enough to truly shepherd youth into thriving adulthood anyway (Damon, 2004). Just as there are "third places" (Oldenburg, 1989) that offer settings for community interaction outside of the home or workplace, so are there also "third persons," those figures who are neither parents nor teachers, but who are guides and resources for youth learning to participate in their communities. These quasi-parental figures are often called mentors. Mentors, by virtue of not being parents or teachers, might be able to provide support that does not threaten the adolescent need for autonomy (Rhodes, Grossman, & Resch, 2000).

T2. Mentors

Mentorship is used to describe a wide variety of relationships, both formal and informal. Some researchers use the term "natural mentoring" to describe significant relationships between young people and non-parental adults (Rhodes, Contreras, & Mangelsdorf, 1994; Zimmerman, Bingenheimer, & Behrendt, 2005). This kind of informal mentoring arrangement is by definition not guided by an explicit arrangement. Typically occurring through the natural course of daily activities in school, work, extracurricular, or informal community contexts such as the home or neighborhood, this type of mentoring is by far the most commonplace (DuBois & Karcher, 2005). Studies of these types of mentoring relationships typically focus on their benefits to at-risk youth, though at least one study suggests that natural occurring relationships with non-parental adults were a normative component of adolescent development not a result of problems in adolescents' lives (Beam, Chen, & Greenberger, 2002).

Programs for positive youth development offer more formal mentoring relationships. The specific goals, practices, and quality of these programs vary widely (Bernstein, Rappaport, Olsho, Hunt, & Levin, 2009; DuBois, Holloway, Valentine, & Cooper, 2002). Although they sometimes focus on academic support, such as homework help and test preparation sessions (Portwood & Ayers, 2005), they often attempt to duplicate the perceived effects of natural mentoring relationships (Freedman, 1999), and thus specifically target at-risk children and adolescents (Mech, Pryde, & Rycraft, 1995; Rhodes et al., 1994; Rhodes, Ebert, & Fischer, 1992). For example, an absent parent is a usual prerequisite for getting an assigned a mentor in the Big Brother/Big Sister program (Freedman, 1999). They emphasize counseling, friendship, and role-modeling in an effort to help young people develop improved work habits, positive social behavior, and a wide set of life skills (Rhodes et al., 2000). While it should not be assumed that the essential features of naturally occurring relationships can reliably be reproduced by programs (S. F. Hamilton & Hamilton, 2004), a meta-analysis of mentoring programs (DuBois et al., 2002), showed the largest effects were for youth considered at-risk (not youth demonstrating dysfunction, however). While they are less common than natural mentoring relationships, the number of youth estimated to have a relationship with a mentor through a program is 5 million and growing (Rhodes et al., 2000).

T2.1 Value

Rhodes and others (Rhodes, 2005; Rhodes, Spencer, Keller, Liang, & Noam, 2006) have proposed that mentors affect youth through three interrelated processes of development—socio-emotional, cognitive, and identity development—that likely act in concert with each other over time. First, ties to a mentor likely enhance young people's social relationships and sense of emotional well-being. A national study found that older adolescents and young adults with mentoring relationships had greater levels of self-esteem and life satisfaction (DuBois & Silverthorn, 2005a). The impact of mentoring relationships on other interpersonal relationships has been shown to be positive. Adolescents in formal mentoring relationships have shown improvements in perceptions of their parental relationships (Rhodes et al., 2000), and adolescent African-American mothers with natural mentors were found to have a greater capacity to benefit from their social networks (Klaw, Rhodes, & Fitzgerald, 2003). A mentor is the type of person who helps young people feel good about themselves and about their relationships with others.

Second, mentoring relationships may contribute to the cognitive development of youth by providing intellectual challenge and guidance and/or by promoting of academic success. Mentoring researchers have mostly hypothesized the positive effects having a mentor could have on attitudes towards schoolwork (Rhodes et al., 2006). Just as positive perceptions of teacher-student relationships are associated with a variety of positive attitudes, behaviors, and achievement in school (Goodenow, 1992), the presence of a mentor could likewise contribute either directly or indirectly to the child's success in school (Diversi & Mecham, 2005; Linnehan, 2001). A mentor is the type of person who helps young people learn.

Finally, mentors serving as role models and advocates may promote positive identity development. A central task for adolescents is to create a coherent sense of self (Csikszentmihalyi & Larson, 1984; Erikson, 1968). Markus and Nurius' concept of possible selves, which represent individuals' ideas of what they might become, what they would like to become, and what they are afraid of becoming, are the "direct result of previous social comparisons in which the individual's own thoughts, feelings, characteristics, and behaviors have been contrasted to those of salient others" (1986, p. 954). Mentoring programs aim to provide at-risk children with positive role models: the idea is that youth will see in mentors what they might potentially become. More generally, mentors may help youth to build both social and cultural capital by facilitating their use of community resources and by opening doors to educational or occupational opportunities (Dubas & Snider, 1993; McLaughlin, Irby, & Langman, 1994; Schneider & Stevenson, 2000). A mentor is the type of person who provides a model of how a young person might want to be in the future and provides opportunities for a young person to explore those possibilities.

T2.2 Key to success

T2.2.1 Trust

The beneficial effects of mentoring relationships can be expected only to the extent that the mentor and mentee manage to forge a strong connection with each other (Rhodes, 2005). Based on their meta-analysis of mentoring programs, Dubois and colleagues (2002) suggest that the intensity of mentoring relationship (frequency of contact, emotional closeness, and longevity) appeared to be predictive of greater perceived benefits as evaluated subjectively by both mentors and youth. In other words, mentoring relationships are by definition not casual, but characterized by closeness and trust.

Most theorists agree on the importance of a sense of connection in mentoring relationships. Given the likelihood that such a connection would take time to evolve, an important moderator of mentoring effects may be the duration of the relationship. In fact, Keller (2005b) has theorized that every mentoring relationship charts a distinctive path—depending the developmental needs, interpersonal capabilities, and social contexts of the mentor and mentee—through a series of mentoring relationship stages. One finding from the meta-analysis of mentoring programs was that length of the relationship predicted greater benefits for the youth (DuBois et al., 2002). Still, as Deutsch and Spencer (2009) suggest, assessing the "dosage" of mentoring is likely a more useful measure: we want to know how much of what the mentor offered the mentee took, not simply how long or how often they were together. In other words, if positive mentoring outcomes are more likely in the context of a long-term connection with a mentor, they are also more likely if that mentor meets the needs of the youth with the right kind of mentoring.

T2.2.1 Quality mentoring

While there is no simple formula for the right kind of mentoring, Larson (2006) recommends a variety of frameworks for guiding the types of interactions that characterize quality mentoring. These frameworks attempt to offer strategies to mitigate the problem of promoting youth agency in a relationship that is, inevitably, unequal in some dimensions. The challenge is to establish interactions that strike the right balance between youth autonomy and adult guidance. As Karcher and Nakkula (2010) have proposed, the most successful mentoring relationships are made up of interactions that are highly goal directed, but mutual in purpose and collaborative in action. Some of these approaches borrow from literature on parenting relationship styles, while others look to cognitive science literature, and still others to positive development literature.

Keller and Pryce (2010b) draw upon authoritative, authoritarian, and permissive parenting models to proffer a model of mentoring that combines other familiar relationship roles. As with parenting, the authoritative role, where the adult tends to "communicate equitably and effectively, provide explanations, encourage maturity, and nurture with support and affection," is recommended as the best for the young person (Keller & Pryce, 2010b, p. 46). By contrast, the permissive role, which "establishes few standards and expectations for child behavior," and the authoritarian role which "generally imposes rules and exacts compliance in a controlling fashion" (Keller & Pryce, 2010b, p. 47), are considered to lead to unhealthy relationships. Larson's intentionality paradox (2006) speaks to the challenges of navigating these different roles. The act of providing guidance itself can be perceived as a controlling. It is easy to be perceived as authoritarian when attempting to be authoritative and yet easing up on guidance can veer the mentor into a permissive role[1]. Keller and Pryce (2010b) emphasize the importance of the mentor

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[1] This is a problem for adult learners too; Schön (1987) describes how different models of mentoring can lead learners to either productive or problematic "stances" in relationship to the mentor. For example, he illustrated how the "Follow me" model of mentoring leads some learners to resent the mentor's restrictions on what or how the learner practices the work, and to reject that the mentor knows what is best.

managing the voluntary nature of the relationship by paying attention to the mutuality of the interactions, while still using his or her greater social influence to support development. In four studies of mentoring, they found a consistent story: the most successful relationships occurred when "the mentor balanced youth-oriented efforts to build an engaging and enjoyable relationship with adult-oriented efforts to provide development-promoting structure and scaffolding" (Keller & Pryce, 2010b, p. 45).

Scaffolding frames the mentor's role as one who supports the young person's activity, letting the youth take the lead on goal-setting all the while providing whatever help necessary to facilitate the meeting the goals (Rogoff, 1990). Joint problem solving (Wertsch, 1978) and other situations where a learner's current capabilities are extended through the support of an adult, are often framed as scaffolded learning (Wood, 1999) or as cognitive apprenticeship (Rogoff, 1990). The work of scaffolding involves the mentor knowing what help the learner needs to accomplish the current obstacle. Some scaffolding strategies include gently directing the learner's efforts. For example, mentors may channel the learner's effort by reducing the possible number of actions she could take, or focus their effort by marking relevant task features. Other strategies involve the mentor demonstrating how to accomplish particular tasks (Halpern, 2010; Schön, 1987). Modeling is such a sound instructional strategy that it is used to teach at every level of human performance, from the basic skills a small child inches to grasp, to complex performances of practice in an apprenticeship (Collins, Brown, & Holum, 1991) The process of imitation leading to internalization is a foundational process of learning and development (Valsiner & Van der Veer, 1999; Vygotsky, 1978).

Scaffolding also often includes the mentor knowing the relative importance of one task compared to another, which allows them to provide guidance about long-term strategy as well as short-term problem solving. For example, adults working in the context of youth activities have been shown to scaffold organizational skills (Hansen, Larson, & Dworkin, 2003; Heath, 1999; Mahoney, Larson, Eccles, & Lord, 2005) by helping young people manage ambitious projects by breaking them into smaller parts. This type of scaffolding often works hand in hand with motivational scaffolding strategies, where the mentor models enthusiasm and expresses confidence that the youth will meet their goals. It is important that they back up this affective cheerleading by ensuring that the youth is engaged in the appropriate level of challenge, keeping them in what Csikszentmihalyi (1996) terms the "flow" state. Mentors should manage the youth's expectations and help them set reasonable and achievable goals so that they can experience successes (Larson, 2006).

It is particularly important for youth to feel like their activity matters to them (Deci, Eghrari, Patrick, & Leone, 1994), and as they get older it becomes increasingly important to them that their activity matters in the real world (McIntosh, Metz, & Youniss, 2005; Yates & Youniss, 1998; Youniss, Mclellan, Su, & Yates, 1999). Engaging in activities that make a difference to others enhances self-efficacy. Participation in the larger community as a genuine contributor is a particularly powerful example of such activities. Such participation is a means of building social capital by expanding the adolescent's social network (Putnam, 1995). Further, as they get older they can begin to take control of their own learning. They set goals, plan their efforts and carry them out, and then learn from their success or their failure. Mentors support their learning by facilitating reflection: making sure they do it, and making sure they can "interpret the experience in ways that draw out the salient lessons" (Larson, 2006, p. 685)

Finally mentors can help youth by increasing their exposure to other positive influences, experiences, and opportunities. Researchers (Lerner & Benson, 2003) have listed "developmental assets" both internal and external, that are those characteristics of an individual or of that individual's context that may be leveraged for positive outcomes. Connecting young people with real world assets has the potential to reduce risk factors in their lives and promote indicators of "thriving" (Lerner, Dowling, & Anderson, 2003). Providing assets could be as simple as finding places that are safe or distraction-free so that the youth can focus on taking care of their existing responsibilities, or it could be opening opportunities that they otherwise would not have had, such as a job or another type of youth program or helpful intervention (Larson, 2006). Quality mentoring can thus expand the youth's social network. By not directly providing support, but rather steering youth to other sources of support and opportunity, the mentor can indirectly promote a young person's sense of competence.

Hamilton and Hamilton (2004, 2005), in their study on workplace mentors, divided mentoring strategies into six categories: demonstrating, explaining how, explaining why, monitoring, reflective questioning, and problem solving. Based on their study's results, Hamilton and Hamilton (2004, 2005) grouped these six teaching strategies into two categories. The first four they found were universal, with both mentors and youth reporting them used, while the last two were much more rare and challenging. While explaining, demonstrating, and monitoring are mentoring strategies that are common, and certainly useful, by themselves they facilitate a type of engagement that reflects a theory of learning predicated on the transfer of information from one source to another. The latter two mentoring strategies, reflective questioning and problem solving, establish more reciprocal modes of participation, where the mentor and youth are mutually engaged. These mentoring strategies are hypothesized to lead to a greater likelihood that learners will be able to apply what they learned to novel scenarios (S. F. Hamilton & Hamilton, 2004).

What many of these frameworks have in common is that they are what Hamilton and Hamilton, drawing on Bronfenbrenner (1979) and Vygotsky (1978), call, “joint activities” (2004, p. 406). Joint activities, which are settings in which learners accomplish tasks with proximal help, have three dimensions. First, they occur in the context of an activity where mentoring can occur. Simply put, the mentor and youth must have regular access to each other. Second, the quality of the mentoring makes a difference, more so even than the duration of the relationship (Mortimer, 2003). Hamilton and Hamilton (2004) emphasize that that quality mentoring for adolescents especially is more instrumental, or focused on the accomplishment of goals. Third, the protégé must be actively engaged and participating in the mentoring. In other words, the joint activities should be mutually agreed upon. Simply put, joint activities involve collaborative, goal-driven, interactions between the youth and mentor. The job of the mentor in these interactions is to structure the youth’s activity so that the youth accomplishes the goals in a way that is productive for the youth. In other words, good mentors facilitate the youth’s task achievement and teach them something worthwhile along the way.

Researchers recommend particular settings that provide contexts for the joint activities required for quality mentoring. In contrast to the low focus/high structure school setting and the high focus/low structure free-time settings, Larson (2000) touts "structured voluntary activities." In these types of activities, youth can opt in or out, but their participation is directed by constraints, rules, and goals. Citing activities such as sports, arts, clubs, and participation in youth organizations, Larson and others (Dworkin, Larson, & Hansen, 2003; Larson, 2000) point to increased levels of self-reported concentration and motivation among youth participants. Participation in these activities requires sustained effort over time—because of their collaborative nature, the natural duration of some activities like sports seasons or performances, and the simply the amount of time required to accomplish the goals (Larson, 2000)[2]. These activities, then, are ideal settings for facilitating the development of initiative.

T2.3 Mentoring interactions and mentoring relationship styles

In the field of youth mentoring research there has been an ongoing conversation about the types of mentoring relationships and interactions that are generally most impactful, and specifically most appropriate based on different contexts and characteristics of the youth in the mentoring relationship (e.g., the youth's age or gender). Two broad categories of mentoring—*developmental* and *instrumental*—have dominated the conversation. The simple distinction between the two categories is in terms of the purpose of the mentoring; developmental mentoring focused on nurturing the relationship between the mentor and youth (Morrow & Styles, 1995), while instrumental mentoring is more oriented towards goals to be accomplished (Hamilton and Hamilton, 2004).

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[2] On the other hand, these contexts are often similar to school in that the ratio of youth to adults is skewed towards the youth. It is unclear what types of relationships are likely between adults and youth in these contexts (Coleman, 1961), and how much mentoring is possible in a group rather than one-on-one setting.

Karcher and Nakkula (2010) describe how these categories are often treated as opposing when in fact they are complementary. They argue that the developmental mentoring and instrumental mentoring are each examples of a relationship style, the “pattern of interactions that evolve across the course of the relationship during a defined period of time” (Karcher and Nakkula, 2010, p.16). Relationship styles are distinct from the type of interactions that comprise those relationships. Therefore, a developmental relationship style may involve some interactions that are goal-directed, and an instrumental relationship may involve some relational focused interactions.

To describe the range of mentoring interactions, Karcher and Nakkula (2010) created a framework of mentoring relationship interactions. They characterize these interactions as falling on a spectrum of three dimensions: focus, purpose and authorship. *Focus* describes the target of the interaction and structure imposed to reach it. The target of the interaction falls on a spectrum of being more or less goal or relationship directed. The *purpose* of the interaction describes whose agenda is served through the interaction. Interactions are either serving the youth’s immediate developmental needs with a playful purpose, or the youth’s future or society’s needs with a more conventional purpose. And finally, *authorship* describes how the interactions are negotiated: by the mentor, by the youth, or collaboratively. Within this typology are interactions that would describe both unsuccessful or problematic mentoring relationship styles, such as what some researchers (Langhout, Rhodes, & Osborne, 2004) term “laissez-faire” in which the mentoring interactions are unstructured, nondirective, non-relational, goalless, and spontaneous. On the other end of the spectrum would be a prescriptive mentoring style, which is goal oriented, highly structured, typically focused on remediation, and led solely by the mentor.

Between those two extremes is a range of styles that incorporate both relational and goal-oriented interactions, that can be either collaborative or primarily led by the mentor or youth, and serving either the youth's immediate interests or focused on adult purposes.

Karcher and Nakkula's framework (2010) explains how some mentoring relationships are successful even when they highly structured and goal oriented and not focused on the relational aspects of the interactions much at all. For instance, they describe interactions that would happen in an apprenticeship setting as highly instructive and directive, minimally relational, future-focused, but nonetheless feel collaborative because the youth agree with the purpose of the interactions. Similarly, coaching scenarios may be highly structured and minimally relational but because they are focused on the youth's current goals and may be more playful they feel less prescriptive. In other words, mentoring relationships are made up of various types of interactions that can be more or less youth centered, more or less focused on the relational aspect of the relationship, and more or less collaborative in nature. Even when the interactions are mentor-led, and goal focused, if there is enough sense of mutuality in their purpose, the mentoring relationship can be effective.

T2.4 Problems

T2.4.1 Good mentors are hard to find, train, and sustain

Organizations that match volunteer mentors with youth in need struggle to recruit enough mentors, and once recruited, struggle to keep them (Stukas & Tanti, 2005). Few mentoring programs recruit enough volunteers to meet the needs of waiting youth. This may be because the criteria for being a mentor (e.g. lack of a criminal record) in a program prohibit some candidacies or because of the usually rigorous screening process for prospective mentors (Stukas & Tanti, 2005). Once recruited, training mentors is important. Unsurprisingly, training mentors has a positive effect on mentoring relationships; as Dubois and colleagues (2002) discovered in their meta-analytics review of evaluations of formal mentoring programs, ongoing training for mentors was associated with greater positive effects for youth in formal programs. Unfortunately, although most mentoring programs have careful recruitment, screening and matching procedures, a much smaller proportion of these provide in-depth training. After being trained, levels of support to mentors often decline, which can lead to the early termination of mentoring relationships, especially in cases where the youth have particularly troubled lives. Retaining mentors is especially important because research shows that youth in formal mentoring programs who are abandoned by their mentors may suffer negative impacts (Grossman & Rhodes, 2002). Only recent research has begun to uncover successful methods of recruiting, training, and supporting mentors (Stukas & Tanti, 2005).

T2.4.2 Relationships are complicated

All relationships are affected by many factors; young people's relationships with mentors are no different. Some of these factors can moderate the positive effects associated with having a mentor. A standard issue in mentoring relationships is the often-considerable social distance between mentors and their charges. In settings where social distance is great, the mentors' world can easily seem "irrelevant or even nonsensical" to youth, "and their goals for the mentees naive" (Freedman, 1999, p. 49). Evidence suggests that the age of the youth—and by extension, developmental level— as well as the individual relationship history and the youth's level of dysfunction all influence mentoring relationships. In addition, the race and gender composition of the mentor-mentee dyad and the longevity and cultural context of the relationship also impact the effects. While research into the manner that these factors affect mentoring outcomes are both unclear in findings and limited in number and scope (Cavell & Smith, 2005), it is accepted that general conclusions about the influence of mentoring are complicated by the relationship context and numerous other personal, environmental, and situational factors that are potential moderators of mentoring effects (Rhodes et al., 2006).

Racial and/or ethnic difference, especially in mentoring programs where at-risk youth are matched with volunteers hoping to make a difference, is widely theorized to impact the quality of the mentee's experience. Perhaps tellingly, most youth who have naturally-occurring mentors report having mentors of the same race/ethnicity (Klaw et al., 2003; Rhodes, 1994; Rhodes et al., 1992). Potentially, adults who are not familiar with the culture of their mentees may have over-generalized assumptions about what it means to be a member of a particular ethnic group (Gutierrez & Rogoff, 2003). Delpit (1995), for example, writes about danger of making inappropriate assessments based on ignorance of difference in cultural language patterns in schools. Ogbu (1990), in a study of mentoring programs for minority youth, suggests that because minority youth internalize the racial and ethnic attitudes of the larger society, they are more vulnerable to low self-esteem and to have restricted views of their possibilities. He goes on to argue that mentors with a similar racial and ethnic background have a better chance of understanding these social and psychological conflicts and offer realistic solutions, while a dissimilar mentor might inadvertently belittle the youth, or fail to affirm the youth's culture. Research, however, into the effects of same and mixed-race matches has been conflicting, inconclusive, and in some cases treats the role of race superficially (Sanchez & Colon, 2005).

The implications from existing literature on gender differences in adolescent development suggest that girls and boys may need different types of mentoring and may form different types of relationships with their mentors (Bogat & Liang, 2005). When girls' relationships with female mentors are characterized by empathy, authenticity, and intimacy, they are more highly valued and result in outcomes such as high self-esteem and reduced depression (A. M. Sullivan, 1996). Research on the relative effectiveness of mentoring for male and female mentees is sparse for both mentoring programs and natural mentoring (Bogat & Liang, 2005), though numerous studies, including the meta-analysis of mentoring programs that Dubois and colleagues (2002) conducted, have shown that gender (of the mentor, mentee, or the match) has no discernible impact on the effectiveness of the mentoring (Darling, Hamilton, Toyokawa, & Matsuda, 2002).

The overall cultural context of the mentoring relationship may also contribute to differences in the types of values and interactions. Cultural values such as collectivism, familism, and individualism have significant effects on social relationships (Sanchez & Colon, 2005). For example, research suggests that Japanese youth may be less likely to seek help from relationships outside of the family compared to Americans (Darling et al., 2002). On the other hand, in Japanese society the potential for peers to function as mentors within the peer culture is explicitly recognized, and in one cross-cultural study of naturally-occurring mentoring in Japan and the US, Japanese students named twice as many peers as significant influences as did the participants in the United States (Darling et al., 2002). In that study, however, in both cultures adolescents were more likely to credit mentoring functions to adults than to peers, to relatives than to non-relatives, and to same gendered rather than different gendered associates (Sanchez & Colon, 2005). Again, although available research suggests that cultural values play a role in the kinds of natural mentoring relationships that youth are likely to develop, findings are mixed and potential confounds are common (Sanchez & Colon, 2005) .

Previous relationships are also likely to impact mentoring relationships. Youth who have enjoyed good relationships with their parents may be drawn to other adults as role models and confidants (Rhodes, 1994). Children and adolescents with more supportive parental relationships have been more likely to report natural mentors (S. F. Hamilton & Darling, 1996; Zimmerman et al., 2005). Thus, natural mentors appear to complement parents more than they substitute for them (S. F. Hamilton & Hamilton, 2004). The prevailing view is that mentoring programs are potentially most helpful to at-risk youth, including those who may lack parental influences in their lives (Freedman, 1999). While this belief has been supported in a meta-analysis of mentoring programs, the same study found that one of the greatest predictors for stronger reported effects in mentoring programs was the presence of mechanisms for support and involvement of parents (DuBois et al., 2002).

The literature on relationship styles/working models (Bowlby, 1988), relationship representations (Ryan, Stiller, & Lynch, 1994) and relationship cognition (Reis, Collins, & Bersheid, 2000) is vast. Obviously, any firm conclusions on the nature of youth-mentor relationships would need to be informed by this research and theory (which usually focuses on parent, teacher, and peer/romantic relationships).

T2.4.3 Mentor relationships are hard to assess

Research on the hypothesized processes and outcomes of mentoring relationships are sometimes conflicting, somewhat sparse, and methodologically limited. A number of factors contribute to this mixed bag of research. Most studies of mentoring relationships for youth have been based on relatively small samples of convenience, with inadequate statistical power to detect the relatively subtle outcomes on youth (DuBois & Silverthorn, 2005b). Most studies of mentoring relationships have been cross-sectional, and longitudinal studies have featured a limited number of assessments over relatively brief intervals (DuBois & Karcher, 2005). Furthermore, these assessments are predominantly based on questionnaires completed by youth only, and few studies have made use of relevant procedures that have been developed for the analysis of dyadic data (DuBois & Silverthorn, 2005b).

Neither natural mentoring scenarios nor program based mentoring fare well in terms of quality research. Studies of mentoring programs typically focus on a single program implemented at one site (DuBois & Silverthorn, 2005b). A notable exception, a recent meta-analysis of mentoring program evaluations, reported significant though small effects on several outcomes on the participating youth, including improved emotional, behavioral, and educational functioning (DuBois, et al., 2002). The meta-analysis, however, reported a wide range of effects, was based on small samples, and used an un-validated instrument (DuBois et al., 2002). Other studies of particular mentoring programs have found no significant differences between control groups and intervention groups (see, for example, Royce, 1998). In any event, most programs lack clearly specified logic models that describe how, and under what conditions, the program's mentoring relationships are expected to lead to positive change among youth (DuBois et al., 2002). Similarly, the lack of any formal criteria to natural mentoring makes both the specific nature of the mentoring and the benefits for the younger members of these relationships unpredictable (Beam, et al., 2002). In addition, in the National Study of Adolescent Health, effects of exposure to individual and environmental risk factors generally were larger in magnitude than protective effects associated with mentoring (DuBois & Silverthorn, 2005b). Relatedly, there is no consensus on an operational definition of who can serve as a mentor in the first place (Dawson, 2014). For example, some studies count family members, while others do not. Some count teachers, while others do not.

Despite increasing enthusiasm for mentoring programs—based on the perceived benefits of naturally occurring mentoring relationships—strong empirical grounding for either type of mentoring relationship has lagged significantly behind (DuBois & Karcher, 2005; Freedman, 1999). To be fair, conducting research on mentoring is difficult. Traditional mentoring relationships operate fairly independently. In mentoring programs, mentor-youth pairs are matched and sent out into the world, seldom connecting with other pairs and only checking in with the program when they need specific help or information. Since what mentors and mentees in these programs do is usually unstructured, few opportunities exist to observe mentoring pairs in action (Deutsch & Spencer, 2009). Similar obstacles face researchers interested in natural mentoring: there are even fewer opportunities to conclusively chart their impact, much less the processes at work in them. In any event, research into the content of mentor–youth activities and discussions together and the mentor's use of different types of strategies for promoting youth outcomes is virtually absent. Researchers acknowledge the need for more research into the normative trends in mentoring relationships, sources of variability within them, and specific processes that comprise them (Keller, 2005b; Rhodes et al., 2006).

T2.4.4 The myth of the super-mentor

While clearly some of the limitations in the research on the impact of mentoring relationships on youth are methodological, there are also suggestions that the beneficial effects of having a mentor are overstated. Freedman (1999) points out that mentoring movements have failed in the past, and that the current enthusiasm of mentoring perpetuates some of the same myths from those previous movements. Mentoring is not, he argues, cheap, easy, or a panacea (Freedman, 1999).

Freedman cautions against the urge to celebrate “super-mentors,” which is what he calls those mythical individuals who single-handedly turn a troubled youth’s life around. Mentoring research provides evidence supporting his concerns. For example, the meta-analysis of mentoring program evaluations showed no effect on participating youth identified as being at risk solely on the basis of individual-level characteristics, such as academic failure (DuBois et al., 2002). Freedman (1999) suggests that at-risk youth often need serious developmental help, and Dubois and Silverthorn (2005a) agree that “mentoring relationships alone are not enough to meet the needs of at-risk youths and therefore should be incorporated into more comprehensive interventions.” Further, given the potential risks to adolescents involved in relationships with adults who may be under-trained, imperfect themselves, and unreliable, caution is appropriate (Rhodes, et al., 2000). More to the point, no single program, intervention, activity, or individual is enough for youth, whether at-risk or not, because *all* adolescents require a variety of assets in their development. As Lerner and Galambos (1998) put it, "a multiplicity of needs must be met for adolescents to develop into healthy and productive adults."

T3. Distributed Mentoring

A multiplicity of needs demands a multiplicity of resources. Some mentoring theorists have incorporated this viewpoint into their thinking about mentoring. Rather than pinning hopes on "super-mentors," Freedman (1999) advocates for creating "mentor-rich environments," in which youth and multiple adults come into contact with each other regularly in circumstances that encourage mentoring. With the increase in the number of interactions with different adults could come more opportunities to interact with someone who could grow into the quasi-parental figure that is so valuable. However, advocating for mentor-rich environments implicitly challenges mentoring models that are contingent on a long-term emotional connection.

T3.1 Mentoring as a function

Hamilton and Hamilton (2004) acknowledge that the benefits of mentoring are typically attributed to caring adults who cultivate long-term relationships with youth, but they also describe how more fleeting relationships can be critical for adolescents. They argue that for some purposes the most important relationships are not close but distal, and that adults can contribute significantly to youth development even when their relationship is only moderately close and of limited duration. Hamilton and Hamilton (2004) examine the role of mentoring in workplaces, which are settings that have the potential to be Freedman's (1999) "mentor-rich environments" in the sense that there are multiple possible adults who can potentially provide the multiple needs that youth require. This potential network of adults leads Hamilton and Hamilton to frame "mentoring as a function distributed among multiple adults, not only a single person identified as a mentor" (S. F. Hamilton & Hamilton, 2004, p. 401). When mentoring is distributed, they argue, youth can potentially benefit from a broader range of expertise than a single mentor could offer. As Darling and colleagues put it, the "mentor is a functional role—it describes the behavior of one person in relation to another" (2002, p. 248). In other words, many people in a young person's life can act as a mentor, whether or not they fit the criteria of a quasi-parental concerned adult. Given that studies have shown that young people have no compunctions about labeling anyone—whether it be friend, family, teacher, preacher— a mentor, what may matter most is not the label but the function (Darling et al., 2002).

For Hamilton and Hamilton (2004), distributed mentoring means that the learner may be a part of many distal dyads that contribute mentoring. While they suggest that these dyads could offer a "comprehensive youth development system" (2002, p.81), they do not address how the mentoring would need to be coordinated in order to make it comprehensive or a system. Others have gone further to examine the interactions between a set of mentoring dyads. Keller (2005a), for example, looked at how an interdependent network of relationships established between the mentor, youth, parent/guardian and caseworker was responsible for positive youth outcomes in the context of a Big Brothers/Big Sisters formal mentoring program. He uses the example of a typical mentoring activity, teaching a young person to skate, to describe the different types of interactions possible among the participants in the network.

> As an example of *direct* pathway, the mentor might suggest that they go skating. In a *reciprocal* exchange, the child might request an opportunity to go skating and the mentor agrees to this activity. In a *transitive* interaction, the parent might recommend skating to the mentor, and then the mentor suggests this activity to the child. In a *parallel* sequence, the parent and mentor might discuss skating as a good activity, and then both parent and mentor independently raise this idea with the child. Finally, in a *circular* pattern, the child might tell the parent about an interest in skating, the parent conveys this information to the mentor, and then the mentor takes the child skating. (Keller, 2005a, p. 173)

Keller (2005a) suggests that the overall effect of mentoring interventions on a young person may be the consequence of the cohesion between caring adults who collectively support the child's development, and that understanding how a mentoring intervention may work would require examining their interdependencies. Nevertheless, Keller still concludes: "the nature of the relationship between mentor and child and the quality of interaction between them is likely to be the strongest determinant of successful intervention" (2005a, p. 184). In other words, multiple relationships matter, but as Larson (2006) argued, the primary success factor in a mentoring intervention is still the trust that comes from a long-term relationship comprised of quality mentoring practices.

While Karcher and Nakkula (2010) attempt to incorporate the instrumentality of Hamilton and Hamilton's (2004) model of mentoring offered by distal figures, they, like Keller (2005a), ultimately place the power of the mentoring in the relationship style rather than the nature of the mentoring interactions. They argue, for example, that while formal mentoring programs for adolescents "may need to consider ways to encourage goal-oriented interactions and foster instrumental mentoring styles to maximize the potential of youth mentoring," they nonetheless maintain that "program staff need to hold true to a vision of the relationship as the core change catalyst" (Karcher and Nakkula, 2010, p.30). However, it is unclear how in mentoring contexts where the relational aspects are minimal, such as the distal workplace mentoring that Hamilton and Hamilton describe, or apprenticeship settings where the mentoring interactions are goal oriented, highly structured, and mentor-led, it is the relationship that is the "core change catalyst." Hamilton and Hamilton (2004) describe how distal figures who provide mentoring ideally grow into more primary relationships that could potentially that occupy the traditional special relationship, but there is little empirical evidence that this phenomenon occurs, and in any case not all distal persons in a young person's life who provide mentoring will grow into such roles.

In the field of mentoring literature, there are always attempts to describe mentoring in terms of the view that mentors provide mentoring, and that even when non-mentors provide mentoring their interactions can be termed mentoring because of the potential privileged role they could eventually assume in the young person's life. Hamilton and Hamilton's (2004) concept of mentoring-as-function challenges this view. Even if they describe the guidance and structure that distal figures provide as mentoring because of the potential of those mentoring sources to transform into relationships, it is evident that in the context of the interactions, the relationship is not the relevant feature, and it may well never be salient at all. A consequence of Hamilton and Hamilton's (2004) introduction of distributed mentoring and the concept of mentoring-as-function is not only an expanded definition of who can provide mentoring, but it also raises questions about what counts as mentoring. The traditional view is that mentoring is what mentors do. Hamilton and Hamilton (2004), in arguing that mentoring can be a function distributed among adults, including non-mentors, introduce the possibility of a different view of mentoring, where mentoring is defined by a set of particular kinds of actions, strategies and goals. This study explores this latter definition of mentoring.

T3.3 Distributed Mentoring and the intentionality paradox

One reason mentors are so valued is that they manage to navigate the intentionality paradox. The problem posed by the intentionality paradox is that youth, in order to be motivated to be producers of their own development, need to feel like they have ownership over their activity but also need structure to keep them engaged and productive. That structured guidance that adults provide can threaten a young person's sense of autonomy. Mentors are ideal candidates for providing non-threatening guidance because of the special relationship they cultivate with youth. Over time, the consistent mutuality that good mentors facilitate results in a trust that gives them more leeway to intervene in a way that does not threaten the youth's autonomy. The youth trusts that the mentor is invested in them as a person, and has their interests in mind, because the relationship with the mentor has reliably, over the long-term, been composed of interactions that are structured yet characterized by a feeling of mutuality. Such a mentor likely uses some of the frameworks described by Larson (2006).

Hamilton and Hamilton's (2004) mentoring framework, where mentoring is a function with no long-term relationship necessary, still requires quality mentoring. The mentoring that distal figures provide still should achieve that recommended balance of adult-provided structure and youth ownership. They, like Larson, emphasize the importance of two particular mentoring strategies that do the work of establishing mutuality, problem solving and reflective questioning (2004; 2006). Hamilton and Hamilton's framework, however, omits the long relationship. One of the two things that Larson (and others) theorize is the source of a mentor's power—the trust gained from the consistency of their relationship—is missing in Hamilton and Hamilton's framework. If mentoring can come from non-mentors who have not built the solid foundation of trust necessary to solve the intentionality paradox, how can distributed mentoring in settings like workplaces still succeed?

T4. Settings for Distributed Mentoring

T4.1 Mentoring in the workplace

Hamilton and Hamilton (2004) suggest that the workplace, where young people interact with adults in a professional context, is a particularly good setting for mentoring. Activities at work are goal-driven, and adults in the workplace often teach youth not only how to do the work but how to behave at work. Sometimes some of those adults build relationships that transcend the duties of the workplace.

Researchers have begun to examine how the qualities and characteristics of the work environments influence adolescents' development and functioning. For example, Zimmer-Gembeck & Mortimer (2006) cite multiple studies that have found that adolescents from one study who report higher quality work experiences tend to have better relationships with their parents, have more pronounced occupational values, and experience more control over their lives. In addition, internships that provide students with opportunities to do the work of a profession (beyond clerical work) can help them have a better understanding about the relevant steps necessary to achieve their vocational goals (Schneider & Stevenson, 2000).

This research into the impact of quality of youth work experiences is important because the jobs available to teenagers, while numerous, are not typically educative or related to greater career goals. Rather, they are typically menial, or service-related (Csikszentmihalyi & Schneider, 2000; Schneider & Stevenson, 2000). There is reason for caution about mentoring in the workplace, as researchers have also found that adolescent employment can hamper development, especially when school and work are in competition in terms of time (Zimmer-Gembeck & Mortimer, 2006)[3]. On the other hand, there has been some indication that the mentoring in a workplace environment, if properly conducted, can have benefits that do transfer to academic settings. Linnehan (2001), for example, studied 202 African-American high school students participating in a work-based mentoring program, and found that those who participated in the program for more than a semester significantly increased their grade point averages and attendance rates at school. The main benefit for youth receiving mentoring in work-based or apprenticeship activities, however, may not be how they help young people in their in school activities, but in how they connect youth to their communities.

Progressive educators, inspired by the philosophy of John Dewey, have long advocated for close connections between youth and their communities. Larson and others argue that it may be particularly advantageous to introduce adolescents to multiple settings that each has its own set of norms and activities, as they identify adolescence as a key time to develop a "versatile social repertoire" (Larson, Wilson, Brown, Furstenburg, & Verma, 2002). They argue that it is "increasingly important to be able to move between heterogeneous types of relationships and social systems and be able to operate effectively within each" (2002, p. 60). Workplace settings are often connected to the community, which can be motivating for youth (Halpern, 2010). It should also be motivating for

[3]This issue is contested. For a review of differing views see work by Zimmer-Gembeck & Mortimer (2006).

communities. Giving young people a voice in their communities, promoting their development, and building community and civil society are overlapping purposes (Zeldin, Larson, Camino, & O'Connor, 2005). In fact, for proponents of positive youth development the measure of healthy development, *thriving*, is the extent to which someone has healthy, positive relations with his or her community (Lerner et al., 2003). Being connected to one's community means having multiple relationships with its constituents; these relationships may be productive sources of mentoring functions.

T4.2 Apprenticeships

T4.2.1 Apprenticeship Mentoring

Given the paucity of quality work experiences available, especially to less privileged adolescents, there has been a push for more opportunities for youth to have apprenticeship opportunities in service-learning/internship programs both in and after-school (Halpern, 2010). Apprenticeships are settings specifically designed to teach how to participate in professional communities. In apprenticeships, novices learn a professional practice in the context of doing that practice under the supervision of someone who is a master at the work already. It is important to note that there is a range of types of training experiences that are often referred to as apprenticeships, and the relevant dimension here is the extent to which they are intended and designed to facilitate learning. For example, in many apprenticeship experiences situated in the actual sites of production, the learning is incidental, and the stakes are high[4]. Other apprenticeships, such as practicum experiences, or some types of internships, are designed to protect the learner, and everyone else, from some of the risks of the profession. There are some things that surgeons shouldn't learn while on the job. Schön describes how novices participate in practices they wish to learn in "simulated, partial, or protected form" under the guidance of a senior practitioner (1987, p. 38). Examples of common practicum experiences include moot court for lawyers, clinical rotations for nurses, or supervised practice for psychologists.

There has been much work describing how mentors and learners in workplace simulations like apprenticeships and practica operate. Most notably, Schön describes how the role of the mentor in a practicum is like that of a coach: the apprentice does work, and the mentor provides guidance. For example, Schön describes the "Follow Me" method of mentoring, where the mentor dictates everything the learner does, assigning tasks, making suggestions, and providing feedback (1987). The learner is expected to trust and follow the mentor's lead. At the same time, the primary function of the mentor is to facilitate reflection. According to Schön, the practicum is an occasion for the mentor to reflect with the learner on just completed activities, so that the learner returns to the work with new insights on it. Repeated cycles of action and reflection on action lead to the ability to reflect-in-action; this ability to reflect while acting is the way professionals are able to handle the messy open-ended problems of creative work (1987).

[4] For example, Lave & Wenger (1991) note that apprentice Yucatanian midwives receive hardly any teaching at all, and apprentice butchers often fail. Also, Zimmer-Gembeck & Mortimer (2006) describe the sometimes negative outcomes associated with teenagers in the workplace.

Some researchers have incorporated concepts of distributed mentoring into their work on understanding the affordances of professional training settings. Khasnabis and colleagues (2013), for example, posed distributed mentoring as a peer-based teaching and learning context for pre-service teachers. In their study, mentoring was not about particular relationships but about particular tasks around which a group of peers interacted. They looked at teacher professional development activities that take place in "designed settings," activities that reduce the number of variables for beginning teachers to contend with by creating teaching situations that focus their attention on just a few highly specified teaching practices. In these settings, multiple peers with multiple viewpoints informally mentored each other, providing feedback and conversation based on the shared experience of the activity. Leon examined how expert faculty and peer mentors worked together to train pre-service resident teachers working in high needs turnaround urban high schools, finding that the distributed expert/peer mentoring provided "confirmatory, additive, and complementary knowledge and skills" (2014, p. 114). In other words, the mentoring that the pre-service teachers received from the one mentoring source served to reinforce the mentoring they received from another.

T4.2.2 Apprenticeships for youth

Apprenticeship settings offer what looks like a promising compromise between afterschool clubs and the typical employment opportunities available to young people. In multiple studies, Halpern (2010) has examined youth apprenticeship programs focusing on a variety of practices (including arts, sciences, and crafts such as boat-building, cooking, and gardening). He describes how youth apprenticeships have a wide range of benefits, including the acquisition of disciplinary skills, knowledge, and sensibilities. The work is demanding, requiring the mastery of particular skills, language, and habits (Halpern, 2010; Heath, 1999) that are valued in the adult world.

In particular, Halpern explains that in apprenticeships youth learn to accomplish longer–term tasks, relying on both cognitive and affective growth to persevere through challenges. For example, he cites the young people's developing ability to do work purposefully, carefully, under pressure, and in the face of uncertainty. In other words, his description of the developmental benefits of youth apprenticeships sounds very similar to Larson's description of initiative. This is unsurprising, as mentors in youth apprenticeships do the types of things that Larson (2006) suggests work best for mentoring adolescents: they model particular behaviors, scaffold both motivation and skills, and facilitate reflective conversations, all in the context of a task-focused setting (Halpern, 2010).

Shaffer has developed simulations of professional training experiences like apprenticeships that he calls *epistemic games*. Epistemic games (Shaffer, 2006a, 2006b), also referred to by Shaffer as virtual internships, are role-playing games in which players engage in the training practices of a socially valued profession, taking up complex problem solving challenges and reflecting with mentors to develop the complex ways of thinking of that profession. In the epistemic game, Nephrotex, for example, youth role-play as interns in an engineering firm. In it, they work with teams of colleagues to do research on the constraints they will be working under, and the needs of non-player-character clients whom they must satisfy. They use professional tools that model complex problems to propose solutions to those problems, and must write about the justifications and limitations of their proposed solutions. As the players do the work of the professional practice, in-game mentors provide directions and help. Epistemic games have been shown to successfully simulate professional practica (Hatfield, 2015), and players of epistemic games have been shown to develop the disciplinary skills, knowledge, and sensibilities of the game's simulated profession (Arastoopour et al., 2013; E. A. S. Bagley & Shaffer, 2009; Chesler, Bagley, & Shaffer, 2010; Nash & Shaffer, 2011; Shaffer, 2010; Svarovsky & Shaffer, 2006).

The purpose of epistemic games is to teach young people what Charles Goodwin calls "professional vision" (1994): the shared way that professionals see and categorize their domain. Professional vision, according to Goodwin, is employed by a community of practitioners who expect from each other a common way of organizing the world that is consistent with the values and methods of the profession. All professional communities rely on a "set of values, preferences, and norms in terms of which they make sense of practice situations, formulate goals and directions for action, and determine what constitutes acceptable professional conduct" (Schön, 1987, p. 33). In other words, an epistemic game simulates a "community of practice" (Lave & Wenger, 1991): a group of people who share similar ways of seeing and solving problems.

T5. Frameworks for understanding distributed mentoring

T5.1 Communities of Practice

A community of practice is a group of people who have defined a set of collective knowledge as a result of working together over time. Members of a community of practice share an identity based on competence. As Wenger describes:

> When we are with a community of practice of which we are a full member, we are in a familiar territory. We can handle ourselves competently. We experience competence and are recognized as competent. We know how to engage with others. We understand why they do what they do because we understand the enterprise to which participants are accountable. Moreover, we share the resources they use to communicate and go about their activities. (1999, p. 152)

In other words, communities of practice cohere along three dimensions: mutual engagement, joint enterprise, and shared repertoire. These three dimensions of practice must be present for a community to be a community of practice, and members of that community are competent participants in each of them.

The mutual engagement is the way the members of the community function together. There are certain expectations about how to interact, how people treat each other, and how to work together. Community members are included in what matters to the community, and directly and routinely influence each other in those matters. Being in a community of practice thus means taking an acceptable and meaningful place in the network of relationships in the community as it conducts its work.

The joint enterprise is what the members of the community dedicate their efforts towards doing. Wenger describes the relationship of enterprise to practice as that of rhythm to music. Not random, but not a constraint, it "spurs action as much as it gives it focus." It defines relationships in the community in terms of the enterprise. In other words, it defines who participants in an activity are to each other, and how they can be accountable to each other, in terms of their shared understanding of that activity. Being in a community of practice means doing and being accountable to the work that the community has claimed as its own.

The shared repertoire is the set of communal resources (routines, sensibilities, tools, vocabulary, ways of doing things, etc.) that the community had developed over time.

It is, as Wenger puts it, "the discourse by which members create meaningful statements about the world" (1999, p. 83). A shared repertoire is thus similar to Gee's concept of Discourse, in the sense that it describes a way of "talking, listening, writing, reading, acting, interacting, believing, valuing, and feeling (and using various objects, symbols, images, tools, and technologies)" (2001, p. 143). In other words, it is the community's shared way of doing work. Being in a community of practice means using the acceptable and meaningful discourse of the community.

Lave and Wenger (1991) call the process of welcoming new members to a community of practice "legitimate peripheral participation." Legitimate peripheral participation is the way in which newcomers to the community take up its practices. Newcomers initially participate in ways that are less essential to the community's continued success. But over time, as they gain more experience, their participation becomes less tangential and more full. They begin to take on more and more of the essential practices of the community, mutually engaging in the community's practice, joining its enterprise, and sharing its repertoire, and assume more of the identity of a full community member. Understanding how one becomes a member of a community of practice means understanding the ways one shares in that community of practice in terms of its enterprise, its network of relationships, and its discourse.

Lave and Wenger (1991) intend that legitimate peripheral participation be taken as a whole and not broken into its constituent parts. For instance, in their view there is no such thing as illegitimate peripheral participation. They instead argue that each of the concept's aspects is "indispensible in defining the others and cannot be considered in isolation" (Lave and Wenger, 1991, p. 35). At the same time, they view legitimate peripheral participation as an “analytical perspective” (1991, p. 37) for understanding changing ways of participating in communities, including trajectories of social activity, developing identities, and forms of membership. These trajectories are not necessarily linear, but rather proceed in complex and relational fashion.

To see how understanding legitimate peripheral participation involves more than just examining the trajectories of learners becoming full partners in the community’s productive practices, consider the range of roles of community members with whom learners interact, due to both the multiplicity inherent in a community, and the multiplicity inherent in the growing expertise and thus changing status of the learners themselves. As they become members, learners in a community of practice also contribute to its processes of reproduction. As Lave and Wenger put it,

> In any given concrete community of practice the process of community reproduction - a historically constructed, ongoing, conflicting, synergistic structuring of activity and relations among practitioners - must be deciphered in order to understand specific forms of legitimate peripheral participation through time. This requires a broader conception of individual and collective biographies than the single segment encompassed in studies of "learners." Thus we have begun to analyze the changing forms of participation and identity of persons who engage in sustained participation in a community of practice: from entrance as a newcomer, through becoming an old-timer with respect to new newcomers, to a point when those newcomers themselves become old-timers. Rather than a teacher/learner dyad, this points to a richly diverse field of essential actors and, with it, other forms of relationships of participation. (1991, p. 56)

Lave and Wenger suggest that the “changing forms of participation and identity” involved in becoming a member of a community of practice includes relationships of participation that include the newcomers themselves helping to facilitate the legitimate peripheral participation of others. In other words, not only are newcomers engaged in a trajectory as *learners* participating in the community’s *productive practices*, but they are also simultaneously engaged in a trajectory as *teachers* participating in the community's *reproductive practices*.

Newcomers adopting the reproductive practices of a community of practice inevitably are teaching not only those who have experience in the community but also their equals. As Lave and Wenger point out, "it seems typical of apprenticeship that apprentices learn mostly in relation with other apprentices" (1991, p. 93). Lave and Wenger's characterization of legitimate peripheral participation thus takes a "decentered view of master-apprentice relations" in which the focus of analysis is not on the particular pedagogical relationship between a learner and expert, but rather to the "intricate structuring of the community's learning resources" (1991, p. 94). In other words, examining how learners join a community of practice involves looking at every corner of the community with which the newcomer engages, not just a single relationship between the teacher and learner. Indeed, considering mentoring as a function rather than the exclusive action of a particular kind of relationship role begs the question of *who* can provide mentoring functions. According to Lave and Wenger, peers qualify as candidates. Communities of practice, with their "richly diverse field of essential actors" (1991, p. 56) would therefore seem to fit the definition of mentor-rich environments.

The concept of Freedman's (1999) mentor-rich environment is predicated on the need for multiple sources of guidance, and the possibility, if not the current reality, of a long-term relationship with a quasi-parental adult. If the presence, or even the promise, of such a relationship is not required, and mentoring is simply a particular type of action taken in the context of a shared activity, then perhaps what is necessary is not a mentor-rich environment, but a *mentoring-rich environment*. To understand such distributed mentoring environments would require examining all the possible sources of mentoring in an environment. For Lave and Wenger, these sources are not limited to experts in the community, or even to peers. They also identify the important role that artifacts play in community practices. As they put it, "artifacts used within a cultural practice carry a substantial portion of that practice's heritage" (1991, p. 101). In a community of practice, then, using artifacts and tools is a way of directly participating in that community's joint enterprise and shared repertoire. They too can thus potentially provide mentoring functions.

T5.2 Activity Theories

T5.2.1 The Distributed Mind

While mentoring researchers suggest that the multiple needs of youth require multiple resources, learning scientists argue that *all* learners *always* rely on multiple resources. In the sociocultural views of cognition that build upon Vygotsyky (1978), such as activity theory (Engeström, 1999), mediational means (Wertsch, 1998) and distributed cognition (Hutchins, 1995; Norman, 1994; Pea, 1993), "participants" in an activity include not just people, but the settings and artifacts that influence and enable their activity. In other words, cognition and action are attributes of a system that includes multiple people and tools in a social, and socio-historical, context. For example, Pea's (1993) concept of distributed intelligence is a framework for addressing theoretical questions around how learners act in environments that are full of artifacts that mediate their activity. The resources that shape and enable activity are distributed in configurations across people, but also environments, artifacts, and situations. That concept gets operationalized in a study on a specific activity by Hutchins' (1995) in his ethnographic study of quartermasters in training. Hutchins describes how the quartermasters learning on the job have a *horizon of observation*, which is the sum of the features of a task that is available to them. There are tools and peer actions that help each individual quartermaster do his job, and understanding a quartermaster's activity requires accounting for the observable tools and peer actions that make his action possible.

According to Shaffer and Clinton (2005), these current sociocultural theories (like mediational means, activity theory, and distributed cognition) overemphasize the role of humans and inadequately consider the active role tools play in activity. Shaffer and Clinton build on these theories and sociologist Bruno Latour's (2005) actor network theory (ANT) to argue that tools play an analytically equivalent role in activity, with tools and people each mediating each other's actions. In ANT analyses humans are not treated any differently from nonhumans, but rather all things, human and nonhuman, are assumed to be capable of exerting force and joining together, changing and being changed by each other. Rather than assuming that tools mediate and enable human accomplishment, ANT looks at how accomplishment is the property of all of the participants—human and nonhuman—in the activity. In other words, agents and artifacts are both *actants* that are equal contributors to activity.

Building on these ideas, Shaffer and Clinton (2005) posit a theory of "distributed mind," in which activity is a process of mutual mediation between people and tools. Because of the reciprocal nature of mediation that is always present, the "actions that result" in activity are not overly attributed to either actant, whether person or tool. From the standpoint of a distributed mind theory view of cognition, then, the question of who can provide mentoring could also be extended to consider *what* can provide mentoring.

T5.2.2 Mentoring with nonhumans

In apprenticeships, learners engage with not just a single concerned mentor, but also with tools and peers and other types of actants, each of which serve to draw the learner into the culture of a practice. Since there are many potential sources of mentoring in a mentoring-rich environment, to examine the full mentoring experience of a learner, one must account for all of the mentoring a learner receives whatever its source. In other words, mentoring could be provided by a variety of humans and nonhumans; discovering that mentoring requires looking at the actants within each learner's horizon of observation.

Some work has already been done to this effect. Campbell and colleagues (2016), building on Hutchins' (1995) distributed cognition framework, examined distributed mentoring as a phenomenon of emergent mentoring functions distributed among fan fiction communities via fanfic websites. Focusing on the informal mentoring that occurs in networks of peers who share a particular interest, they found that artifacts—such as forum responses, reviews, private messages, and author's notes—provided key mentoring functions. The fanfic authors received numerous small pieces of advice in the form of story reviews or discussion forum responses; aggregated, these mentoring efforts were greater than the sum of their parts, just as in a cognitive system. From the perspective of a theory of distributed mind, then, there was no functional difference between direct correspondences between two human participants on the forum and encountering artifacts such as author's notes. They were both *mentoring actants,* participants in an activity that served mentoring functions.

While it is relatively simple to imagine how an artifact can explain a concept or model how to do something, it is more difficult to see how nonhumans could provide mentoring that consist of a sustained interaction. For example, one of the mentoring strategies that Hamilton and Hamilton characterize as desirable is *problem solving*, or "engaging the youth in a sustained interaction to achieve something the mentor may not initially know how to achieve" (2004, p. 420). While problem solving interactions are typically characterized by instant back-and-forth exchanges, such as a mentor and a novice huddled over a tricky problem, puzzling over how to make something work, the defining characteristic of this mentoring strategy is the position of each participant in the activity relative to the problem and to each other. For the problem solving mentoring strategy to work, both the more experienced participant and the more novice participant must be on relatively equal footing. Even if one participant is more experienced, the particular problem must still be new and unique (or treated as if it was new or unique), because if the more experienced participant already knows the solution, then the problem is not shared. While the novice participant is trying to solve the problem posed by the practice, the experienced participant is trying to solve the problem posed by the learner, and the interaction is no longer reciprocal.

Theories of distributed mind suggest that we always "interact" with tools and resources as equals in activity. As Campbell and colleagues (2016) demonstrate, with mentoring functions provided by nonhuman sources, issues of unequal power statuses are potentially deflected or diminished. Moreover, tools and resources have become more interactive with the advent of computational technologies. Advances in computational technology have filled every aspect of our lives with tools that interact with us and help us accomplish tasks and solve problems (Shaffer & Clinton, 2005). The number of these tools designed for learning purposes is growing, and now populate both formal and informal learning settings (Shaffer, Nash, & Ruis, 2015). Computational tools, such as games and simulations, increasingly provide sustained interactions that can look more like the back and forth collaborative problem solving that characterize traditional mentor-youth interactions. In other words, even the interactive mentoring strategies that promote reciprocity, such as Hamilton and Hamilton's (2004) problem solving, could potentially be offered by nonhuman tools.

T5.3 Participant structures

In mentoring rich environments like communities of practice, which involve multiple actants and participants rather than simply dyadic relationships, there are social and physical configurations that influence the way participants interact. Often referred to as *participant structures*, these arrangements of activity have been studied from a range of perspectives. Originally used to describe the different ways that teachers arrange the verbal interaction with their students (Cornelius & Herrenkohl, 2004; O'Connor & Michaels, 1996; Philips, 1972), participant structures have also been used to refer more widely to the norms of participation that dictate the characteristics of interactions. In other words, participant structures may be analyzed at both the micro-level of back-and-forth utterances between participants interacting, but also at a macro-level of social arrangements that may include discourse actions that go beyond verbal communication.

Theorists have investigated the ways some participant structures arrange interactions in the service of enrolling participants into communities of practice. Two such participant structures, jigsaws and re-voicing, operate at different levels of organization, but each one positions its participants as members of a community.

T5.3.1 Jigsaws

Some educational theorists have applied the concept of communities of practice into the design of learning experiences for the classroom by creating programs that incorporate participant structures meant to facilitate student's participation in classroom communities. For example, the Fostering a Community of Learners (FCL) program developed by Brown and Campione (1996) relies on particular participant structures to facilitate student's participation in classroom communities based on deep disciplinary (e.g., Math, Science) content. The FCL program has three main activities (a) *research*, in which students engage in independent and group inquiry, then (b) *sharing the information* that is a result of the information, in order to (c) perform a *consequential task*. In the FCL program, these three activities occur as part of a *jigsaw* participant structure:

> Students are divided into research groups, and then regroup into Jigsaw units composed of one member of each of the research groups. These "experts" share the benefits of their research so that all will be prepared for the consequential task, whatever it might be. By definition, the consequential task demands the compilation of all subunits of the knowledge unit under inquiry. (1996, p. 301)

Jigsaws organize students by distributing knowledge and the efforts to gain the knowledge amongst the students. The acquisition of that knowledge, from the original source and from the students' peers, is motivated by a consequential task that would be impossible without it. Each student, equipped with some unique and valued information, is then posed as an expert in charge of teaching that information to peers. In other words, the jigsaw participant structure positions students as equal and valued contributors of the classroom community's goal. It operates on the level of connecting different modes of activity, organizing the students' participation in distinct tasks, from individual research, to the interactions involved in sharing that research, to whatever the consequential task might be. Other participant structures can operate at the level of individual interactions.

T5.3.2 Reflection and Revoicing

The FCL program is intended to be a metacognitive environment (Brown & Campione, 1996). Throughout the stages of the jigsaw, students are encouraged to reflect on their work and understanding, whether that be the topics they are researching, their performance as participants in the community of learners, or the relationship between them. Some settings feature participant structures where reflection is its own important activity within a sequence of other actions. In the context of joining a community of practice, mentor-guided reflection is a way for the learners to see how to calibrate their activity so that it better matches the community's practices.

Schön (1983, 1987) describes how such mentor-guided reflection can occur in a reflective practicum, in which a mentor acts as a coach to novice professionals engaging in authentic, messy, and ill-structured problems. In a reflective practicum, one of the functions of the mentor is to help interns develop the ability to *reflect-in-action*, which is the ability to creatively solve the problems of the domain that do not have simple solutions (1983, 1987). Reflecting-in-action involves engaging in thought and action experiments during practice, considering potential actions, their consequences in the moment, and any cascading consequences that would result. To teach reflection-in-action, the mentor and novice meet to discuss the novice's progress on an authentic problem from the field. In this meeting, the mentor and novice engage in *reflection-on-action*, where they together examine the novice's past actions and discuss how to move forward in light of any lessons learned. This reflective conversation that occurs during the meeting between mentor and student is essential to make the ways of thinking of a profession visible and understandable to the novice (Schön, 1987). Through repeated cycles of reflection-on-action, novices gain the ability to reflect-in-action.

In these reflection meetings, when the mentor and learner engage in reflection-on-action, they are examining learner's work (their action) from the viewpoint of a seasoned professional. The job of the mentor is to reformulate what the learner has done so that it is better aligned with the way an experienced practitioner would act. In other words, the mentor is helping position the student and his work in the context of the profession. This type of reformulation happens in particular kinds of group discussions as well.

Theorists describe the potential of group discussions for "aligning students with each other and with the content of the academic work while simultaneously socializing them into particular ways of speaking and thinking" (O'Connor & Michaels, 1993). O'Connor and Michaels describe how participant structures function as participant frameworks, in which conversational turns systematically position students in relation to one another, to the teacher, and to the domain of inquiry (Cornelius & Herrenkohl, 2004; O'Connor & Michaels, 1996). They describe one particular participant framework, called *revoicing*, which is a kind of re-uttering (oral or written) of a discussion participant's contribution by another participant in the discussion. This re-utterance can have multiple features and purposes that all involve positioning participants in relationship to each other and to the topic of discussion. For example, a teacher's re-utterance of a student's contribution is not an exact replication of the language the student used, but rather a reformulation using language that is more appropriate or aligned with the norms of the domain. The teacher also provides credit to the student, by placing the student as the subject of the reformulation and by using the discourse marker "so" which marks a warranted inference (e.g. "So you think…" or "So you agree with George that…"). The student is then granted the right to affirm the teacher's reformulation, either because the teacher explicitly asks (e.g. "Do you agree?") or because the reformulation is itself posed as a question. As O'Connor & Michaels explain, the revoicing strategy has numerous benefits:

> It allows the teacher to effectively credit a student for his or her contribution while still clarifying or reframing the contribution in terms most useful for group consumption. It may socialize students into particular intellectual and speaking practices by placing them in the roles entailed by the speech activity of group discussion. It may also bring them to see themselves and each other as legitimate participants in the activity of making, analyzing, and evaluating claims, hypotheses, and predictions. (1996, p. 78)

In other words, revoicing is a participant structure that is uniquely well suited for socializing learners into a community of practice in the context of reflection meetings. It allows the facilitator of the discussion to reframe the discussion in terms and ways particular to the practice, and therefore train participants to speak in the certain register of the community's shared repertoire. At the same time, it assigns ownership of the repertoire to the learners, thereby granting them status as authentic participants in the community's practice.

T5.4 Epistemic Frame Theory

While mentoring functions distributed among multiple mentoring actants could be a mechanism by which learners are enculturated into a professional community of practice via apprenticeships, to understand what it means to adopt a culture requires a framework for deciding what counts as professional culture. The professional way of seeing the world that Schön describes as “the competence by which practitioners actually handle indeterminate zones of practice” (1987, p. 13) can be opaque to those outside the community of practice in question. Some specification of “professional vision” is provided by Goodwin (1994), who, in his description of archeological field work and courtroom practices, describes the concrete ways practitioners highlight and elide things that are important or not according to their professional perspective. Likewise, Sullivan (1995) offers a sense of how professionals employ an ensemble that includes intellectual, practical, and ethical components. Shaffer (Shaffer, 2006b) extends these insights by emphasizing the relationships between “the combination—linked and interrelated—of values, knowledge, skills, epistemology, and identity” that characterize the professional ensemble—what he calls the “epistemic frame.” Shaffer’s theoretical construct of epistemic frames is faithful to prior conceptions of professional expertise in that frames are both social and individual, and constituted with elements that inform particular ways of thinking, seeing, talking, doing, and decision-making. As Shaffer points out, an epistemic frame is thus like the grammar of a Discourse (Gee, 1999, 2001), or a more formal way of describing the shared repertoire of a community of practice (2010).

The way epistemic frame theory extends the concept of a shared repertoire is that epistemic frames further emphasize the specific ways that the elements of the frame are linked in practice (Shaffer, 2010). For example, reporters may write a certain way because they view their job as serving the important societal function of being a community watchdog. In this epistemic frame, a particular journalistic skill is informed by a specific journalistic value and a specific sense of professional identity. Although it could be argued that working a certain professional way, possessing certain professional knowledge, and having certain professional values are always unavoidably linked, particular frame elements are not always linked to all of the others in practice. As Shaffer (2010, p. 17) puts it, "the purpose in marking certain frame elements as significant to a community of practice is to understand how they become linked in the ways characteristic of expertise within the community." That is, by not assuming *a priori* that all epistemic frame elements are always linked in practice, one can examine *when they are* linked, and thus gain a valuable perspective on how professionals see and solve problems in practice.

This perspective is valuable for understanding how newcomers to a profession develop aspects of the epistemic frame. For example, in their study on how lawyers are educated, Sullivan and colleagues (2007) describe that while law schools train their students analytical skills, concepts, and profession-specific ways of making claims and arguments, a major limitation of legal education in the US is the lack of ethical preparation. Restated in terms of epistemic frame theory, law schools may teach the skills, knowledge, and epistemologies of the legal profession well, but they are not paying enough attention to legal values.

As teaching an epistemic frame is a way of enrolling a newcomer into a community of practice, particular participant structures play a role in this process. Participant structures have been used to explain teaching mechanisms in professional practica that help teach epistemic frames. Some of these structures are activities that correspond to the practices of a specific domain and serve a particular pedagogical purpose in terms of epistemic frame development. Shaffer (2005), for example, uses the term to refer to recurring social arrangements in a journalism practicum that help teach an epistemic frame. Hatfield and Shaffer (2010) showed how different participant structures in a journalism capstone course, which included activities such as news meetings and copy editing, integrated particular groupings of epistemic frame elements in a way that helped students bind together the epistemic frame of journalism. Other participant structures, however, are particular to practicum experiences but are not domain-specific. For example, mentors in the practica of a variety of different professions employ Schön's "Follow me!" coaching model. Nash and Shaffer (2013) examined Schön's "Follow Me!" coaching model in the context of a game design practicum, and found that the mentor scaffolded particular connections in the epistemic frame of game design in order to forge other connections.

Previous work on epistemic frames and how they are constructed in practice demonstrate the way learners' connect epistemic frame elements through participating in epistemic games (Arastoopour et al., 2012; Nash & Shaffer, 2011, 2012; Shaffer, 2006b; Svarovsky, 2011) and in other training settings (Nash & Shaffer, 2013; Ruis, Shaffer, Shirley, & Safdar, 2016). The focus of these studies is how different actions associated with particular professional subjects are connected to other actions associated with subjects from the same profession. For example, in Nash and Shaffer's study of mentoring in a game design practicum (2013), the focus was on how the mentor helped his students forge connections between three elements of the epistemic frame of game design: the skill of concept development, the knowledge of content domain, and the knowledge of game mechanics. However, each of these frame elements is itself a connection between two things. With the skill of concept development, a particular subject related to the professional practice of game design, *concept development*, contextualizes a general kind of action that involves some technique, a *skill*.

Epistemic frame elements are thus themselves made up of connections between two categories of practice, *practice-actions* and *practice-subjects*. The first category, practice-actions, includes the types of general actions that characterize participation in a community. They include actions that involve technique (skills), understanding (knowledge), valuing (values), warranting (epistemologies), and identifying (identities). Practice-actions are not specific to any particular community of practice; they are domain-general. In other words, members of all professional communities use skills, know things, value things, justify decisions, and identify members. Practice-actions are contextualized when they are connected to an aspect of a specific community of practice's purview. The subjects that contextualize different practice-actions may be grouped into subject areas that characterize the overall areas of interest to a community. These domain-specific areas of interest are practice-subjects.

To see how subjects are paired with practice-actions in an epistemic frame coding scheme, consider a study of an engineering virtual internship called Nephrotex (Arastoopour et al., 2013). In this study, Arastoopour and colleagues (2013) identified 20 epistemic frame codes based on the ABET criteria for undergraduate engineering program outcomes (Accreditation Board for Engineering and Technology, 2011). Those codes include (but are not limited to) the *Skill of design* and the *Epistemology of design*. These two epistemic frame elements share a subject, design. Two other codes included in their scheme, the *Knowledge of attributes*, and the *Knowledge of manufacturing process*, were also related to design. *Attributes* referred to a designed device's performance metrics, and the *manufacturing process* was one of the design parameters that the intern engineers could manipulate in the design process. Thus while the subject of these latter two epistemic frame elements was not design, by virtue of them being subjects that were specifically concerned with design, they would fall under the design practice-subject.

When examining how learners join a community of practice, Shaffer describes the importance of not assuming that all epistemic frame elements are always connected in practice, and that looking to see how and when they are connected can reveal the ways of thinking and acting characteristic of a community. Extending the same logic, when examining how epistemic frame elements are taught by multiple sources of mentoring, considering how epistemic frame elements themselves are constructed in practice—how general practice-actions are connected to practice-subjects by mentoring actants—may reveal another aspect of how thinking like a professional is taught.

T6. Nephrotex

Shaffer's epistemic games are virtual internships designed to teach the epistemic frame of a community of practice (Shaffer, 2006b). They have simulated a variety of professional communities of practice, including urban planning, journalism, engineering, community organizing, and graphic design (E. A. Bagley & Shaffer, 2010; Hatfield, 2015; Shaffer, 1997; Svarovsky & Shaffer, 2007). Nephrotex is an epistemic game focused on the field of engineering that has been implemented as a first year design course in the engineering departments of multiple universities (Arastoopour et al., 2013; Arastoopour & Shaffer, 2013; Chesler, Arastoopour, D'Angelo, & Shaffer, 2011; D'Angelo, Arastoopour, Chesler, & Shaffer, 2011).

In Nephrotex, first-year engineering students work as interns at a fictitious engineering company to design a filtration membrane for a hemodialysis device. Under the guidance of fictional employees at the engineering company, also called Nephrotex, interns work both individually and in teams, performing tasks that they would do in a real internship. They read and analyze research reports, design and test prototypes, respond to client and stakeholder requirements, write reports, and propose and justify design prototypes, all within a self-contained workplace simulation. All activities and interactions in Nephrotex take place through a web-based platform that includes communication tools such as internal email and chat clients, calendar tools that include a Gantt chart and a dynamic task notification system, engineering tools that allow interns to analyze data and design and test prototypes, and a notebook tool for authoring and sharing research reports. Nephrotex engages the students in a real-world design problem, provides a realistic work environment complete with authentic professional tools, and assigns tasks that real engineers would do, over the course of a multi-week project. Nephrotex thus enables first-year undergraduates to experience an authentic engineering community of practice that consists of a weeks-long, multi-stage design task and features multiple potential sources of mentoring guiding them in this project.

In Nephrotex, nearly all intern activity, including chat and email correspondence, all work products, and all navigational actions in the site (e.g. accessing an email, looking at a calendar or any other resource) is captured by Nephrotex's online platform and stored in downloadable log files. Nephrotex thus also enables researchers to access a near-complete activity record of late adolescents working on tasks in a simulated community of practice that features multiple potential sources of mentoring.

T7. Framework, Hypotheses, and Research Questions

The theory of distributed mentoring examined in this study claims that mentoring is a function that can be provided by non-mentors, both human and nonhuman, and that in the context of mentoring-rich environments that include multiple mentoring actants, what matters is the way that the mentoring is coordinated. It is hypothesized that this distributed mentoring framework can show how properly coordinated mentoring can simulate a community of practice, and how such a community of practice can enroll young people as members in it.

It tests these hypotheses in a virtual internship designed to simulate a professional community of practice, the epistemic game Nephrotex. In examining Nephrotex, this study asks the following four research questions:

1. Does Nephrotex feature mentoring, and if so, how?
2. Is the mentoring in Nephrotex distributed among sources, and if so, how?
3. Does the mentoring distribution in Nephrotex contribute to the simulation of an engineering community of practice, and if so, how?
4. Does the mentoring in Nephrotex successfully enroll the participants as members in an engineering community of practice, and if so, how?

Methods

The research questions were addressed in this study through an analysis of participants' discourse and work products in interaction with diverse mentoring actants during the epistemic game, *Nephrotex*.

To answer the first research question, I looked at one participant's experience in the internship. Focusing on the different people, resources, and tools with which he interacted, I examined the data for instances of mentoring strategies that used both didactic and reciprocal methods.

To answer the second research question, I followed that same participant in one particular activity early in the internship. I examined whether the mentoring he encountered during that activity was provided by multiple sources, and then mapped out how different mentoring strategies and goals were distributed among those sources.

To answer the third research question, I continued with that same participant through the two following activities in the internship. In these activities, I examined how the distributed mentoring strategies and goals he encountered reinforced or complemented each other. I then considered how the coordination of these mentoring strategies and goals constructed the key aspects of a community of practice: a joint enterprise, a shared repertoire, and mutual engagement.

To answer the fourth research question, I examined how three participants responded to the coordinated mentoring strategies and goals. I looked at two participants' task performances early in the internship and then again late in the internship to see how they adopted the shared repertoire they were taught. Then I looked at another participant (the one I followed to answer the first and second research questions) in yet another activity to examine whether and how in a group activity he used mentoring strategies used by mentors with him.

After describing the setting and participants, this chapter provides definitions of key terms in a description of different sources and forms of data. It then provides an explanation of which categories were used for which analytical purpose, how that data was segmented for analysis, and finally the methods of coding and analysis of mentoring and learning.

M1. Setting and Participants

In the fall semester of 2014, Nephrotex was offered as an Introduction to Engineering Design course for 26 first-year undergraduate engineering students at a large, public, midwestern university. Participants self-selected to enroll in the virtual internship; no other participant selection or filtering effort was made.

Although participant demographic data was not collected in this study, Nephrotex is offered as a first-year undergraduate course, and the assumption here is that the average first–year undergraduate student at a public state university is likely between eighteen and nineteen years old (i.e. a late adolescent).

Nephrotex was an 8-week long engineering virtual internship program in which students role-played as interns at a fictional biomedical engineering design company, also named Nephrotex, to design dialyzers for hemodialysis machines. The students accessed the internship by logging into an online web platform, called WorkPro, which included email and chat interfaces, an online notebook, calendar tools, and design and research tools. Participating in this virtual internship involved interacting with the other employees of the fictitious firm, including teams comprised of their fellow interns. The typical faculty instructor of the undergraduate engineering design course did not play a role within the internship simulation. Fictional veteran employees at the firm who were controlled and role-played by internship managers, who were trained engineering senior undergraduate students instead guided the intern's experience through the company web platform. Internship managers logged into the platform during the scheduled class sessions and played the role of the design advisors who interacted with the interns via the chat client. They also controlled a character that functioned as the interns' supervisor, who interacted with the interns only through email. Interns could log on to do work outside of class and the internship managers could log on to assess interns' submitted work products so that the supervisor character could send the interns' the appropriate feedback.

To start the internship, the interns conducted background research within the Nephrotex website, reading a set of curated company white papers based on actual experimental data with a variety of polymeric materials, chemical surfactants, carbon nanotubes, and manufacturing processes. They also learned about the company's five internal consultants, who prioritized different design outcomes and were the arbiters of whether the interns' final design was successful or not. After collecting and summarizing research data, interns began the actual design process using a simulated engineering design tool. Interns designed devices based on their prior research, tested their designs, and analyzed their test results. During the second half of the internship, students switched teams and informed their new team members of the research they had conducted thus far in the internship. In the new teams, students tested more devices, analyzed the second iteration of results, and made a choice for a final prototype. During the final days of the internship, students presented their final device design and justified their design decisions to their peers and instructor, then completed an exit interview with survey questions about their attitudes towards the engineering profession. Nephrotex thus consisted of activities focused on a variety of engineering and internship tasks (Table 1).

Table 1

Sequence of activities in Nephrotex

Activity	Type
Introduction and Workflow Tutorial with Entrance Interview	Logistics
Background research on dialysis	Research
Graphing Surfactant Data	Research
Reflection team discussion of surfactants	Group Reflection
Summarize internal consultant requirements	Research
Choose consultants to analyze	Research
Individuals design 5 prototypes	Design
Team designs batch using 1 material	Group Design
Individual analysis of first batch	Analysis
Reflection team discussion of first batch results	Group Reflection
New teams design second batch	Group Design
Individual analysis of second batch	Analysis
Reflection team discussion of second batch results	Group Reflection
Individual final design justification	Design
Presentation Preparation	Group preparation
Presentations and peer assessment	Group presentations
Exit interview w team bonuses	Logistics

M2. Data

This study examines mentoring from the perspective of a distributed mentoring framework. Therefore, the data include all possible sources of mentoring that participants encountered in the virtual internship.

Two different categories of data were collected: *Internship system data*, including tools and resources in the internship's work portal, WorkPro, and *Participant data*, including logs of nearly all of the participant interactions and communications generated through their activity in WorkPro (Table 2).

Table 2

Categories of Nephrotex data

Internship system data			**Participant data**		
Data type	**Form**	**Description**	**Data type**	**Form**	**Description**
Engineering tools	Screenshots	Interactive data analysis and design tools	Chat messages *sent*	Log file	Chat messages the participant sent
Calendar tools	Screenshots	Task management and notification tools	Chat messages *seen*	Log file	Chat messages from the participant's design advisor and peers
Technical Documents	PDFs	Curated research papers related to participants' design task	Email messages *sent*	Log file	Email messages the participant sent
Example Notebooks	Log file	Examples of work products that participants could use as models	Email messages *seen*	Log file	Email messages from the participant's supervisor, design advisor, and peers
			Notebooks submitted	Log file	Notebook entries authored by participant and sent to supervisor
			Notebooks shared	Log file	Notebook entries authored by participant and shared with peers
			Peer notebooks shared	Log file	Notebook entries authored by participant's peers and shared with participant
			Navigational Data	Log file	Records of participant navigational actions, such as when participants visited tools, resources, or their inbox

Each of these categories, along with a description of the data format, and examples of the types of data within each category, are described in more detail below.

One commonality across many of the different types of data is the format: a log file. Nearly all of the activity and interactions in Nephrotex occur in an online work portal called WorkPro. This portal was also designed as a research tool to record, organize, and store the data associated with these activities and interactions in log files for use in research. These files can then be downloaded as CSV files and analyzed via spreadsheet program (e.g., Microsoft Excel). In these log files, each action is represented as a separate row while each column contains the different fields and parameters important for that kind of activity or content. In addition, certain common fields are recorded for all log types including, but not limited to, who initiated the action and what time it occurred.

M2.1 Internship system data

Many resources and tools in Nephrotex were designed and created by the virtual internship developers, rather than being created by participants. Internship system data comprises these forms of data, including engineering and calendar tools, technical documents and example engineering notebooks.

M2.1.1 Engineering and Calendar Tool Data

Two engineering tools were used in the internship, a graphing tool and a design tool. The graphing tool was a data analysis tool that created a visual representation of data that the interns provided. The design tool, the Form for Electronic Experimental Device

Simulation (FEEDS), allowed interns to design prototype dialyzers and submit them for testing.

Two calendar tools were used in the internship. The Gantt chart was a spreadsheet indicating the full list of tasks in the internship and their due dates. The Deliverable list was a notification tool that informed interns of their latest tasks, their deadlines, and their completion status (whether they had been submitted, approved by the supervisor, or returned for revision). For the purposes of this analysis, the developers provided screenshots of these tools. It is important to note that the screenshots of the Graphing Tool, FEEDS, and the Deliverable List illustrated the type of information that they provided participants. Screenshots of these tools for every single participant at every stage in the internship were not available.

M2.1.2 Technical Document Data

The participants read internal Nephrotex technical documents about experimental research and design related to their tasks. While there were 28 total technical documents, interns were not required to read all of them. They accessed the technical documents they were assigned to read in a shared resources space in the WorkPro site. For the purposes of this analysis, the developers provided PDFs of these documents.

M2.1.3 Example Notebook Data

The interns also had access to twelve example notebooks that were available as models for their own notebook submissions. They accessed these technical documents in a shared resources space in the WorkPro site. For the purposes of this analysis, all of the example notebooks in Nephrotex were accessed via downloaded log files (Figure 1).

id	created	content	title
356	9/16/14 23:27	Title Background Research Example Notebook 	Background Research Example Notebook
607	9/18/14 9:42	Title Power Source and Control Sensor Example	Surfactant Example Notebook

Figure 1. Excerpt of an example notebook log.

Each row was a separate example notebook. The body of the example notebook was available under the column labeled "content," and the title of each example notebook was available under the column labeled "title." Relevant metadata included a unique identification number, and the timestamp, which indicated the time at which the notebook became available (column labeled "created").

M2.2 Participant data

WorkPro logged both who did what when and the content of those actions. In the former case, log files recorded *activity data*, tracking when each participant used a particular feature on the site. Any time a participant triggered some action by "clicking" on the site (e.g. saving a notebook or sending an email) the website recorded that action in a log file with a time stamp and various meta-data that identified that action. The complete data set of these actions of all the participants from the beginning to the end of the internship included 69,774 unique actions. In the latter case, log files recorded *content data* (*Email Data, Chat Data,* and *Notebook Data*), which was what was "said" in all of the emails, chats, and notebooks.

For content data, different kinds of content featured different important elements, but some elements were always recorded. For all content creation log entries, the content itself (e.g. the body of the email or notebook entry or the substance of the chat) was recorded under a column labeled "content." With all content data, in instances where interns referred to each other by their actual names, those names were replaced with pseudonyms in the analysis that followed.

The meta-data in the log files for the various types of content data reveal some of the same information as the log files for the activity data. For instance, every email or chat sent appears in both the activity data and the content data. Content data, however, also contains the content of the chat or email message. For this reason, it was particularly important to include the information in the activity data that was not also available in the content data: the *navigational data*, or when participants visited particular tools and resources.

In all log files, different types of meta-data were recorded that were specific to the type of data, but some meta-data was common across all of the log files. All of the participants (the interns) and the fictional characters in the internship with whom the participants directly interacted (the design advisors and the supervisor) were assigned unique user identification number ("user_id" in the log files) by which their actions and activity could be identified and attributed to them. Also, in all log files the specific moment that the action happened was recorded under a column labeled "created."

M2.2.1 Navigational data

Whenever a participant navigated to a specific message in their inbox, or their calendar, or any other tool or resource log files recorded that action. This navigational data was accessed via downloaded activity logs. In the logs, each row was associated with one action in WorkPro (Figure 2).

id	created	displayString	page	user_id
3044	9/16/14 16:14	Viewing Resource: Internship Workflow	/uw2014a/resources/view/4	36
3047	9/16/14 16:14	Reading Email	/uw2014a/email/getEmailMessage/t24	36
3056	9/16/14 16:15	Saving Note	/uw2014a/notebook/saveNote/52	36

Figure 2. Excerpt of activity log for participant 36

The “displayString” column describes the action, and the “page” column adds further identifying information about the action. For example, in action 3047, participant 36 was reading an email (“Reading Email”). The email he was reading, “t24” in the “page” column, could be identified as the instructions email he received from the supervisor in the “Introduction and Workflow Tutorial” activity by looking in participant 36’s email log.

Note that in the *Excerpt log for participant 36*, the ID numbers are not consecutive. This is because the original log file contained actions from all the participants sequenced chronologically. Thus the actions happening at the same time but by other participants had been filtered out of this excerpt. This phenomenon will be repeated in all excerpts shown in the following sections in this chapter.

M2.2.2 Email data

Interns used an internal WorkPro email client where they received emails from their supervisor, and where they could author and send emails to other participants in Nephrotex. Email data was accessed via downloaded data log files (Figure 3). In the log files, each row was associated with one email.

id	created	content	title	user_id	to_user_id
1928	9/25/14 10:17	Tim,</br></br>For the next part of the design process, I'm asking each team to	Assessment of Consultants' Requests	5	43
2115	9/26/14 17:06	Tim, I reviewed and witnessed your notebook entry. Your research and	Re: Assessment of Consultants' Requests	5	43
2117	9/26/14 17:06	Tim,</br></br>The next step in the design process is to create five preliminary	Individual Experimental Device Design	5	43
2131	9/28/14 15:02	Tim, Thanks for completing your notebook. 	Re: Individual Experimental Device Design	5	43

Figure 3. Excerpt of email data log file for emails sent to participant 43.

This excerpt shows the log of five emails sent to participant 43. Additional relevant metadata included the email's recipient (column labeled "to_user_id"; in this case the recipient is participant 43), and email subject line (column labeled "title"). During the internship, participant 43 received fifty-two emails, and sent twenty-five emails.

M2.2.3 Chat data

Interns were grouped into teams, and each team had its own private chat "channel." Chat conversations were accessed via log files. In the log files, each row was associated with one chat message (Figure 4). There were 4,186 total chat messages in the internship, divided among the interns and design advisors.

id	roomName	user_id	ChatGroup	created	content
2826	Team designs batch using 1 material	40	PSF	10/2/14 9:56	So what do we want to do for the third one?
2827	Team designs batch using 1 material	35	PSF	10/2/14 9:56	3rd and 4th were surfactant changes
2830	Team designs batch using 1 material	35	PSF	10/2/14 9:57	So maybe Phase, Steric, and 2%
2831	Team designs batch using 1 material	41	PSF	10/2/14 9:57	We can change a surfactant to Negative Charge
2834	Team designs batch using 1 material	35	PSF	10/2/14 9:57	or 1.5%

Figure 4. Excerpt of a chat log.

This excerpt shows five chat messages in one team's chat channel. Additional relevant metadata associated with each chat message included the intern team having the chat conversation (column labeled "ChatGroup"; the name of the team is "PSF"), and the activity that the team was currently working on (column labeled "roomName").

M2.2.4 Notebook data

Interns wrote and submitted notebook entries, their "deliverables," for each activity. Intern notebooks were accessed via notebook logs. In the log files, each row was associated with one notebook entry (Figure 5).

id	created	content	title	submitted	user_id
1026	9/23/14 9:33	<p>The meeting occured today on September 23, 2014 at 9:39am and er	Reflection team discussi	9/23/14 10:16	43
1707	9/25/14 9:23	<p>Attribute: Blood Cell Reactivity Standards: Minimum: 75	Summarize internal cons	9/25/14 10:13	43
2031	9/26/14 1:08	<p>Michelle Proctor</p> <p>Attribute: Flux 	Choose consultants to a	9/26/14 16:56	43

Figure 5. Excerpt of notebook log for participant 43.

Relevant metadata associated with each notebook submission included the title the participant gave his notebook (column labeled "title") and the date and time the notebook was sent (column labeled "submitted").

M3. Analysis

This study examined data from a virtual internship for evidence of mentoring actions, and for evidence of participant use of the epistemic frame. The analysis involved:

1. Identifying which data would be included in the analysis.
2. Segmenting the activity in the internship into sensible units for analysis.
3. Coding the segmented units for the existence of mentoring and for the existence of epistemic frame usage. This study looked for evidence of mentoring strategies, and also looked for evidence of two distinct mentoring goals, facilitating task achievement and teaching the engineering epistemic frame. This study looked for epistemic frame usage in participant discourse, including chats, emails, and submitted notebooks.

M3.1 Data Inclusion

As an interwoven mixture of individual and team-based activities, the virtual internship provided participants multiple opportunities to witness the discourse and actions of others. Simultaneously, participants were also provided numerous opportunities to act and create discourse throughout their experience. This meant two related but different data inclusion strategies were required. For each participant a *horizon of observation* was constructed to determine which data to include for analysis of mentoring available to a participant. Each participant's *participant content data* were used to determine which data to include for analysis of epistemic frame acquisition.

M3.1.1 Participant horizons of observation

Each participant in Nephrotex had a horizon of observation, which was defined by what, during the internship's activities, the participant witnessed in the WorkPro site. For example, participants were grouped into teams, and each team had its own private chat "channel." This chat window was a persistent presence on the WorkPro site and thus participants saw all teammate and design advisor chat activity in their team's chat channel. Participants could not access other team's chat conversations, so anything in those chat windows was not in a participant's horizon of observation. Similarly, any emails sent to a participant were seen by that participant alone, as email inboxes were accessible only to their owners. Participants could also navigate to different sections of the WorkPro site to access different tools and resources. If, based on the Navigational log file, there was a record of a participant visiting a particular tool or resource, then it was deemed part of that participant's horizon of observation.

Thus each participant's horizon of observation included any emails that participant received, any chat conversation that took place in that participant's groups chat window (minus the participant's own chat messages), any places in WorkPro that participant visited, including resources like the technical documents, engineering tools like FEEDS and the graphing tool, calendar tools like the Gantt chart and Deliverable list, and example notebooks and shared notebooks in the shared space (Table 3).

Table 3

Constructing participant horizons of observation from the data

Potential source of mentoring	**Data source to determine what participant witnessed**	**Data source to be segmented**	**Data source to be coded**
Any emails that participant received	Navigational Data	Email data	Email data
Any chat conversation that took place in that participant's groups chat window (minus the participant's own chat messages).	Chat data	Chat data	Chat data
Any notebooks shared (example notebooks or peer notebooks)	Navigational Data	-Notebook Data -Example Notebook Data	-Notebook Data -Example Notebook Data
Any other places in WorkPro that participant visited, including resources like the technical documents, engineering tools like FEEDS and the graphing tool, calendar tools like the Gantt chart and Deliverable list	Navigational Data	Navigational Data	-Technical Document Data -Engineering Tool Data -Calendar Tool Data

Being considered within a participant's horizon of observation, these emails, chat conversations, and tools and resources were segmented and coded in the next steps of the analysis. Any mentoring that happened in any of those places or from any of those sources was considered to be mentoring in that participant's horizon of observation.

M3.1.2 Participant content data

Participant content data was the combination of each participant's authored email and chat messages along with the notebook entries that player prepared and submitted as part of each of the internship's activities[5]. Data in this type were segmented and coded for use of epistemic frame elements[6].

M3.2 Segmentation

The general criteria for determining units of analysis in this study were activity, source, and utterance.

M3.2.1 Activity

The Nephrotex internship was organized by a series of discrete activities (illustrated in Table 1), each with a particular focus, related resources and tools, and a particular deliverable. These activities were thus the meaningful segments in which the participants' activity and horizons of observation could be observed.

M2.2.2 Source and Utterance

As revealed in the description of the data, all of the data that come in the form of log files were automatically segmented into rows that represent a single action in WorkPro. Depending on the data type, these single actions might be a chat comment, an entire email message or notebook entry, or a visit to a feature (such as a technical document) on the website.

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[5] Note that in the chat window, each participant's authored content was in that participant's teammates' horizons of observation. In other words, one participant's chats could be another participant's mentoring. Similarly, if a participant shared a notebook entry or sent an email to another participant, those data points were in one intern's participant content data category and in the receiving participant's horizon of observation category. Therefore, while these analytical categories are exclusive for each participant, they are nonexclusive across participants.

[6] Unless noted in the analysis, no Nephrotex discourse presented in the Results section has been edited. Therefore, all typos, misspellings, and other grammatical offenses are properties of the data, and not the analysis. On the occasion that bracketed numbers have been added to discourse for ease of reference in analysis text, it has been noted in the analysis.

In the example below (Figure 6), three participants (user_ids 35, 40, and 41) were having a discussion in their chat window. This log file excerpt had already been filtered to show only the chat of the participants in one team (the "PSF" team). Within this log file excerpt are the data that provide the analytical boundaries for segmenting chat data into analytical units.

id	roomName	user_id	ChatGroup	created	content
2826	Team designs batch using 1 material	40	PSF	10/2/14 9:56	So what do we want to do for the third one?
2827	Team designs batch using 1 material	35	PSF	10/2/14 9:56	3rd and 4th were surfactant changes
2830	Team designs batch using 1 material	35	PSF	10/2/14 9:57	So maybe Phase, Steric, and 2%
2831	Team designs batch using 1 material	41	PSF	10/2/14 9:57	We can change a surfactant to Negative Charge
2834	Team designs batch using 1 material	35	PSF	10/2/14 9:57	or 1.5%

Figure 6. Excerpt of a chat log.

As seen in this excerpt, the chat data collected in log files were automatically segmented by row, where each row was a single message added to the chat. These single actions, one per row, are referred to as *utterances*. There are five utterances in this segment. This excerpt also takes place in a single *activity* ("Team designs batch using 1 material").

While each utterance had an author (the sender of the message), the *source* construct for segmentation was contingent on the analytical target. For instance, when examining the participant content (what a participant created), a single analytical unit in the chat data was all of the aggregated utterances for a single participant within the bounds of a single activity. For example, participant 35's three utterances, along with all of the rest of participant 35's utterances in this activity, would be considered a single analytical unit. In this case, source and author were equivalent.

However, when creating a horizon of observation for a participant, source and author were not always equivalent. This study focuses on how mentoring can be distributed among different sources. These different sources were distinguished by type, rather than personal or individual differences. Therefore, for participant 35, the potential mentoring contributions provided by participant 40 were not distinct from the potential mentoring contributions provided by participant 41. In other words, when creating the horizon of observation for participant 35, a single analytical unit in the chat data was all of the aggregated utterances for all of participant 35's peers within the bounds of a single activity. In this instance, the source construct was based on the functional role, *peer*, rather than individual author.

To see another example of different ways of using source to construct analytical units, Figure 7 shows another chat excerpt, in which the same three participants (user_ids 35, 40, and 41) were having a discussion with their design advisor (user_id 4) in a different activity.

id	roomName	user_id	ChatGroup	created	content
3673	Reflection team discussion of first batch results	4	PSF	10/7/14 9:41	What role did the requests of the internal consultants play in deciding which prototypes to test?
3680	Reflection team discussion of first batch results	35	PSF	10/7/14 9:41	For surfactants, we chose the most popular ones based on flux, blood cell re activity, not on cost. After we just adjusted the other attributes from the control group, as in slightly changing nanotube % to see which performed better, etc.
3685	Reflection team discussion of first batch results	41	PSF	10/7/14 9:42	Which ever was most recommended to the consultants was the one we wanted to test, then we changed a variable depending upon what we thought was second most recommended etc
3686	Reflection team discussion of first batch results	40	PSF	10/7/14 9:42	We tried to fulfill each consultants request as best we could but still had to compromise on certain things

Figure 7. Excerpt 2 of chat log.

When creating the horizon of observation for participant 35 in this instance, two distinct analytical units were included from the chat. One single analytical unit in the chat data was all of the aggregated utterances for all of participant 35's peers within the bounds of a single activity. Another analytical unit present was all of the aggregated utterances for participant 35's design advisor (user_id 4) within the bounds of the same single activity. In other words, this chat data revealed two sources, each with the potential for providing mentoring, in participant 35's horizon of observation: his design advisor and his peers.

There is one other source formed by the aggregation of chat messages in this excerpt. Some of the activities in Nephrotex were collaborative. Therefore the activity of the participants during activities when they were, for example, making group decisions in the chat window, could be considered as a whole. In this case the analytical unit was not based on individual participants' chats, but on the aggregation of all of the participants in the team. In this way, another meaningful category of participant was the *team*. In other words, when examining the performance of the participant team, the single analytical unit in the chat data was all of the aggregated utterances for all of participants within the bounds of a single activity

Emails were likewise segmented by utterance and source. Figure 8 shows the emails sent by the supervisor to one participant, participant 43. In other words, they show the emails in participant 43's horizon of observation.

id	created	content	title	user_id	to_user_id
1928	9/25/14 10:17	Tim,</br></br>For the next part of the design process, I'm asking each team to	Assessment of Consultants' Requests	5	43
2115	9/26/14 17:06	Tim, I reviewed and witnessed your notebook entry. Your research and	Re: Assessment of Consultants' Requests	5	43
2117	9/26/14 17:06	Tim,</br></br>The next step in the design process is to create five preliminary	Individual Experimental Device Design	5	43
2131	9/28/14 15:02	Tim, Thanks for completing your notebook. 	Re: Individual Experimental Device Design	5	43

Figure 8. Excerpt of email data log file for emails sent to participant 43.

Like the chat log files, email data collected in log files were automatically segmented by row, where each row was a single email sent. Each row was thus an utterance. Each utterance had a source, which was the sender of the message. There is only one source in this excerpt (participant 5, the supervisor). Finally, this excerpt reveals emails that were sent in two activities (The subject lines of the emails are the same as name of the activity:

“Assessment of Consultants’ Requests” and “Individual Experimental Device Design”). When analyzing the mentoring that a participant received in a particular activity, the analytical unit for emails was the aggregated set of emails from a single source within the bounds of a single activity.

The interns’ submitted notebooks were segmented just like the emails. Figure 9 shows three notebook submissions for three different activities by participant 43.

id	created	content	title	submitted	user_id
1026	9/23/14 9:33	<p>The meeting occured today on September 23, 2014 at 9:39am and er	Reflection team discussi	9/23/14 10:16	43
1707	9/25/14 9:23	<p>Attribute: Blood Cell Reactivity Standards: Minimum: 75	Summarize internal cons	9/25/14 10:13	43
2031	9/26/14 1:08	<p>Michelle Proctor</p> <p>Attribute: Flux 	Choose consultants to a	9/26/14 16:56	43

Figure 9. Excerpt of notebook data log file for participant 43.

Each single notebook entry, authored and sent by a single participant in a single activity, was considered a single analytical unit. The same held true when constructing the horizon of observation for a participant. Any example notebook or shared peer notebook accessed by a participant in an activity was treated as a single analytical unit.

For the resources and tools that the participants visit and use in the course of an activity, source and utterance were treated as equivalent. For example, if a participant visited the Gantt chart in one activity, any mentoring that the Gantt chart offered was treated as happening in that activity from the Gantt chart. If the participant also visits a technical document in that activity, the content of that technical document was treated as a single analytical unit, distinct from the content of the Gantt chart. When considering the mentoring that the participant encountered in that activity, both were included as distinct sources. The same logic followed for participants accessing engineering tools like FEEDS and the graphing tool, or the other calendar tool, the deliverable list.

M3.3 Coding for Mentoring Strategies

Since Nephrotex simulates a workplace setting, this study used a mentoring strategy coding scheme that is based on the set of six mentoring strategies Hamilton and Hamilton (2002; 2004) used in their study on workplace mentoring. Their scheme included strategies that were common and didactic, such as *Demonstrating, Explaining how, Explaining why,* and *Monitoring*, and also more rare and reciprocal strategies, like *Problem solving* and *Reflective questioning*.

This study adjusted Hamilton and Hamilton's coding scheme by combining two of their strategies. Hamilton and Hamilton specified the types of explaining that the mentors in their study did: *explaining how* and *explaining why*. However, mentors explained for other purposes in Hamilton and Hamilton's study that were not captured by the *explaining how* and *explaining why* categories. For example, in their results, Hamilton and Hamilton quote one youth describing an interaction with a mentor explaining a task to him:

> Like when we did this block, he gave me a block of wood, rectangle shape, and he said, "We need to fit four screws on the top and three screws on the bottom."
> …
> And then he showed me how you take measurements from each dimension with the screws and how you plot it on there the correct way, taking measurements and taking into account the size of the hole and the size of the screw (2002, p. 69)

Although the mentor very clearly helped the youth by *explaining how* the task could be done ("he showed me how…"), he also *explained what* the task was ("we need to…"). One could easily imagine mentors also *explaining when* a task needed to be finished. In another example from Hamilton and Hamilton's study (2002), a mentor turned over the planning of a dental health station at a Head Start health fair to the summer intern in her pediatric dental clinic. Part of the mentor's job of facilitating the intern's accomplishment of this task involved explaining when tasks needed to be completed, as the health fair was happening on a specific date. These examples of other types of explaining focus more on defining a task (explaining what or when) rather than supporting how to do it (explaining how or why). As this study looked for mentoring from a variety of potential sources, and treated mentoring purposes as separate analytical categories, it considered all the types of explaining that could occur. Using a more general *explaining* category is consistent with other researchers who have categorized mentoring strategies (Hamilton and Hamilton, 2002).

This study's revised mentoring strategy coding scheme is described, with examples, in Table 4.

Table 4

Mentoring Strategy Coding Scheme

Mentoring Strategy	Description	Type	Example
Explaining	Delivering information.	Didactic	"Just to confirm for everyone, the notebook for this task will be due at 5pm today followed by an additional task due 5pm on Monday."
Monitoring	Observing and giving feedback.	Didactic	"I reviewed and witnessed your notebook entry. Your research and recommendations will be invaluable as we move forward with the design process."
Demonstrating	Explicitly modeling how something can be done successfully.	Didactic	*Note: Modeling is only determined when it has been explicitly signaled that it is a model. The following excerpt was identified as a model design justification:* "We chose the Series Elastic actuator because of its overall good performance.

			At ROM 4, the payload and agility were very good without losing too much recharge interval time. The Series Elastic actuator did not have great recharge interval stats but we knew from previous tests we could make up for that with the other design choices. The only real negative was that the cost of the actuator was fairly high at $72."
Reflective Questioning	Engaging the learner in a conversation about the learner's relationship with—and understanding of—the task and the learner's development.	Reciprocal	"What did you discover about the design problem?"
Problem Solving	Engaging the youth in a sustained interaction to achieve something the mentor may not initially know how to achieve	Reciprocal	*Note: Problem solving occurs over multiple interactions, and is contingent on contextual information an excerpt may not reveal.* "33: Alright team, how should we go about this? 26: It would probably be easiest to choose from the prototypes we already have. 37: Do we want to test things that we think will work, test things that will give us information on how aspects relate, or both?"

M3.4 Coding for Mentoring Goals

Mentoring strategies are used for particular purposes. In joint activities, mentoring has a dual purpose. First, it creates some structure and guidance to facilitate the accomplishment of a task or set of tasks. Second, it promotes development by teaching what the youth need to accomplish those tasks. There are thus two coding schemes used in this study: one to categorize the mentoring actions focused on facilitating the participants' task achievement, and one to categorize the mentoring actions focused on teaching the participants engineering epistemic frame elements.

M3.4.1 Facilitating task achievement

In Nephrotex, the task goals were the deliverables assigned for each activity. Mentoring actions that were associated with defining the interns' task, setting the deadline for the task, supporting the interns' completion of the task, or evaluating the interns' performance on the task were considered mentoring actions for the purpose of facilitating task achievement.

Defining the task involves describing the task itself. It includes giving instructions, both general and specific. For example, assigning an essay would be defining a task. Specifying that the essay needs 5 paragraphs, a thesis statement, and a conclusion and references would also be defining that task, only with more specificity.

Setting the deadline for the task involves any mentoring actions or messages that made the interns aware of a deadline or due date.

Supporting the interns' efforts to complete their task involves providing help to get the task done. One way to support effort is to contextualize the task by explaining why it is necessary. Providing a rationale for a task has been shown to improve task motivation in students (Assor, Kaplan, & Roth, 2002; Deci et al., 1994). Another way is to provide, identify, or direct the youth to resources that can help facilitate task completion or teaching them what they need to complete the task. Mentors often see their role as someone who provides resources to help their charges (Halpern, 2010; Larson, 2006). Finally, mentors often scaffold learners' efforts using a strategy called focusing, in which they focus the attention of the learner by directing their attention to key aspects of the task (Pea, 2004).

While teaching the ways of thinking to complete a task could be considered "support," for the purpose of this study teaching is treated as a mentoring goal that is distinct from task achievement. In this study, providing support is a way of getting a particular task done, while teaching the frame is a way of teaching how this community does tasks like these. Take, for example, a mentor who has directed a learner to a model that will demonstrate a successful task performance. In this case, the mentor is supporting that intern's effort, and the resource is teaching how the task can be done successfully.

Evaluating the interns' performance involves deciding and letting the intern know whether the intern has completed the task satisfactorily.

These different aspects of facilitating task achievement, along with examples from the data, are illustrated in Table 5.

Table 5

Task Achievement Mentoring Goals

Components of facilitating task achievement	**Description**	**Examples from data**
Define task	Actions associated with what needs to be done	"As a team, select five experimental devices you would like to send to the lab for testing."
Set deadline	Actions associated with when task needs to be done	"Your team needs to submit your notebooks to me by **09/30/14 10:20AM."**
Support Effort	Actions that help to get task done • *Contextualizing or rationalizing task* • *Identifying resources necessary or helpful for completing task* • *Identifying key parts of the task*	• The goal of these tests is to understand how different design parameters will affect the dialyzer attributes that Nephrotex's internal consultants prioritize. • Once all five device designs are agreed upon, create a batch in FEEDS • After you meet and select your designs, each team member should create a notebook entry including:

		1. A list of each prototype and its specifications 2. A justification for each prototype explaining why it was selected for testing 3. An attachment of your team's batch"
Evaluate work	Actions associated with assessing whether task has been done satisfactorily	"Tim, Thanks for your thorough notebook entry. You can expect to receive your results around the same time I send you the next task. Thanks, Alex"

In this study, I coded actions by their primary purpose, though I recognize that they could be interpreted as also serving secondary functions. For example, the supervisor often provided a numbered list in his emails that described what exactly interns should include in their notebook submissions. The primary purpose of this numbered list was to define the task. That the supervisor put in a numbered list could be interpreted as a way of focusing the intern on the importance of including those items, and thus also be coded as supporting effort. Since this would be considered a secondary purpose of the mentoring action, however, it is not included as supporting effort.

M3.4.2 Teaching the Epistemic frame

Epistemic frame theory provides a framework by which this study examined what aspects of a community of practice's shared repertoire are taught by mentoring sources, and what aspects of that community of practice newcomers adopt. This study examined what engineering epistemic frame elements are taught by mentoring sources and what engineering epistemic frame elements the participants used in response to that mentoring.

To develop the coding scheme for an engineering epistemic frame, I started with an existing coding scheme used to identify an engineering epistemic frame in previous studies that examined Nephrotex (Arastoopour et al., 2013; Arastoopour & Shaffer, 2013). This coding scheme was developed for studying previous instances of the Nephrotex virtual internship, and was based on the ABET criteria for undergraduate engineering program outcomes (ABET, 2011).

A grounded theory approach (Strauss & Corbin, 1998) was used to revise this set of qualitative codes reflecting different aspects of engineering expertise represented in the data. Data from Nephrotex were used to establish the coding scheme as representative of professional engineering practice. Identification and revision of the codes continued until the coding scheme reached saturation (Strauss & Corbin, 1998), and the process resulted in a rubric of 16 codes (Table 6).

Table 6

Epistemic frame element coding scheme

Practice-Action	**Code**	**Description**	**Examples from data**
Epistemology	Epistemology of data	Justifying decisions using data such as graphs, results tables, numerical values, or research papers.	"Yea, I'm looking at the graph, and I think that if you consider all 5 of the attributes, the 5th or the 1st had the best overall performance between the five attributes."
	Epistemology of Design	Justifying decisions using design references such as device development, device specifications, ranking/priority of attributes, comparing designs, or tradeoffs in design.	"We chose this device because it performs well in all categories and keeps the cost lower than the prototypes that perform similar to it."

	Epistemology of Client	Justifying decisions by referring to the client, including the customer, but especially the patient's safety, health, or comfort.	"We tried to maximize the flux rate to speed up the process and minimize blood cell reactivity for patient comfort"
	Epistemology of Internal Consultants	Justifying decisions by stating internal consultants' preferences and concerns.	"This prototype meets all the internal consultants requirements. It met most of the suggestions as well, it only fell short of two suggestions"
Values	Value of Client	Valuing the client/patient or stating that their needs are important	"We figured blood cell reactivity as well as flux were two of the most important specifications because they allow a patient to be as safe as possible while using the product and to keep treatment time very low."
	Value of Internal Consultants	Valuing the internal consultants' needs and thresholds or stating that their needs are important.	"I think overall, prototype 5 meets all the requirements and meets the most suggested thresholds of the consultants. I believe that is important"
	Value of Data	Valuing scientific research, data, and the scientific process, or stating that they are important.	"We would probably need to do more research on how it fully works and what materials it is made of or different techniques if there is any."
	Value of Collaboration	Valuing the contributions of peers or stating that they are important.	"We will need to trust that our teammates are knowledgeable and hope we have at least one very good design at the end!"
Skills	Skill of Data	The action of using numerical values, results tables, graphs, or research papers.	"The graph will be a big help in showing how each prototype compared."
	Skill of Design	The action of design development, prioritizing, tradeoffs, and making design decisions.	"We basically made each prototype focus on maximizing one or two factors, like flux or reliability"
	Skill of Collaboration	The action of collaborating or participating in a team meeting, or asking for help from or providing help to peers.	"Which device do you guys think performed best?"

Identity	Identity of Engineer	Identifying as an engineer or member of a team. Possession/ ownership of an engineering notebook, lab result, team, or company. Enthusiasm for engineering work or for being an engineer.	"Additionally my prototype functioned best at 20% carbon nanotubes"
Knowledge	Knowledge of Design Parameters	Referring to manipulable design inputs: carbon nanotubes, chemical surfactants (biological, hydrophilic, negative charge, and steric hindrance), materials (PMMA, polyrenalate, polysulfone, PESPVP, Polyamide), or manufacturing processes (dry-jet, phase inversion, vapor deposition polymerization)	"PAM also only needs CNT % of 0-4% to have positive impact on the device."
	Knowledge of Design Attributes	Referring to design performance metrics: reliability, flux, biocompatibility, marketability, and cost	"The only trade off is that its more expensive, but would a higher flux be a nice tradeoff?"
	Knowledge of Data	Referring to numerical values, results tables, graphs, or research papers	"PRNLT, Phase, Hydrophilic, 6% came back with 9 Reliability, 700k Marketability, 29 Flux, 77 BCR, and 120 cost."
	Knowledge of Product	Referring to design objects, their components, or the scientific process involved in their operation or design.	"The blood pump is what controls the pressure and flow of the blood as it flows through the dialyzer."

This study not only examined what engineering epistemic frame elements were taught by mentoring sources but also what engineering epistemic frame elements the participants used in response to that mentoring. The same coding scheme for epistemic frame elements was used when determining whether and when interns were using epistemic frame elements in their chats, emails, and notebook submissions.

As this study is focused on the ways that different sources of mentoring can coordinate to teach an engineering epistemic frame, I also looked for the domain-specific practice-subjects that grounded and organized the different general practice-actions into epistemic frame elements. In other words, I looked for instances where the teaching of epistemic frame elements was aligned by a common engineering practice-subject.

From these epistemic frame codes I identified four engineering practice-subjects, those areas of engineering practice in which participants act (Table 7).

Table 7

Engineering practice-subjects

Engineering practice-subjects	**Description**	**Epistemic frame elements**
Design	Thinking in terms of design development, prioritizing, tradeoffs between design specifications (attributes), and making design decisions (manipulating parameters)	-Skill of Design -Knowledge of Design Parameters -Knowledge of Design Attributes -Knowledge of Product -Identity of Engineer -Value of Design -Epistemology of Design
Data	Thinking in terms of scientific methods, including testing, controlling variables, using graphs and graphic representations, results tables, numerical values, research papers, and citations.	-Skill of Data -Knowledge of Data -Identity of Engineer -Value of Data -Epistemology of Data
Collaboration	Thinking in terms of cooperation, collaboration and teamwork.	-Skill of Collaboration -Identity of Engineer -Value of Collaboration
Stakeholders	Thinking in terms of people who care about the final design, including internal consultants, patients, users, and consumers.	-Value of Internal Consultants -Value of Client -Epistemology of Internal Consultants -Epistemology of Client

One epistemic frame element appears in multiple practice-subjects. The Identity of Engineer element can be based on different engineering domains. For example, when an intern referred to “my data,” she inhabited an identity of an engineer based on data.

Similarly, when she referred to “my device” or “my team,” she claimed an identity of an engineer based on design and collaboration, respectively.

Results

This chapter describes the qualitative findings of this study’s four research questions. The first section examines whether there was mentoring in Nephrotex by looking for instances of workplace mentoring strategies. The second section takes a closer look into how mentoring in one activity was distributed, and identifies the different sources of the mentoring strategies, as well as how mentoring actants focused on facilitating task achievement or teaching the epistemic frame. The third section examines the two activities following the activity in section two, and describes the mechanisms by which the mentoring was coordinated in ways in order to create a community of practice. The fourth and final section looks at whether Nephrotex’s coordinated mentoring system successfully enrolled the interns as members into its community of practice.

R1. Mentoring

This section describes five examples of mentoring strategies that one intern, Tim, encountered during the course of the Nephrotex internship. Each mentoring strategy is described in the context of the activity in which it occurred, and

R1.1 Explaining

On the first day of the internship, as soon as Tim logged into the Nephrotex site, he received an email in his Nephrotex inbox from Alex Delgado, the "Dialyzer Membrane Design Team Leader at Nephrotex":

Tim's first email on the first day of Nephrotex

Tim,

My name is Alex Delgado, and I am the Dialyzer Membrane Design Team Leader at Nephrotex. During your internship, you will be working on a team with other interns, and each team will be assigned a Design Advisor. You are in **Team PAM** along with **PJ, Ron, and Lee.** Together, you will be designing a new dialyzer membrane for kidney hemodialysis equipment.

Here is an overview of how that process works at Nephrotex. To complete your prototype, you will:

1. Review previous experimental results
2. Investigate a single polymeric material
3. Join a new team comprised of interns with expertise in other materials
4. Conduct a second set of experiments
5. Decide on a final prototype design
6. Present and justify your prototype design to the firm

You can find a more detailed schedule in the Gantt chart, which you can access any time in the resources section of WorkPro, Nephrotex's online workspace.

Before you begin work on this project, I need you to do two things:

1. You must complete a short tutorial on the workflow you are expected to follow as an intern.
2. You must complete an intake interview.

To begin your tutorial, please read the resource on our company's workflow here. This is the workflow you are expected to follow for each stage of the design process.

After reading the workflow resource, you should begin the intake interview, a Human Resources requirement for all incoming interns. You can access the interview here. The interview should only take about half an hour. Don't worry if you can't answer all the questions. Your responses will help us improve our internship program. After you have completed the workflow tutorial and the interview, please write a notebook entry that summarizes the information provided in the Internship Workflow resource. Make sure you summarize all of the steps that are required to complete each task. Additionally, please make a note confirming that you successfully completed the entrance interview.

Submit this notebook entry by **09/16/14 10:20AM**. After your team's notebook are submitted, I will send you instructions for your next task.

Alex

Alex's email provided considerable detail about what Tim needed to do. It informed him that the overall goal of the internship was to design a "dialyzer membrane for kidney hemodialysis equipment," but also included multiple details that defined what accomplishing that task would entail. It explained that the task would need to be done collaboratively, with a team of fellow interns and a design advisor. It outlined six steps that comprised in the design process. It described the first tasks he needed to complete, which were a workflow tutorial and an intake interview, and that completing those tasks involved writing and submitting a notebook entry that summarized the tutorial and documented that he had completed the intake interview.

The email also informed Tim that he needed to follow a schedule. Alex instructed Tim not just what things to do, but also the order in which he should do them. Before even starting the 6-step design process of designing a prototype he had to complete two tasks, in a specified order: first, the workflow tutorial, then the intake interview. These tasks needed to be done by a specific time, and so Tim was under a deadline.

In addition to explaining what he needed to do and what his timeline was, the email also explained why they were necessary. The workflow tutorial, because it described the work procedures that he would be "expected to follow for each stage of the design process," was presented as a task that would help Tim complete all of his future tasks going forward. Because of its format, Tim could have been approached the intake interview as a test or a quiz. But because it was a HR requirement meant to help the firm improve the internship program, Alex clarified that Tim shouldn't worry if he didn't know all the answers, and also let him know that he shouldn't take too much time on it by projecting both how long completing it should take.

As "Dialyzer Membrane Design Team Leader," Alex acted like he was Tim's boss. His email explained, with detailed instructions, what Tim needed to do. It set a timeline for those tasks by providing a deadline and specifying the order in which things needed to be accomplished. It explained the rationale for the tasks, and projected how long one of them should take.

At this point in the internship, Tim was mainly having things *explained* to him. A non-exhaustive list of the things Tim had explained to him in just his first email message from the supervisor included: who everybody was, what he was about to be doing for the next few weeks, what the goal was, what he should do right now, why those tasks were important, when they should be done, what resources were available to help him, where he could find what he supposed to be doing, and when his current task was due. While even more explaining happened in this activity (e.g., the workflow tutorial explained the procedures for completing tasks at Nephrotex), the first email Tim received explained a substantial amount of information that Tim needed to know.

R1.2 Monitoring

As described in every instructions email from the supervisor, Tim had to write and submit a notebook entry, or deliverable, to complete each activity. By his third activity he had therefore already submitted two notebook entries, and received two feedback emails from Alex indicating that Tim's deliverables had been approved (one of them simply read, "Thanks for submitting your research summary. Nice work.").

In the third activity of the internship, Alex assigned a research task in which Tim had to read a curated set of internal technical documents that explained the impact of chemical surfactants on filtration membrane performance. He then had to take the data he found there and input it into a graphing tool. The graphing tool transformed the inputted data into a graph that showed the performance of each surfactant on the five device attributes by which the prototypes would eventually be evaluated: reliability, marketability, flux, blood cell reactivity, and cost. Using the graph he created, he needed to write a notebook entry that described the effects of surfactants on dialyzer membrane performance, recommend one of those surfactants as the best, and justify his recommendation based on how it performed for each attribute.

After Tim read the documents, used the graphing tool to create a graph, wrote his summary, and submitted his notebook entry, he received his third feedback email from Alex. This one was different from the first two. Alex informed Tim that his submitted notebook entry on the surfactant research he had done needed some additional attention:

> Tim,
> Your attached graph has incorrect values. Please review the relevant Nephrotex research documents on surfactant performance and try again. Once you're sure you have entered the correct values, resubmit a notebook with your new graph for me to review. Contact your design advisor if you need further assistance.
> Thanks,
> Alex

The email pointed out that Tim's graph had incorrect values. Since Tim had not successfully written an acceptable research summary, more mentoring was necessary. Tim needed two things, and the feedback email provided both of them. He needed to know what to do next, and the feedback email informed him: he needed to "try again." He also needed some direction about what to do if he still was unable to complete the task, or, where he could go for help. The feedback letter identified that he could go to his design advisor for "further assistance."

As compared to the feedback email in the previous activities, the feedback email in the surfactant research activity did a little more mentoring. In addition to letting Tim know whether he was meeting the standard for quality work, the message explained what to do in the event that he failed. In both cases, however, the main objective was to maintain Tim's satisfactory progress by checking on his work, evaluating whether it was good enough, and letting him know what to do either way. In other words, the supervisor used the *monitoring* mentoring strategy.

R1.3 Demonstrating

In the next instructions email, Alex explained that he had asked some consultants from the other divisions of Nephrotex to comment on "their priorities for membrane design." His assistant had compiled the responses from these "experts" in an attached email. Reading the attached message, Tim learned about 5 other divisions of the company, each of which had an internal consultant that represented that division's interests. Each internal consultant prioritized two dialyzer attributes from the five that Tim had learned about previously (reliability, marketability, flux, blood cell reactivity, and cost), and indicated a preferred threshold value and a required threshold value for those two attributes. Tim's job was to review and record the consultants' priorities and thresholds, which, according to Alex, would help his team when they began to design to prototypes.

As she had in previous activities, Maria provided another example notebook that the interns could use as a model.

Excerpt of Example Notebook

Laura Rivers - Chemical Engineer:

Attribute: Recharge Interval
Standards:
Required - Above 5.8 hours
Preferred - Above 7.4 hours

Attribute: Cost
Standards:
Required - Below $15020
Preferred - Below $13160

Recommendation:
For Laura, I would recommend the Optic Binary control sensor and the NiCd battery power source. Laura would love the Optic Binary sensor because it has the best recharge interval and the lowest cost among the control sensors. I recommended the NiCd battery because it has the lowest cost and the second best recharge interval.

Reflection
It is clear that the internal consultants will play an important role in our design process. Our design will be successful if we can find a way to meet their standards. However, it seems like it will be a challenge to design a prototype that satisfies the requests of every consultant. This would be a much easier task if each consultant had only preferred standard, rather than two.

The example notebook modeled exactly the notebook entry that Alex told Tim he wanted from him, with the obvious exception being that the content of Maria's write up was focused on a different engineering problem. Nevertheless, she described five internal consultants (only one is shown in the excerpt; the rest look like the one shown), indicated which design attributes each one cared about, and reported the required and preferred thresholds for each of those attributes. In addition, she included a reflection that provided a glimpse into her first impressions of the magnitude of the design task with so many stakeholders with so many requests.

The example notebook was presented explicitly as model for the interns. As it showed the interns exactly how their deliverable should look, in terms of the types of information to include, and how to organize and to write about it, the example notebook thus used the *Demonstrating* mentoring strategy.

R1.4 Problem Solving

In the first activity of the design phase of the internship, Alex's instructions email assigned two tasks. The first was that he needed to share what he had learned about the internal consultant that he had researched in the previous activity with his peers. He had researched internal consultant Michelle Proctor, a Product Engineer who cared about flux and reliability. The other four consultants had been researched by his four teammates. As Alex explained, it was "important that all members of the team are knowledgeable about all the internal consultants' requirements," so they all needed to share their notebook entries with each other.

The next part of his task was to make use of that shared information by designing prototypes. The design tool that Tim would use was called FEEDS (Form for Electronic Experimental Device Simulation). This tool gave Tim the ability to select different combinations of components (design parameters) that would create the specifications of a device (Figure 10).

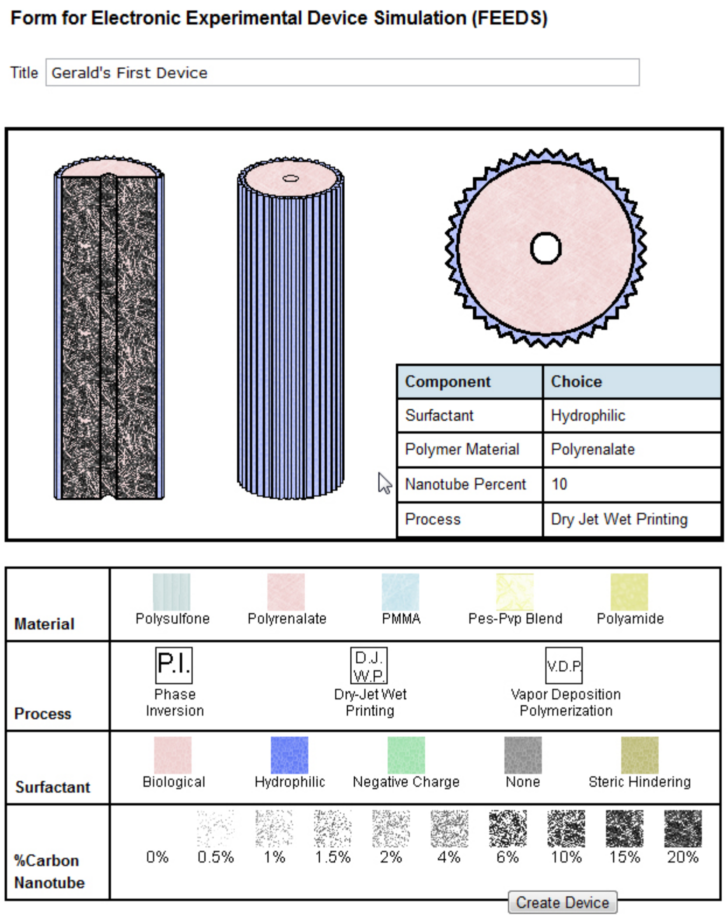


Figure 10. Example of FEEDS interface.

FEEDS included no sketching, no thinking "outside-the-box," and no brainstorming, all activities sometimes associated with design. Instead, it presented a quite limited design task, with design choices available for only 4 parameters (the polymeric material of the device, the manufacturing process used, the surfactant used, and the percentage of carbon nanotubes used). Tim's design task in this activity was even further constrained by his membership in a group that had been assigned to investigate only one of the materials, Polyamide (PAM), which reduced the parameters he could manipulate to only three. Further, not all of the options of the three parameters remaining to him—which filtration process, which surfactant, and what percentage of carbon nanotubes—were possible given his assigned material. With these constraints, it was possible for Tim to create 90 unique prototype devices using FEEDS. His options were limited by Alex's instructions as well. Tim had to come up with 5 prototypes, and of course, just like every other deliverable, he had to do it by a deadline.

Even with this array of limitations—the scant design options offered by FEEDS, the focus on only one material associated with his team assignment, and the time pressure presented by a deadline—Tim still had meaningful choices to make when designing his devices. How would he decide what percentage of nanotube technology or which filtration process? What combinations would be best? Alex's email provided some guidance. As he had in his previous instructions emails, Alex made clear that the essential part of the task was not just a deliverable, but some increased understanding that would help Tim later in the internship. Even though Tim had begun the design phase of the internship, Alex explained that the "goal in this first design phase" was still research-focused. Creating and testing "preliminary designs" was a way to collect data that would provide "more information about how to meet internal consultant design requirements" and, ultimately, "to achieve a better final product."

Using FEEDS, on the surface, was not a complicated task. As described above, there were limited actions Tim could take. But on closer examination, even though FEEDS was a simple tool, Tim's interaction with it was an instance of the *problem solving* mentoring strategy. FEEDS sidestepped the tricky relationship dynamics typically at play in problem solving by being nonhuman. It did not assign the design problem, did not know the answer to the design problem, and could not solve the design problem itself, but nonetheless contributed a crucial function in solving it. Tim came to the interaction with FEEDS with instructions and guidance from the supervisor, and understanding of the design parameters and attributes from his and his teammates' research. FEEDS helped Tim transform that into designs, and those designs into test results. In other words, Tim and FEEDS interacted in a sustained way to generate test results that would provide Tim with information that would help him design a "better final product."

R1.5 Reflective Questioning

After the first, individual, design activity described above, Tim and his team collaboratively designed five devices and submitted them for testing. Once he got the test results back, he had to summarize the results in terms of how well the different devices met all of the internal consultants' preferred and required thresholds. Equipped with their summaries, Tim and his team had a meeting, facilitated by the design advisor, about the team's test results. This meeting was the last activity Tim had with his team before all of the groups were reshuffled.

Like other interactions between the interns and Maria, this meeting took place in the chat window. In most activities, the design advisor supported the interns as they worked to accomplish the goals that Alex had set for them. She offered reminders about the deadlines and due dates. She offered examples that the interns could use as models. In this meeting, she invited the interns to join her in a conversation. While this conversation had more back-and-forth interactions than any of the other activities highlighted in this section, it was still highly structured. The design advisor chose the topics discussed, and she steered the direction of the conversation from start to finish.

In the meeting, Maria asked a series of questions. Parts of this meeting will be examined in greater detail in a later section of this chapter, but for now, it is worth pointing out the subject of some of the design advisor's questions. The first five questions were about the work that the interns had just finished doing:

1. Now that your team has received the batch results, was it a successful trial?
2. What did you discover about the design problem?
3. What do you know now that you didn't before about how different design choices affect the properties of a device?
4. How did you decide on the 5 devices that you just received results for?
5. What role did the requests of the internal consultants play in deciding which prototypes to test?

The last three questions were about what would come next:

6. Soon, you will be switching teams and sharing your design experience with your new teams. What do you plan to bring to your group?
7. You will bring knowledge about a unique material to that group. What important things do you want to discuss with them about your material?
8. Which attributes does your material maximize and how is that important to the design?

The bulk of the meeting was thus focused on the previous activity. Some of Maria's questions (questions #2 and #3) were prompts to discuss specific information the interns learned from their tests. For example, she wanted to know what they discovered about the design problem, and about how different design parameters affected the design attributes ("how different design choices affect the properties of a device"). Other questions (#4 and #5) were focused on how they did their work. For instance, she wanted to know how they made design decisions, and what role the internal consultants played in those decisions. In other words, she wanted them to talk about what they did, how they did it, and what they learned.

Even the final questions, about what to do next, were contextualized by the activities, questions, and lessons that had come before. Asking about the interns would "plan to bring" to their new groups, after having a discussion about what they just did and learned was a way of drawing a connection between past and future. These final questions framed what the interns had done and learned as something they could use in coming activities.

In this team discussion, the design advisor facilitated the interns thinking about their tasks and what they learned by asking them questions. In other words, the design advisor was using a *reflective questioning* mentoring strategy.

R1.6 Summary

Each of the workplace mentoring strategies could be found in the Nephrotex internship. The mentoring strategies in Nephrotex were not limited to the instances described in this section. The supervisor sent an instructions email that looked very similar to his first in every activity of the internship. Tim thus had similar types of things explained to him again and again. Similarly, the supervisor used the *monitoring* mentoring strategy in every activity of the internship. Tim had to submit a deliverable in every activity in the internship. The supervisor evaluated every one of those deliverables and sent Tim a feedback email letting him know the status of his work product. The design advisor also regularly used mentoring strategies. She provided an example notebook in nearly every activity in Nephrotex, with the sole exceptions being when that the activity was similar enough to a prior activity that an additional model would be redundant (e.g. there was an example notebook shared that showed how to summarize a reflection meeting; an additional example notebook was not provided for subsequent reflection meetings).

The reflection meeting focused on the team's test results was not the only one of its kind. The design advisor facilitated similar discussions two other times. She was the only person who used the reflective questioning mentoring strategy, and these meetings were the only activities where she used it. Finally, the interns engaged in design activities using FEEDS multiple times during the internship. The changing nature of the problem solving in those activities will be examined in forthcoming sections.

Some mentoring strategies, like *explaining* and *monitoring*, were present in every activity, or, as in the case of *demonstrating*, in nearly every activity. Others, like *reflective questioning* and *problem solving*, happened less frequently, in particular activities exclusively dedicated to them. Nephrotex thus featured both the didactic and reciprocal types of mentoring strategies.

Mentoring, however, does not simply consist of a set of strategies. Looking more closely at the structure of the mentoring in one activity will reveal more about how those mentoring strategies were used by different sources of mentoring.

R2. Distributed mentoring

The Nephrotex internship involved a series of tasks. In completing these tasks, Tim regularly interacted with two Nephrotex employees (other than his fellow interns on his team), his supervisor and design advisor. In other words, in Tim's activity they functioned as different types of *mentoring agents*.

Available tools and resources also informed Tim's activity and learning. They defined his tasks and taught him essential aspects of what it meant to be and work like an engineer. Tools like FEEDS and resources like the technical documents allowed him to complete design and research tasks respectively. These tools and resources served as *mentoring artifacts*.

The supervisor, design advisor, the other employees, and these tools and resources, all played different roles in helping Tim learn what he needed to learn and to accomplish the tasks of the internship. In other words, in Tim's activity they functioned as different types of *mentoring actants* using mentoring strategies for particular mentoring goals.

This section examines mentoring actants using mentoring strategies for particular mentoring goals in the second activity in the internship, where the interns conducted background research about hemodialysis and dialyzers in order to catch up enough on the relevant concepts so they could successfully design prototypes at Nephrotex.

R2.1 Mentoring Actants

R2.1.1 Supervisor

As he did every activity, Tim received an email that provided instructions for his background research task from his supervisor, Alex.

> Tim,
>
> In order to get you up to speed on the work we do here at Nephrotex, I'll need you to complete some background research on hemodialysis and dialyzers. The resources section of WorkPro gives you access to the company's previous experimental reports and technical documents. To get started, read the how dialysis works and introduction to diffusion documents. There is a hemodialysis filtration glossary for specific terminology you don't understand.
>
> Additionally, I want you to locate and read research articles about recent advances in hemodialysis from sources outside of Nephrotex. This will ensure that our internal research is consistent with the latest work in the field. Ask your design advisor if you need help locating reliable external resources.
>
> The essential part of this background research is to make sure that we all have a common understanding of the critical design parameters. Specifically, we need to be sure we are all using the same definition of what a dialyzer is and how it works.
>
> Here are the key things to summarize from your research:
>
> 1. The definition of a dialyzer
> 2. The functions of hemodialysis
> 3. The components of a dialyzer

4. The physical principles behind hemodialysis
5. Two significant, recent advances in dialyzer design or technology
6. Citations for the internal sources (those from Nephrotex) and the external sources (those you found outside of Nephrotex)

Also, include a brief reflection on your research process. When reflecting on your research process, consider the efficiency of your research process and how determined the reliability of your sources.

The Gantt chart has this deliverable due by **09/17/14 5:00PM**. Everyone on your team must submit their notebooks for witnessing by that time.

Thanks,
Alex

As described in the previous section, Alex's instructions emails focused on defining Tim's task, setting the deadline for achieving it, and supporting Tim's efforts to achieve it. In this email, Alex defined the task for Tim by explaining that he needed to "complete some background research on hemodialysis and dialyzers" and "summarize" this research in a notebook entry. This research involved both accessing the company's own previous research as well as "research articles about recent advances in hemodialysis from sources outside of Nephrotex." Further specifying the task, he provided a numbered list of 6 items Tim needed to summarize in his notebook entry. He told Tim by when he needed to complete the task, boldfacing the deadline for when the "deliverable" was "due."

He supported Tim by directing him to resources that would help him complete his task. He identified the company's curated set of "experimental reports and technical documents" as the place he could find the information that he needed to learn, and notified him there was as a "hemodialysis filtration glossary" in case there was "specific terminology" that was new to him. He even provided hyperlinks to these resources to reduce the number of required navigational steps to find them. If Tim struggled with the part of the task that involved finding "reliable external resources" outside of WorkPro, Alex suggested that he could use the design advisor as a resource to help him ("Ask your design advisor if you need help…").

He also supported Tim by contextualizing the task, explaining that this background research was important because everyone at Nephrotex needed to share a "common understanding" in order to do design work, and that they needed to be sure that their research was "consistent with the latest work in the field."

The supervisor's mentoring strategies for the purpose of facilitating Tim's task achievement in the background research activity are illustrated in Table 8:

Table 8

Supervisor's instructions email facilitates task achievement

Mentoring Purpose	**Excerpts**	**Description**	**Mentoring Strategy**
Define task	"…I'll need you to complete some background research on hemodialysis and dialyzers."	Tells what the task was	Explaining
	"Here are the key things to summarize from your research: 1. The definition of a dialyzer 2. The functions of hemodialysis 3. The components of a dialyzer 4. The physical principles behind hemodialysis 5. Two significant, recent advances in dialyzer design or technology 6. Citations for the internal sources (those from Nephrotex) and the external sources (those you found outside of Nephrotex) Also, include a brief reflection on your research process."	Tells what needed to be included in work product	Explaining
Set timeline	"The Gantt chart has this deliverable due by **09/17/14 5:00PM."**	Tells what the deadline is for completing the	Explaining

		task	
Support effort	"The resources section of WorkPro gives you access to the company's previous experimental reports and technical documents. To get started, read the how dialysis works and introduction to diffusion documents. There is a hemodialysis filtration glossary for specific terminology you don't understand. ... Ask your design advisor if you need help locating reliable external resources."	Tells what resources are available to complete the task.	Explaining
	"The Gantt chart has this deliverable due by **09/17/14 5:00PM**."	Tells what tools are available to complete the task on time.	Explaining
	"This will ensure that our internal research is consistent with the latest work in the field." ... "The essential part of this background research is to make sure that we all have a common understanding of the critical design parameters. Specifically, we need to be sure we are all using the same definition of what a dialyzer is and how it works."	Explained context for the task	Explaining

Alex's email did more than just facilitate Tim's background research. It also served to teach Tim aspects of engineering thinking. In describing why their task was important, Alex explained a key engineering value:

> The essential part of this background research is to make sure that we all have a common understanding of the critical design parameters. Specifically, we need to be sure we are all using the same definition of what a dialyzer is and how it works.

Alex framed the rationale in terms of shared understanding. In order to move forward, he claimed, everyone needed to be sure that they were "using the same definition of what a dialyzer is and how it works," including what the "critical design parameters" were. The suggestion was that without that "common understanding" they wouldn't be able to work together. Alex emphasized the value of collaboration by describing how important it was that the interns were on the same page. There was some information about the task that was already known internally to the firm, and the interns needed to get "up to speed," as he put it in the first line of the email message. Being on the same page is important to engineering because engineers need to share a common language. In other words, engineers value *collaboration*.

It wasn't just important that everyone at Nephrotex was on the same page, but that Nephrotex itself was on the same page as the biomedical engineering field as a whole (at least as far as an understanding of current issues in dialyzer design and technology). As Alex explained, in order for the company to be sure that their internal research was "consistent with the latest work in the field," Tim needed to find and summarize "research articles about recent advances in hemodialysis from sources outside of Nephrotex." Alex's concern about being consistent with the rest of the biomedical engineering field described how important the research was by framing it as something shared by engineers in general. In other words, Alex was describing how engineers value *data*.

Alex did one other subtle thing in his email to teach Tim the engineering epistemic frame. In describing the task that Tim had to do, he referred to aspects of that task as if they were Tim's already. For example, when telling Tim that he needed to include a brief reflection in his submitted notebook, he told Tim to reflect on "your research process" and to think about the reliability of "your sources." By assigning him ownership over the research process and sources, Alec granted Tim the identity of an engineer based on his being the type of person who had the type of thing that engineers would have: data.

Alex promoted the engineering values of collaboration and data and connected it to Tim's identity as an engineer. His mentoring strategies for the purpose of teaching Tim the engineering epistemic frame in the background research activity are illustrated in Table 9:

Table 9

Supervisor's instructions email teaches epistemic frame

Mentoring Purpose	**Excerpts**	**Description**	**Mentoring Strategy**
Teach Skills			
Teach Knowledge			
Teach Identity of an engineer	"Your research process"; "your sources";	Referred to engineering work associated with data as belonging to Tim	Explaining
Teach Value of Collaboration	"The essential part of this background research is to make sure that we all have a common understanding of the critical design parameters. Specifically, we need to be sure we are all using the same definition of what a dialyzer is and how it works."	Rationalized task in terms of requisites for collaboration	Explaining
Teach Value of Data	"This will ensure that our internal research is consistent with the latest work in the field."	Rationalized task in terms of standard of engineering field's research.	Explaining
Teach Epistemology			

Alex did use one other mentoring strategy, and performed one additional mentoring function. Once Tim submitted his notebook, Alex evaluated Tim's work, and sent him a brief email response:

> Tim,
> Thanks for submitting your research summary. Nice work.
> Thanks,
> Alex

Alex's email showed Tim that his notebook entry was observed and evaluated. In other words, Alex was monitoring his work (Table 10).

Table 10

Supervisor feedback email facilitated task achievement

Mentoring Purpose	**Excerpt**	**Description**	**Mentoring Strategy**
Define task			
Set timeline			
Support effort			
Evaluate Performance	"Nice work."	Checked work to determine if it met internship standards.	Monitoring

Since Alex seemed to have submitted a satisfactory notebook, the email from Alex was unremarkable in content. Not every feedback email was so complimentary. As described in the previous section, Tim received a feedback email for his surfactant research notebook submission that required him to revise and resubmit it. The key function of the feedback email, whether it accepted the Tim's work or returned it for another try, was to let him know that there were in fact standards that he had to meet.

R2.1.2 Calendar tools

As Alex mentioned in his instructions email, the information about the deadline for Tim’s task was also available in a Gantt chart. The Deliverable List likewise contained information about the deliverable and its deadline.

The Gantt Chart (Figure 11) presented a granular sequence of the tasks that he would need to accomplish, with due dates included:

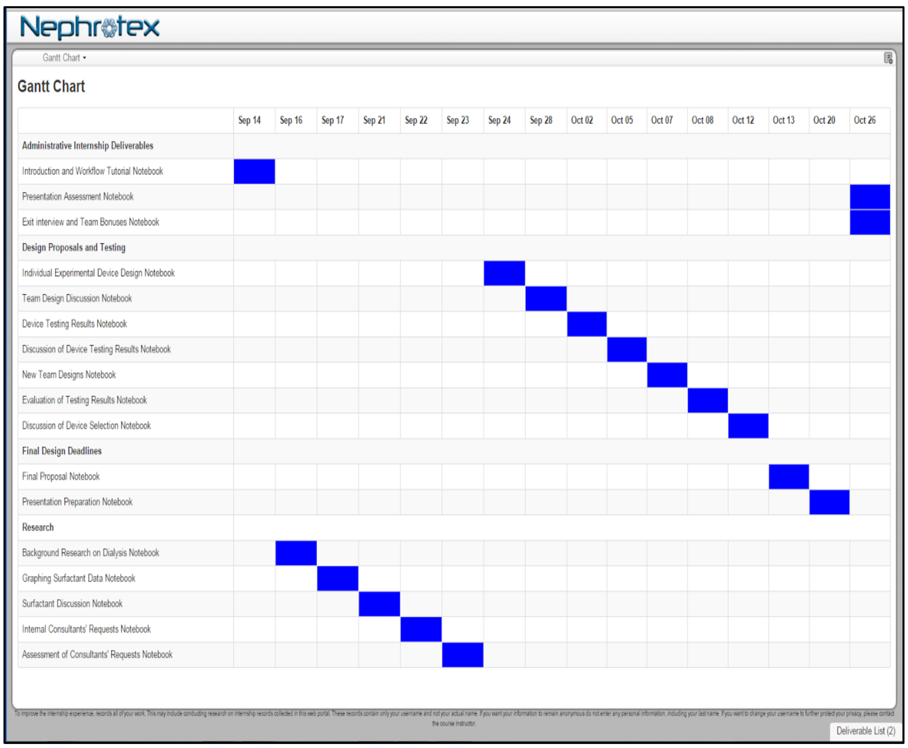


Figure 11. Gantt chart with sequential tasks.

His schedule was comprised of variously titled “Notebooks” which were grouped into categories. According to the Gantt chart, his current task, under a category called “Research,” was the “Background Research on Dialysis Notebook” which was consistent with Alex’s instructions email.

Tim could track all of his deliverables with the *Deliverable List*, which was a pop-up box that showed him all of his current tasks, whether he had submitted them or not, and whether they had been evaluated (Figure 12).

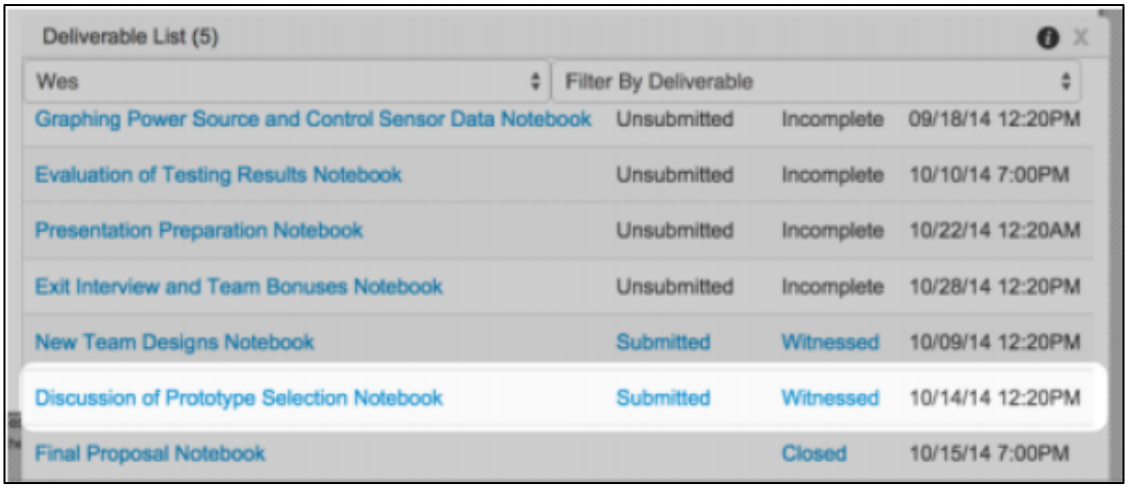


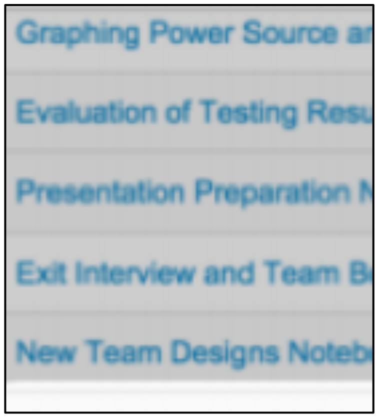
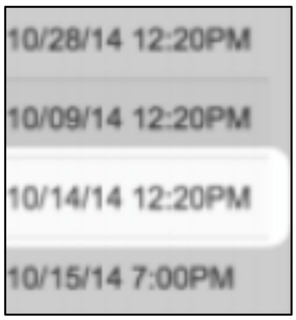
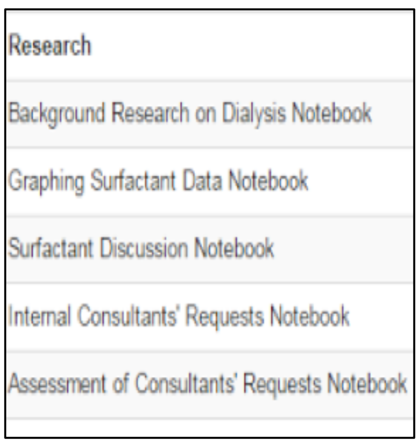
Figure 12. Sample Deliverable List with submission statuses.

The primary purpose of these calendar tools was to communicate when and what tasks needed to be done. They also, however, contextualized Tim's current task by listing it with all of the others in an effort to help Tim see the place of each task in terms of the larger effort and the longer timeline (Table 11).

Table 11

Calendar tools facilitated task achievement.

Mentoring Purpose	**Excerpt**	**Description**	**Mentoring Strategy**

Facilitate Task Achievement	Define task		Indicated task.	Explaining
	Set timeline		Indicated deadline.	Explaining
	Support effort		Indicated task in context of other tasks.	Explaining
	Evaluate Performance			

Calendar tools like the Gantt Chart and Deliverable List told Tim what he needed to do and by when he needed to do it in the context of his other tasks and deadlines. These tools shared the same information about the task that Alex's instructions email did, though in a different format and with far less detail. They were both more easily accessible than

Alex's email; finding information buried in an email, which in turn might be buried in an inbox, would likely be more difficult than clicking on the pop-up box accessible any one of WorkPro's pages.

R2.1.3 Technical documents

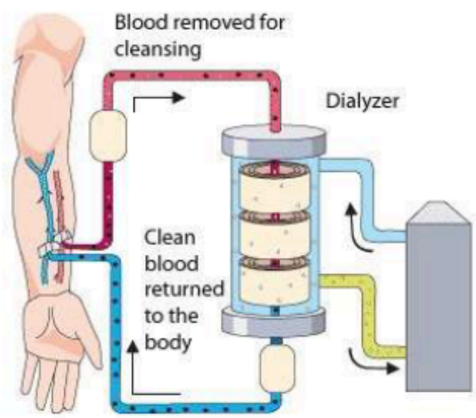
As he learned from Alex's email, Tim had to read technical documents that had been internally published at Nephrotex. These documents described the physical process of diffusion and how dialysis works (Figures 13 and 14).

How Dialysis Works

Blood has a delicate balance of various non-biological components such as potassium, sodium, bicarbonates, and of course, water. Maintaining this balance is critical to health; imbalance can be lethal.
Metabolic waste (such as urea) is filtered out by healthy kidneys. When the kidneys begin to fail, they become less capable of balancing blood components and removing metabolic waste. Kidneys are said to have three main functions:

1. They remove metabolic waste from the bloodstream.
2. They maintain appropriate water-electrolyte balance in the body.
3. They release key hormones into the bloodstream.

Hemodialysis treatment can perform the first two functions. During this treatment, blood is circulated outside the body into a filtration apparatus.



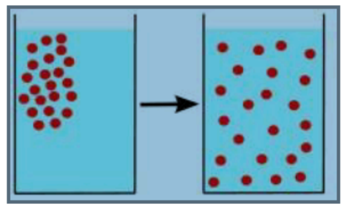
The filter is basically a tube made from a porous membrane. Blood flows through the center of the tube. The area outside the tube is flooded with a fluid called dialysate. Dialysate is mostly water, containing physiological concentrations of salts such as potassium and sodium, and no metabolic waste products. Due to the difference in concentration of metabolic waste products from one side of the membrane to the other, they diffuse across the membrane from the blood into the dialysate fluid. Anything in the blood which is too large to pass through the pores (such as blood cells) will remain in the blood. Since the concentration of salts is equal on both sides of the membrane, there is no concentration gradient to drive diffusion of salts across the membrane.

Therefore, hemodialysis is used to remove metabolic waste products from the blood and ensure maintenance of desired concentrations of other blood components.

Figure 13. Technical Document: How Dialysis Works.

Introduction to Diffusion

Diffusion is a process where particles will move from an area of high concentration to an area of low concentration.



Solutes are removed by the physical process of diffusion. During dialysis, the blood is separated from the dialysate fluid with a porous membrane. The concentration of waste is much higher in the blood than in the dialysate. This difference in concentration is called a ***concentration gradient*** and causes the waste particles to diffuse across the membrane. Controlling the size of the pores in the membrane is important because some blood components need to be removed and some do not. For example, there is a higher concentration of blood cells in the blood than in the dialysate, but the membrane pores are too small to allow blood cell diffusion.

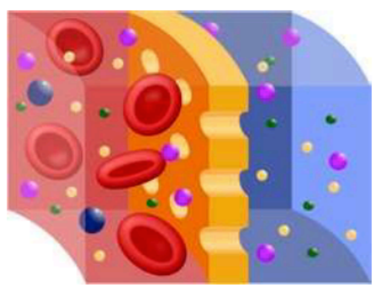


Figure 14. Technical Document: Introduction to Diffusion.

The technical documents explained the information that would help Tim better understand his design task: what hemodialysis is, how a dialyzer works, and the physical principles by which it operates. For example, the "How Dialysis Works" document described how "hemodialysis is used to remove metabolic waste products from the blood and ensure maintenance of desired concentrations of other blood components." The "Introduction to Diffusion" document describes how those waste products are removed in a dialyzer. Dialyzers rely on the physical process of a diffusion, "where particles will move from an area of high concentration to an area of low concentration." The blood in a dialyzer is "separated from a dialysate fluid with a porous membrane." The pores of the membrane are big enough for the waste material, but too small for blood cells. Through the process of diffusion the waste products thus travel to the less concentrated dialysate fluid, thereby removing some of the waste particles from the blood. The technical documents assigned by the supervisor, and available in Nephrotex's resources, provided Tim with key engineering knowledge about his overall task in the internship (Table 12).

Table 12

Technical documents teach epistemic frame element

Mentoring Purpose	**Excerpt**	**Description**	**Mentoring Strategy**
Skills			
Knowledge of Product	"…hemodialysis is used to remove metabolic waste products from the blood and ensure maintenance of desired concentrations of other blood components." "Diffusion is a process where particles will move from an area of high concentration to an area of low concentration."	Described what dialysis is, how dialyzers work, and the physical process of diffusion.	Explaining
Identity			
Values			
Epistemology			

Explaining what he would be designing, and the science behind how it worked, the technical documents thus taught the knowledge of product.

R2.1.4 Design Advisor

Maria, Tim's design advisor, did not interact with Tim and his team during this research activity, except to inform them that she once had been an undergrad intern at an engineering company too, and that during her internship, she had to write a research summary similar to the one they were now being asked to produce. To help them complete their task, she had put a copy of her research summary notebook entry into WorkPro's shared space. As she explained in the chat (two consecutive chat messages condensed into one):

> Back when I was an undergrad, I interned at a mechanical engineering company that designed exoskeletons for rescue workers. You are working on a different project, but I have put an example of the summary I used for my previous project in the shared space. Alex is pretty similar to my boss at the internship, so you're welcome to use this as a template to write your own. Note the language and the length of the response. Please pay close attention to the citation methods used in my example. I know Alex will be a stickler for following correct citation methods.

While the subject matter of Maria's research was different than the subject matter that Tim needed to research, she made it clear that the characteristics of a successful research summary (and, apparently, bosses at engineering firms) were the same. Her summary therefore could be used as a "template," for Tim's deliverable. Just in case he was unclear what in her example he was supposed to imitate, she specified the "language," the "length," and the "citation methods."

Maria's mentoring was thus focused on helping Tim achieve his task (Table 13). First, she directed him to a resource that she claimed would demonstrate what his deliverable should look like. Second, she went one step further to identify what aspects of her provided model were most worth emulating, in effect pointing out important parts of the task.

Table 13

Design Advisor facilitates task achievement

Mentoring Purpose		Excerpt	Description	Mentoring Strategy
Facilitate Task Achievement	Define task			
	Support effort	“I have put an example of the summary I used for my previous project in the shared space. Alex is pretty similar to my boss at the internship, so you're welcome to use this as a template to write your own.”	Described a resource available to Tim that could help him complete the task.	Explaining
		“Note the language and the length of the response.” “Please pay close attention to the citation methods used in my example.”	Described what parts of the task were important.	Explaining
	Set timeline			
	Evaluate Performance			
Teach	Skills			
	Knowledge			
	Identity			
	Values			
	Epistemology			

The design advisor’s brief mentoring moment in this activity was dedicated solely to supporting Tim’s effort.

R2.1.5 Example Notebook

When Maria identified her notebook as a resource that could potentially help Tim complete his task, she acknowledged that the subject of her notebook was different. This difference, however, was irrelevant for its intended purpose, because she explained that even though she "designed exoskeletons for rescue workers" in her internship, her notebook was still a "template" that Tim could use to write his own summary. In other words, the content of her example notebook was not important, it was the way she wrote it. As Alex had specified, Tim's background research summary needed to have the following six items, plus a brief reflection on his research process:

1. The definition of a dialyzer
2. The functions of hemodialysis
3. The components of a dialyzer
4. The physical principles behind hemodialysis
5. Two significant, recent advances in dialyzer design or technology
6. Citations for the internal sources (those from Nephrotex) and the external sources (those you found outside of Nephrotex)

Maria's notebook was organized with almost those exact items as headers:

<u>Maria's Example Notebook for the background research activity</u>
Title
Background Research Example Notebook

Definition of an Exoskeleton
An exoskeleton is a powered apparatus that can be attached to a person's body. It has two primary applications: operator support and operator enhancement [2].

Functions of an Exoskeleton
Exoskeletons have two main functions: to either support or enhance the operator's strength. An exoskeleton can also assist in heavy lifting and fatigue reduction. This makes exoskeletons useful for anyone working in emergency services, fire services, and disaster response workers [2].

Parts of an Exoskeleton and How They Enhance Human Movement
An exoskeleton needs a control sensor to detect the operators movements and an onboard computer to send signals from the control sensor to actuated joints [2]. In order to properly mimic the movements of the operator, an exoskeleton also needs actuators and a power source. Actuators amplify human movement at the joints by utilizing power provided by batteries and other power sources [2].

Physical Principles Behind Human Movement in Exoskeletons
RescuTek's paper "Movement of Human Body in Three Dimensional Space" talks about the three different ways joints are capable of moving.

Flexion/Extension movement decreases/increases the joint angle in the sagittal plane. Human hips, knees, and ankles utilize flexion/extension movement in order to walk or run in a straight line [5].

Abduction/Adduction is movement away/towards the center of the body in the coronal plane. Human hips and ankles use abduction and adduction to move sideways in a straight line and maintain balance on uneven surfaces [5].

Medial/Lateral movement is rotation towards/away from the center of the body in the transverse plane. The hips and ankles use rotation in order to change directions [5].

An exoskeletons actuated joints must allow for the above joint movement in the user.

Recent Advances in Exoskeleton Technology or Design:
The ankle joints of an exoskeleton are one of the more difficult joints to replicate due to the variety of movements human ankles are capable of [1].

Recent experiments with exoskeletons have provided a new way to simulate ankle movements. By attaching a pair of fiberglass struts to the boot, a unidirectional actuator is used to create torque about the ankle joint [4].

Another experiment involving the ankle joint of the exoskeleton attempted to make the joint as natural as possible by replicating the way tendons and ligaments assist human joints. Using a special kind of spring-like tendons, participants in the experiment hopped with and without the assistance of the exoskeleton. When hopping with the exoskeleton, the force was increased by 30% [3].

Works Cited
Brown, M., Tsagarakis, N., Caldwell, D.G. (2003) "Exoskeletons for human force augmentation", Industrial Robot: An International Journal, Vol. 30 Iss: 6, pp.592 - 602

"Exoskeletons". (2012.) Retrieved July 18, 2014 from http://rescutek.com

Farris, D. J., Robertson, B. D., & Sawicki, G. S. (2013). Elastic ankle exoskeletons reduce soleus muscle force but not work in human hopping. Journal of Applied Physiology, 115(5), 579. Retrieved from http://search.proquest.com.ezproxy.library.wisc.edu/docview/1430309689?accountid=465

Mooney, L.M. , Rouse, E.J., Herr, H.M. (2014) "Autonomous exoskeleton reduces metabolic cost of walking during load carriage", Journal of Neuroengineering and Rehabilitation, 11:80
"Movement of Human Body in Three Dimensional Space". (2012). Retrieved July 18, 2014 http://rescutek.com

Reflection on Research Process:
The next time I do research of this type I will spend time doing a more comprehensive literature search. In the future, I would like to use more peer-reviewed sources when doing my write-ups.

The notebook defined what an exoskeleton is (“a powered apparatus that can be attached to a person's body”) and described its functions, parts, and the physical principles involved in its operation in dedicated sections. It described recent advances in the technology, such as a "new way to simulate ankle movements," and cited internal company documents ("http://rescutek.com") as well as articles from professional journals from the field (e.g. "Exoskeletons for human force augmentation"). Finally, it included a brief "**Reflection on Research Process**," in which she indicated she would spend more time and find more "peer-reviewed sources" the next time she did this type of research. Maria's research summary closely mirrored the structure of the research summary Tim was expected to produce.

Maria's example notebook did more than just model how Tim's summary should be structured. For example, as Tim was instructed to do, Maria included summaries of external sources on the design exoskeletons. In one study she cited, engineers attempted to replicate natural ankle joint motion by using a special kind of artificial tendon:

> Using a special kind of spring-like tendons, participants in the experiment hopped with and without the assistance of the exoskeleton. When hopping with the exoskeleton, the force was increased by 30% [3]

In reporting the study's findings, she referred to its experimental test design, noting that participants "hopped with and without…the exoskeleton." She cited the quantitative data of test results when reporting on the findings of one of the external articles on exoskeletons ("the force was increased by 30%"). And finally, she demonstrated how to properly cite the article, with an inline citation, and a properly formatted corresponding entry in the reference list. In these ways, Maria's example notebook demonstrated the skill of data.

She modeled all of the above in the context of her own internship, where she had engaged in the same type of design process that Nephrotex was facilitating for Tim. In her reflection on the research process, she talked about how she would do research in the future:

> The next time I do research of this type I will spend time doing a more comprehensive literature search. In the future, I would like to use more peer-reviewed sources when doing my write-ups.

When she referred to “my write-ups,” she was claiming ownership of a particular kind of engineering identity: the kind of person who does background research that is “comprehensive,” and that uses “more peer-reviewed sources.” In other words, she modeled an engineering identity based on the type of data that engineers use when doing research. The Example notebook thus taught epistemic frame elements focused on skills and identity (Table 14).

Table 14

Example Notebook teaches epistemic frame elements

Mentoring Purpose		**Excerpt**	**Description**	**Mentoring Strategy**
Facilitate Task Achievement	Define task			
	Support effort			
	Set timeline			
	Evaluate Performance			
Teach	Skill of Data	“Using a special kind of spring-like tendons, participants in the experiment hopped with and without the assistance of the exoskeleton. When hopping with the exoskeleton, the force was increased by 30% [3]”	Modeled the use of experimental design, quantitative test results, and citations	Demonstrating
	Knowledge			

	Identity of an Engineer	"The next time I do research of this type I will spend time doing a more comprehensive literature search. In the future, I would like to use more peer-reviewed sources when doing my write-ups."	Modeled the ownership of engineering data	Demonstrated
	Values			
	Epistemology			

The example notebook did not model the most expert performance possible on the task, but rather a performance that the design advisor was confident would meet the expectations of the supervisor. In other words, it modeled a performance that more closely matched the interns' likely level of attainment.

R2.2 Distributed Mentoring

The background research activity had a twofold purpose. First, there was a concrete task. Tim needed to read technical documents, summarize them in his notebook, and submit them to his supervisor on a deadline. Second, there were learning goals associated with this task. Tim needed to learn important background knowledge about his overall design task. Since he would be designing prototype dialyzers, this background knowledge included understanding dialysis and the physical processes associated with it. Accomplishing this task would move Tim closer to accomplishing the overall task of the internship (by getting him "up to speed," as the supervisor put it) while also teaching him key aspects of what it means to be an engineer. Tim was meant to learn specific engineering knowledge about dialysis and his dialyzer design task, engineering skills like how to write about research with the proper citations, and why research and collaboration were important to engineers. Moreover, he was meant to see himself as someone who engages in these practices valued by engineers.

These goals were divided among multiple mentoring actants. Some of these actants were mentoring *agents*: people with whom he interacted via asynchronous email clients or in synchronous chat rooms. Others were *mentoring artifacts*, tools and resources that defined Tim's activity space and shaped what was possible for him to do. The types of information that Tim needed to accomplish his tasks, including finding out what the task was, when it was due, strategies for accomplishing it, and notifying him whether he had completed it successfully were provided to him not by one source but by multiple sources. Likewise, the ways of thinking he needed to use to accomplish those tasks, including the engineering skills, knowledge, values, and self-identification, were taught to him by multiple mentoring sources. Moreover, this set of mentoring actants used different mentoring strategies to these ends. In other words, both mentoring strategies and their purposes were distributed among multiple mentoring actants (Table 15).

Table 15
Distributed Mentoring in the Background research activity

		Mentoring Actants				
		Artifacts			**Agents**	
Mentoring Purpose		**Calendar Tools**	**Technical Documents**	**Example Notebook**	**Supervisor**	**Design Advisor**
Facilitate Task Achievement	**Define task**	Explaining			Explaining	
	Support effort				Explaining	Explaining
	Set timeline	Explaining			Explaining	
	Evaluate Performance				Monitoring	
e a c	**Skills**			Demonstrating		

	-Data					
	Knowledge *-Product*		Explaining			
	Identity *Engineer*			Demonstrating	Explaining	
	Values *-Data* *-Collaboration*				Explaining	
	Epistemology					

The supervisor defined the task, set the deadline, supported Tim's effort and let him know whether he accomplished the goals. The design advisor and the calendar tools supported the supervisor in these duties. In his explanation of the task, the supervisor made it clear why the task was important in terms of both the value of research generally and the particular data that Tim needed to master. Other actants provided equally important information. The technical documents contained the details that Tim needed to learn. The example notebook demonstrated how to write the research summary he was assigned. The mentoring actants each played a different part in facilitating Tim's task achievement and learning.

The mentoring actants not only distributed the mentoring goals among themselves, but they also used different mentoring strategies. Some actants used a single mentoring strategy. For example, the technical documents exclusively explained information that Tim needed, and the example notebook exclusively modeled a way of writing about research topics by showing him how his work product would look if it were on a separate subject matter.

The supervisor, by contrast, used multiple strategies, explaining what it was that Tim needed to do, but also monitoring Tim's work to make sure the task was accomplished. In the background research activity, then, mentoring was distributed among multiple actants, who used multiple mentoring strategies to accomplish different mentoring goals (Figure 15).

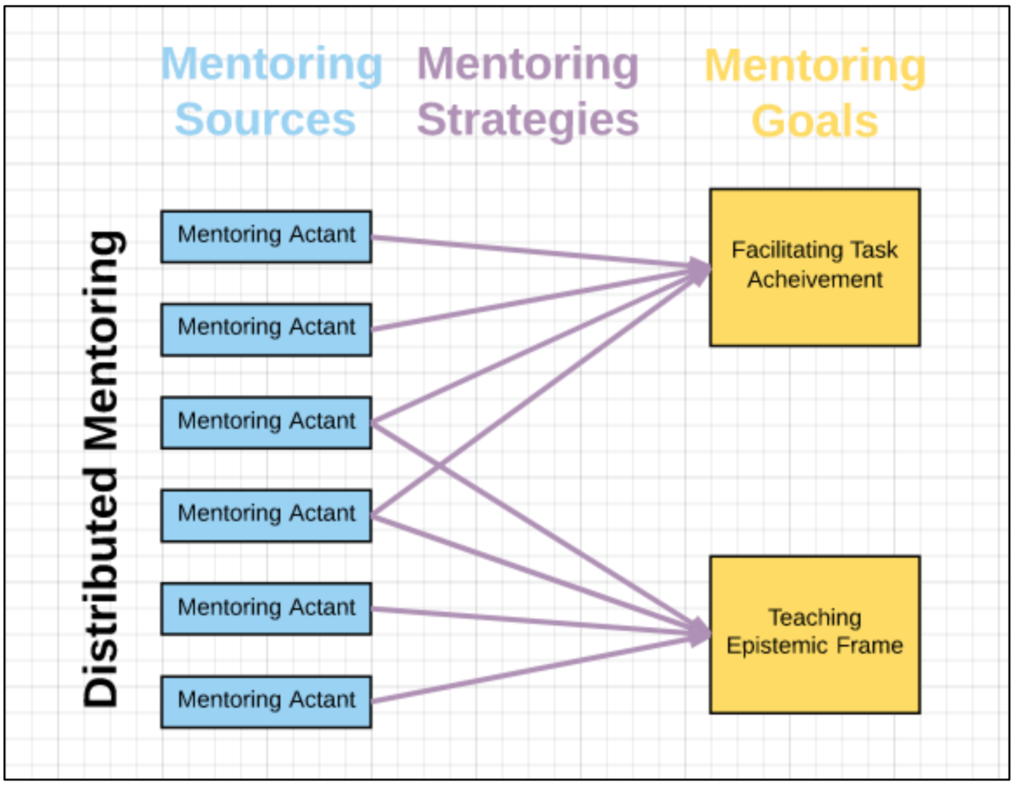


Figure 15. Mentoring strategies and goals distributed among multiple actants.

Despite the variety of mentoring strategies present in this activity, the mentoring actants were mainly delivering information to Tim. From the supervisor telling him what he needed to do, and why it was important, to the design advisor telling him about a resource that could help him, to the technical documents explaining key research about surfactants that he needed to know, these actants told Tim what he needed to know. The example notebook provided by the design advisor modeled important research skills, but even this actant was simply delivering information: rather than telling Tim *what,* it was showing him *how*. Tim was expected to absorb the information regardless. Not all activities were structured this way; other activities were structured so that Tim was doing more than simply summarizing information that he needed to know.

R3. Coordinated Mentoring

The mentoring actants in Nephrotex did not provide their mentoring functions independent of each other's efforts. Instead, they worked together in a coordinated manner. The purpose, and outcome, of their coordinated mentoring was to create a community of practice.

This section examines the two activities that immediately followed the background research activity. The first was another research activity, in which Tim had to read research documents and analyze data on one of the key design parameters, the choice of chemical surfactant. As illustrated in the previous section, the actants in every activity had two overall mentoring goals: facilitating the achievement of a specific task, and teaching the engineer practices related to both the task in the current activity and the overall task of the internship. The first two parts of this section (3.1 and 3.2) look at the way the mentors coordinated their efforts to accomplish these two goals.

The activity following the surfactant research was a reflection meeting in which Tim, his team, and his design advisor discussed what had been learned thus far. As pointed out in the previous section, the mentoring actants used an array of mentoring strategies to accomplish the aforementioned goals. The third part of this section (3.3) looks at the way the mentoring actants coordinated the mentoring strategies they used to establish particular kinds of participation in Nephrotex.

R3.1 Reinforcing Mentoring

As described previously, one the main goals of the mentoring actants was to facilitate the interns' task achievement by defining the task and its timeline, providing resources to help the interns accomplish the task, and judging whether the task had been satisfactorily completed.

The supervisor was a regular source of this type of structure. After the background research activity, the supervisor's next email informed Tim that he would be continuing his research, by learning about the use of chemical surfactants:

> **Supervisor Instructions Email in the Surfactant Research activity**
> Tim,
> In addition to current concentration gradient technology, we are pursuing an innovative method of pressure-driven filtration techniques. One area of filtration research that our company has been investigating is the use of chemical surfactants. For the next step in your design process, you'll need to analyze the impact of surfactants on membrane performance and recommend a surfactant based on your analysis.
>
> We have compiled a list of research documents that our staff scientists published internally. These documents describe experiments in which chemical surfactants have been used on cellulose membranes. You can find information about these experiments in the surfactant reports. For an overview of membrane performance metrics, review a summary of 5 attributes. For information about how they are measured, read the reliability and flux benchmark test and the blood cell reactivity benchmark test documents.
>
> Once you've read over the provided research documents, I need you to create a graph that shows the performance of each surfactant. Use the graphing tool in WorkPro to generate the graph. The technical documents noted above will provide you with all the necessary information.
>
> After graphing the surfactant data, document your work in your engineering notebook. In this notebook entry, you will summarize the effects of surfactants on dialyzer membrane performance. Summaries like these are necessary for myself and internal consultants to keep tabs on the project. They will also prove to be an important reference for you as you get further into the design process. In your notebook entry, be sure to:
>
> 1. Briefly summarize how each surfactant performs for each attribute based on your graphed data
> 2. Make a recommendation to the company on which surfactant to use

3. Justify your recommendation by referring to how the surfactant you chose performs for all five attributes
4. Attach your graph

In addition to the points above, please include a brief reflection on your analysis process. Consider whether the graphing tool was helpful in synthesizing the information in the research documents and analyzing surfactant performance. As noted in the Gantt chart, your notebooks need to be submitted by **09/18/14 10:20AM.** Once each intern on your team has submitted a notebook, you will have a team meeting with your design advisor to discuss your research. Be sure to submit your notebook on time so you will be prepared for the meeting.

Alex

In this email, as in all of his instructions emails, he explained what the task was. In this email, Alex defined the task for Tim by explaining that he needed to "analyze the impact of surfactants on membrane performance and recommend a surfactant based on… [that] analysis." In order to conduct this analysis, Tim needed to read a number of technical documents, and then use a graphing tool to create a graphic representation of the impact different surfactant choices have on a prototype's attributes. He added more details to better define the task by providing a numbered list of what Tim needed to include in his notebook entry:

1. Briefly summarize how each surfactant performs for each attribute based on your graphed data
2. Make a recommendation to the company on which surfactant to use
3. Justify your recommendation by referring to how the surfactant you chose performs for all five attributes
4. Attach your graph

He further clarified what was expected in Tim's notebook entry by telling him to "include a brief reflection" on the "analysis process" that Tim used in the activity. In other words, Alex defined the task for Tim.

He supported Tim by directing him to the technical documents and the graphing tool that would help him complete the task, even providing hyperlinks to reduce navigation steps. Finally, he helped Tim by contextualizing the task, explaining that he needed to do it so he would have a data based “reference” that would help him “further into the design process,” and so he and Tim’s design advisor could “keep tabs on the project.” As he had in previous emails, he boldfaced the deadline for the task to make sure Tim would not miss it. Just as he provided links to the technical documents and the graphing tool, he provided a link to the Gantt chart in case Tim needed to see the deadline for this or any other task. In these ways, Alex supported Tim’s effort.

Information about the task was also available in the calendar tools. As always, the Gantt chart and Deliverable List each identified Tim’s task and deadline, and presented that information in the context of his other tasks and deadlines (Table 16).

Table 16

Supervisor and Calendar tools have reinforcing mentoring goals

Mentoring Goal	Calendar Tools	Supervisor
Define task	Explaining	Explaining
Set timeline	Explaining	Explaining
Support Effort	Explaining	Explaining

In this way, the mentoring focused on task achievement that the calendar tools and the supervisor each provided to facilitate Tim’s task achievement was *reinforcing*, meaning that the different actants mentoring actions shared mentoring goals.

While Tim was getting instructions from Alex via email, Maria, the design advisor, was simultaneously greeting him in chat window. In addition to offering a pleasant salutation, Maria let Tim and his peers know that they probably already had an instructions email from Alex in their inboxes, and reminded them that she was available to help them if they had any questions:

Maria	9/18/14 9:32	Good morning interns!
PJ	9/18/14 9:37	Good morning!
Maria	9/18/14 9:41	By now you should have received Alex's next task. I'm here to help if you have any questions

While she didn't tell Tim what his task was, she supported Tim's effort by identifying two resources that could help him: Alex, whose email could tell him what he should be doing, and herself, who could answer any questions if he got stuck. And, he did in fact get stuck. A minute later, he informed Maria that he was having trouble accessing Alex's email:

Tim	9/18/14 9:42	When I tried to open the email I received an error and couldn't see it.
Maria	9/18/14 9:50	Do you have it now?
Tim	9/18/14 9:51	Yes I do thanks!
Maria	9/18/14 9:51	Great! Sorry about the delay

It was unclear what exactly Maria did in the eight minutes between Tim alerting her that he had a problem and her asking whether it was resolved, and it could certainly be argued that an eight-minute delay before any sort of acknowledgment of the problem was not the best mentoring practice. Nevertheless, she did eventually respond, and his problem had been resolved (possibly because of actions she had taken behind the scenes, but that is an unknown). Judgment of how good her mentoring was in that particular moment aside, Maria attempted to support Tim when he had an obstacle to achieving his task.

Maria did not limit her support to answering questions. She also, as she did in the background research activity (and many other activities), informed Tim that there was an example of the type of notebook he was expected to write in WorkPro's shared space:

> I posted another notebook entry from my old internship in the shared space. In my internship we studied control sensors and power sources, but you're looking at surfactants. Nevertheless, you're welcome to use the example to model your own response after.

So, not only did she offer Alex and herself as resources to help Tim, but she also offered an example notebook entry as a "model." In these ways, the design advisor reinforced the supervisor's efforts to support Tim's completion of the task.

She also, as she so often did, reminded Tim and his peers about the task's deadline:

Maria	9/18/14 10:09	Alex wanted me to remind all of you that you should submit what you have by 10:20am.
Maria	9/18/14 10:20	Alex is extending the deadline. If you're not done yet, please make sure you submit a notebook by 5pm.
Maria	9/18/14 10:20	Anything after 5pm will not be reviewed.
Maria	9/18/14 10:27	That's all for today's work session. Again, remember to submit a notebook to Alex by 5pm. Have a great weekend!

Her first reminder came roughly half way through the work session. Ten minutes later she informed the team that Alex was extending the deadline, and then ten minutes after that she reminded the team again of their new deadline.

The design advisor thus joined the supervisor and calendar tools in facilitating Tim's task achievement in the reflection meeting activity (Table 17). She reinforced both the supervisor and calendar tools in setting Tim's timeline and supporting his effort in completing the task.

Table 17

Three mentoring actants have reinforcing mentoring goals

Mentoring Purpose	Calendar Tools	Supervisor	Design Advisor
Define task	Explaining	Explaining	
Support effort	Explaining	Explaining	Explaining
Set timeline	Explaining	Explaining	Explaining

By reinforcing each other's mentoring that intended to facilitate the intern's task achievement, the mentoring actants in the surfactant research activity established that they were on the same page. The mentoring actants seemed to speak with one voice. They did, in fact, explicitly speak for each other at times. For example, the supervisor did not just send the interns to the Gantt chart to find out their deadline, but rather sent them there via hyperlink *and* directly told them the information they would find there (emphasis his): "As noted in the Gantt chart, your notebooks need to be submitted by **09/18/14 10:20AM."** Similarly, when the deadline was changed in the middle of the activity, the design advisor explicitly spoke for the supervisor (emphasis added): "*Alex* is extending the deadline." In other words, the actants not only used reinforcing mentoring to make sure that the interns got the information they needed about to accomplish the task, but they used it to make sure that the interns knew that the actants were unified in their agreement about all of the details associated with accomplishing that task.

R3.1.2 Joining a joint enterprise

The surfactant activity in Nephrotex was task focused. The process of achieving tasks is largely procedural: knowing what is expected, by when, how to get help, and whether the task is complete. The mentoring actants coordinated their efforts to facilitate Tim's achievement of the surfactant research summary by reinforcing each other's messages around the task, its deadline, and about where to get help. Participating in this activity involved getting information about those four things again and again, from different actants.

Being a member of a community means doing the tasks that the community does. The reinforcing mentoring in the surfactant activity not only facilitated Tim accomplishing a particular task, but also that the task was shared by multiple constituents of Nephrotex. The supervisor, the calendar tools, and the design advisor had all aligned their attention on it; in other words, the task belonged to the community. In the surfactant activity, then, the mentoring's consistent message regarding the task communicated to the interns that they were joining a *joint enterprise* (Figure 16).

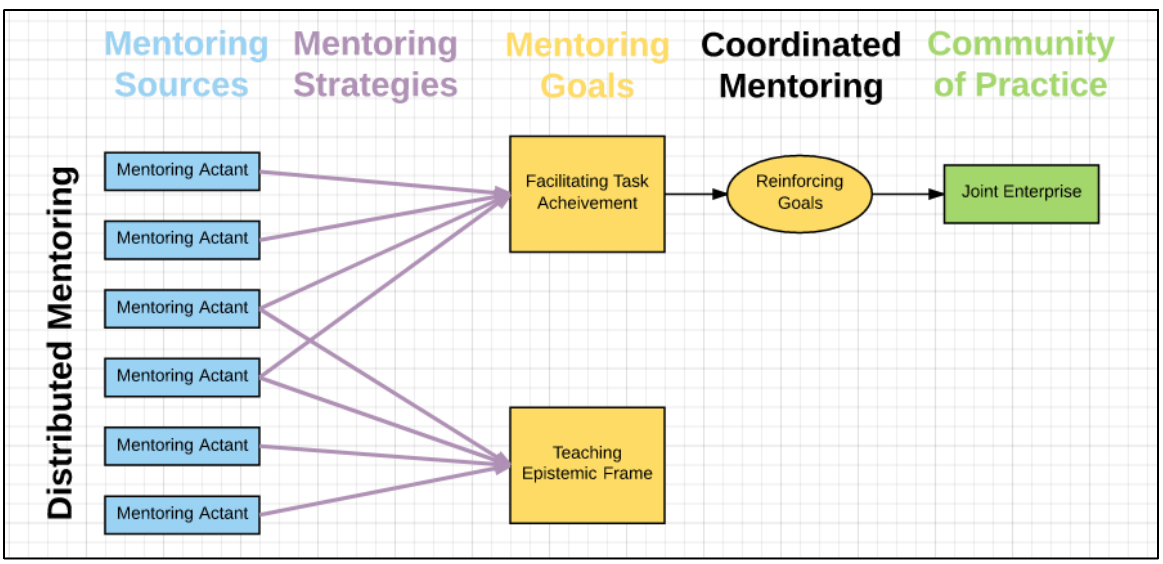


Figure 16. Reinforcing goals for task achievement lead to a joint enterprise.

Participating in the surfactant research activity was about more than writing a notebook entry, submitting it on time, and getting the supervisor's approval. The next section focuses on how the mentoring actants were coordinated in their efforts to teach the interns what they needed to know in order to accomplish the task as if they were engineers.

R3.2 Complementary Mentoring

The surfactant activity required Tim to use multiple aspects of the engineering epistemic frame to accomplish the task. Participating in the surfactant activity involved learning particular content, practicing particular skills, understanding why knowing and doing those particular things was important, and seeing one's identity as that of someone who does these things. In terms of the engineering epistemic frame, that meant the surfactant activity required Tim to mobilize the knowledge, skills, values, and identity epistemic frame elements.

While the mentoring actants were coordinated because they duplicated each other's mentoring efforts on particular mentoring goals related to task achievement, they also focused their mentoring efforts on teaching the engineering epistemic frame. Here too, their efforts were coordinated. This section examines how the mentoring actants worked together to teach the epistemic frame of engineering through *complementary mentoring*.

R3.2.1 Practice-actions aligned by Practice-subjects

Although the surfactant research activity covered a number of different aspects of the engineering epistemic frame, certain aspects of the engineering domain were more emphasized than others. As this activity was in the early research phase of the internship, and the activity itself involved reading research and analyzing data, the relevant engineering practice-subject was "Data." All of the mentoring actants in the surfactant research activity were focused on data (Figure 17).

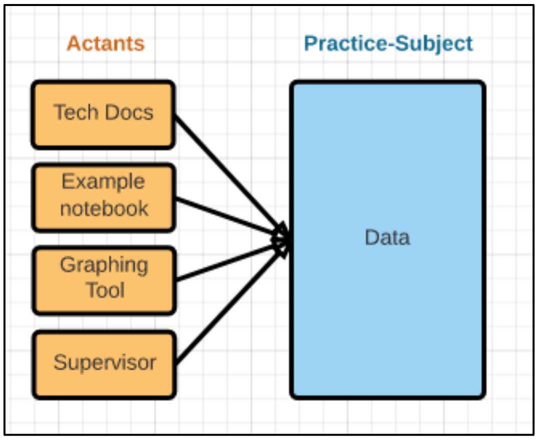


Figure 17. Actants share a Practice-Subject.

Each actant, however, approached this practice-subject differently, and the ways in which the different actants taught the interns about data reveals that their mentoring was complementary.

In his instructions email, the supervisor explained why Tim had to write the research summary of surfactant data:

> After graphing the surfactant data, document your work in your engineering notebook. In this notebook entry, you will summarize the effects of surfactants on dialyzer membrane performance. Summaries like these are necessary for myself and internal consultants to keep tabs on the project. They will also prove to be an important reference for you as you get further into the design process.

The supervisor let Tim know that the data that he would be learning in this activity would be an "important reference" as he continued into the design process. In other words, he communicated that data was an engineering value. In the same email, he granted Tim ownership of the work on data that he would be doing in the activity, referring to "your work, and "your research" and "your analysis process." In this way, he granted Tim an engineering identity based on the ownership of data. The supervisor taught data by presenting it as a value, and by associating it with an engineering identity that he assigned Tim (Figure 18).

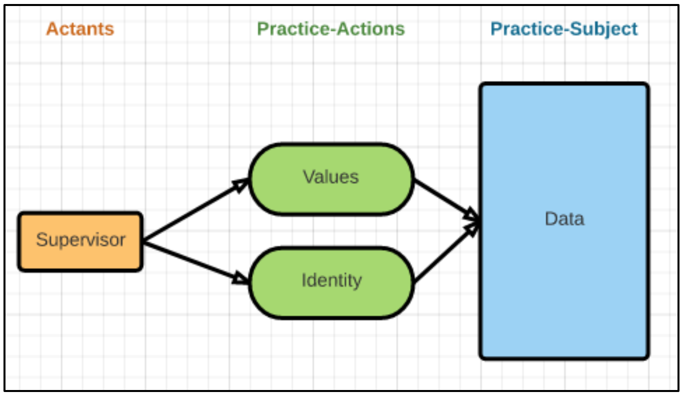
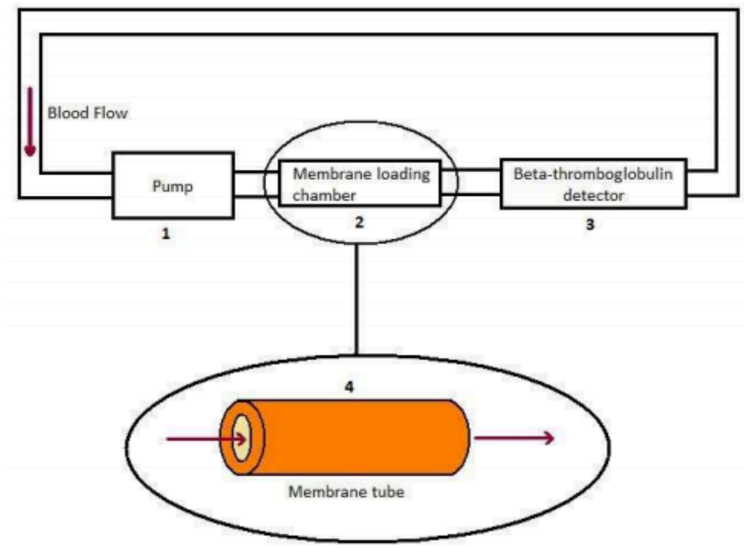


Figure 18. Supervisor connects two practice-actions to Data Practice-subject.

The supervisor was the only mentoring actant who approached the domain of data by talking about values and assigning Tim an engineering identity associated with data.

Other actants approached teaching the data differently. For example, the technical documents contained information that Tim would need going forward in the design process. These documents, authored by Nephrotex staff scientists, described the results of scientific experiments that focused on the effects of different surfactant choices on "membrane performance metrics." In addition, there was a document that described the desired device attributes with an "overview of membrane performance metrics," and documents that described the methods for measuring surfactant performance on reliability, flux, and blood cell reactivity ("benchmark tests"). Tim's task was to read these documents so that he could learn important information about surfactants, their relationship to device attributes, and how that relationship was tested and measured (Figures 19 and 20).

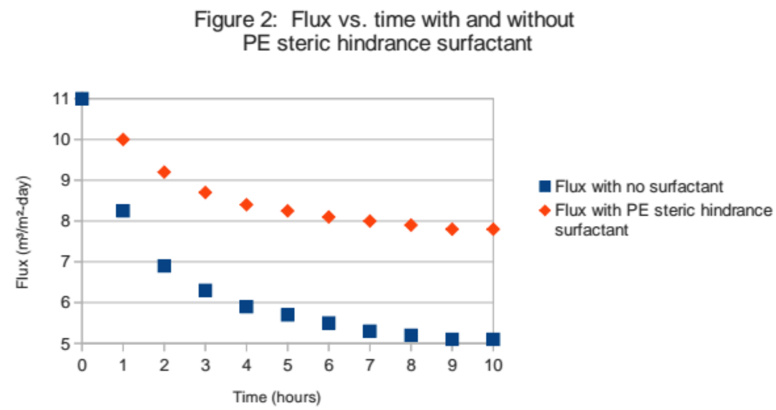
The body's immune response may be activated (undesirably) by contact of blood foreign bodies such as hemodialysis filtration membranes. Platelet activation is one such undesirable immune response, accompanied by beta-thromboglobulin release. Blood cell reactivity is a term denoting the body's immune response and is indexed by beta-thromboglobulin levels in the blood.

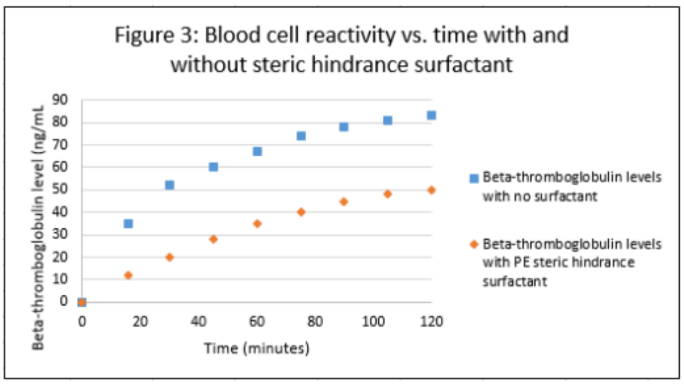


The blood cell reactivity test is a closed system of tubing, containing pig's blood. The pump (1) can be adjusted to apply anywhere from .01 to .4 bar of pressure. The standard experimental pressure is .25 bar, which is roughly one-and-a-half times the average pressure in a human's arteries.

To determine the blood cell reactivity of an experimental membrane, the blood must be exposed to the membrane surface. Membrane tube samples (4) can be loaded into the membrane loading chamber (2). Beta-thromboglobulin levels are measured with the beta-thromboglobulin detector (3). This allows the experimenter to track the blood's reaction to the membrane surface over the course of a simulated dialysis treatment.

Figure 19. Excerpt from “Blood Cell Reactivity Benchmark Test.”





3. Conclusion

PE had a positive effect on both membrane fouling resistance and biocompatibility. The effect of the steric hindrance surfactant on membrane fouling resistance was significant, increasing the time to 75% performance from 1 hour to 3 hours. The effect on biocompatibility was slightly more significant, decreasing the beta-thromboglobulin level after a 2 hour exposure by about 30 ng/ml.

Figure 20. Excerpt from "Nephrotex Experimental Device Testing Report No. 2013-2."

By describing how the surfactants were tested, the technical documents taught Tim how data was produced and provided him with the actual information he needed. The technical documents thus taught Tim the knowledge of data.

The example notebook, by contrast, took another approach to teaching data. When Maria identified her notebook as a resource that could potentially help Tim complete his task, she acknowledged that the subject of her notebook was different. This difference, however, was irrelevant. Even though she "studied control sensors and power sources" in her internship, the notebook was still an “example” that Tim could use to “model” his own response after. Its structure closely mirrored the structure of the research summary Tim was expected to produce:

Power Source and Control Sensor Example Notebook

<u>Control Sensor Performance Summary</u>:

Strain-Gauge

Control sensors don't seem to have any effect on payload, because every sensor (including the strain-gauge) had a payload of 3000 N. Strain-gauge has the best agility of any sensor with 140 deg/sec. However, its the worst sensor in regard to recharge interval with 1.8 hours. It ranks in between the other two control sensor option in both cost and safety with $99 and 84 RPN respectively.

Piezoelectric

As previously stated, this control sensor has a payload of 3000 N like the other sensors. The piezoelectric sensor had the best safety rating at 55 RPN. However its also the most expensive control sensor option, costing $110. This sensor is the the ranks between the other two control sensor options in both agility and recharge interval at 110 deg/sec and 2.4 hours respectively.

Optic-Binary

The payload for the Optic-Binary sensor is also tied for payload at 3000 N. This sensor performs best in recharge interval and is the cheapest option. The recharge interval is 3 hours and the cost is only $54. However, the Optic-binary sensor ranks last in both agility and safety. The agility is 90 deg/sec and the safety rating is 102 RPN.

<u>Power Source Performance Summary</u>:

Lithium Polymer Battery (LiPO)

At 4000 N, the LiPO battery offered the best payload. The agility was tied in the lowest ranking at 50 deg/sec. The recharge interval was also ranked last in a tie at 2.4 hours. The cost of a LiPO battery is $54, which makes it the middle option in the price range for available power sources. Finally, at 72 RPN, LiPO's safety rating was easily the worst compare to the other available power sources.

Nickel Cadmium Battery (NiCd)

The NiCd battery ranked second in payload among power sources with a payload of 3500 N. However, NiCd is easily the best option for agility at 110 deg/sec. the recharge interval for NiCd is 2.4 hours, which ranks it tied for last with LiPO. The NiCd battery is also the cheapest option at $39. At 56, the RPN has the second best safety rating.

Hydrogen Pro Fuel Cell (PFC)

The payload for the PFC is low at 2000 N, making it the worst power source for payload. Its agility is also ranked last at 50 deg/sec. The PFC also costs the most at $78. However, the PFC ranks best in both recharge interval and safety at 3.6 hours and 20 RPN respectively.

<u>Recommendation</u>

For my device, I would chose the Strain-Gauge control sensor and Nickel Cadmium Battery. The Strain-Gauge sensor is the best or second best choice in all categories with the exception of the recharge interval. The NiCd also was the best or second best option in all categories. I think the combination of these choices would make a device which would perform well at a decent price.

<u>Reflection</u>

> I thought the graphing tool was helpful. The graphs gave a clear representation of which control sensors and power sources performed the best for each attribute. I found it easier to synthesize the data from a visual comparison than from the research documents.

As Maria indicated, her example notebook was a model for Tim's task. The notebook summarized the performance of three control sensors and three power sources, with a dedicated section for each. It also included a recommendation for which sensor and power source Maria would have chosen for the device she needed to design in her internship, and a reflection on the research process.

It demonstrated how to write about data, specifically by citing quantitative data when making claims. For example, when she claimed, "control sensors don't seem to have any effect on payload," she cited quantitative evidence: "every sensor (including the strain-gauge) had a payload of 3000 N." The example notebook, then, demonstrated how to write about data in a research summary. In other words, it modeled the skill of data (Figure 21).

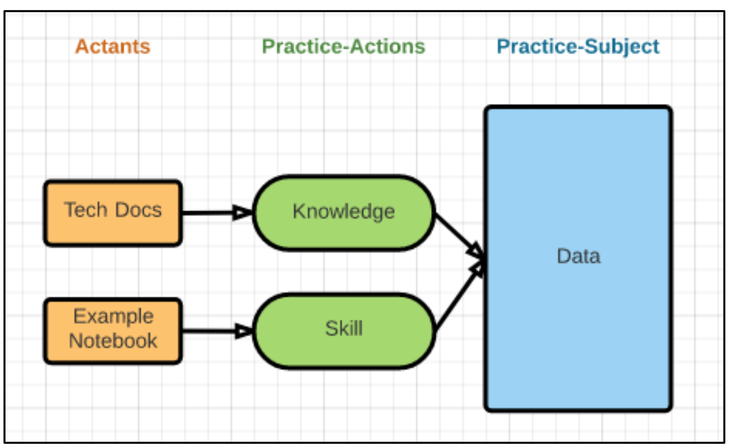
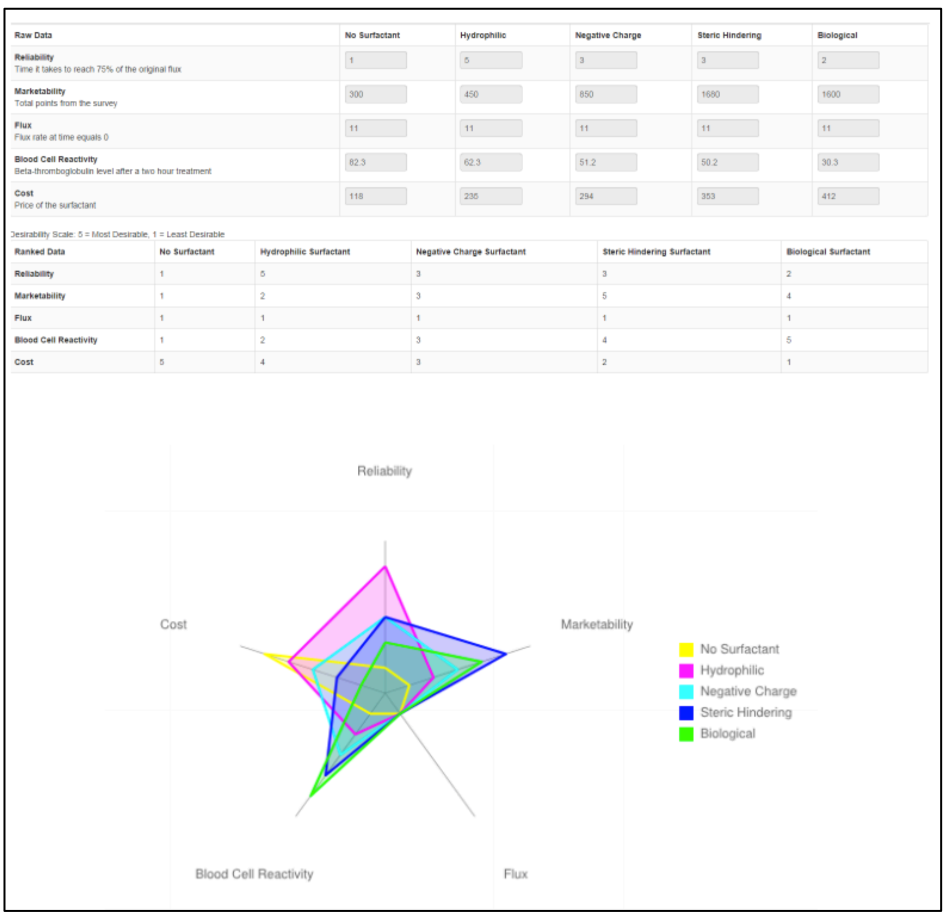


Figure 21. Technical documents and Example notebook complement each other.

These two actants each taught how data was a subject of engineering practice; where they differed was in the type of action they used to access that specific practice-subject of engineering. They complemented each other's mentoring efforts by teaching different practice-actions of the data practice-subject: *knowing* data and *doing* data.

Just as they reinforced each other when facilitating the completion of tasks, mentoring actants sometimes reinforced their efforts in teaching the engineering practice. Part of Tim's task was to use a graphing tool to analyze the data he found in the technical documents. When Tim entered test result values into the graphing tool, it ranked the surfactants for him and generated a graph that helped him see the relationship between the choice of surfactants and the membrane performance metrics (Figure 22).



Raw Data	No Surfactant	Hydrophilic	Negative Charge	Steric Hindering	Biological
Reliability Time it takes to reach 75% of the original flux	1	5	3	3	2
Marketability Total points from the survey	300	450	850	1680	1600
Flux Flux rate at time equals 0	11	11	11	11	11
Blood Cell Reactivity Beta-thromboglobulin level after a two hour treatment	82.3	62.3	51.2	50.2	30.3
Cost Price of the surfactant	118	235	294	353	412

Desirability Scale: 5 = Most Desirable, 1 = Least Desirable

Ranked Data	No Surfactant	Hydrophilic Surfactant	Negative Charge Surfactant	Steric Hindering Surfactant	Biological Surfactant
Reliability	1	5	3	3	2
Marketability	1	2	3	5	4
Flux	1	1	1	1	1
Blood Cell Reactivity	1	2	3	4	5
Cost	5	4	3	2	1

Figure 22. Nephrotex graphing tool.

The graphing tool interactively worked with Tim to analyze and synthesize data using a graphical representation and provided him with specific data values he needed. It taught Tim significant information about the surfactants and attributes and also helped him conduct research. While the technical documents provided Tim with information by explaining research methods and results related to his design task, the graphing tool helped Tim analyze that research by playing an interactive role in the task. When Tim inputted the raw data he found in the technical documents into the graphing tool, the tool responded by creating a graph. This graph, created by both Tim's research and the tool's response, helped Tim synthesize and analyze data by comparing how the different surfactant choices affected the desired device attributes. This tool, then, helped teach him about the relationship between surfactants and device attributes. Moreover, by revealing the relationship between the different surfactants and attributes, the tool framed all of this information as data that would be useful in the context of Tim's design task. It therefore reinforced the teaching goal of the technical documents by teaching the knowledge of data, and reinforced the teaching goal of the example notebook by teaching the skill of data (Figure 23).

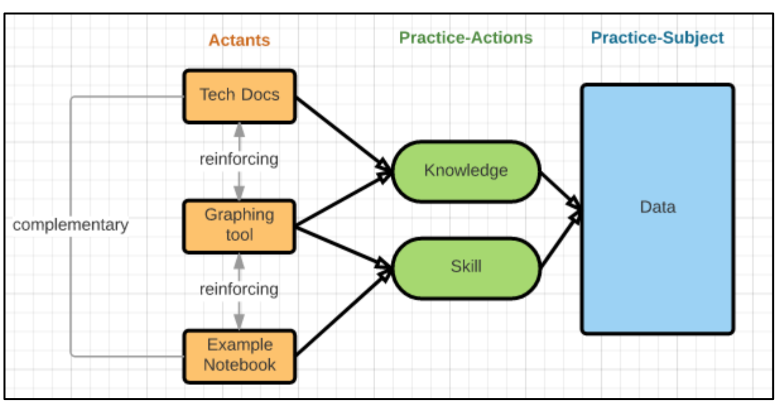


Figure 23. Graphing Tool reinforces Technical documents and Example notebook.

Mentoring actants reinforced each other when teaching data by focusing on the same epistemic frame elements, and complemented each other when teaching different epistemic frame elements that nonetheless shared the same practice-subject. Actants could do both. One actant might reinforce a second actant, and complement a third. For example, the technical documents reinforced the graphing tool's focus on teaching the knowledge of data, but complemented the example notebook's teaching the skill of data. Or, two actants might both reinforce and complement each other actant by both teaching the same epistemic frame element, but each also teaching a different frame element that still share a practice-subject as well. For example, the graphing tool reinforced the example notebook's focus on the skill of data, but complemented the example notebook by also teaching the knowledge of data.

The surfactant research activity was focused on data, one of the specific practice-subjects of engineering. The different mentoring actants accessed this practice-subject by teaching the interns different facets of it. Three mentoring actants treated data as a way of knowing and using information. The technical documents presented data as a set of things to understand. The example notebook, by contrast, shared an exemplar of data analysis, and thus presented how to write about and use data. The graphing tool taught both particular data and how to analyze it. The supervisor complemented all of these approaches by presenting data as something more than simply knowledge or skill, but as something that motivates understanding and doing. In other words, he shared how data is an engineering value. And finally, he associated data with a certain kind of person, an engineer, and granted the interns ownership of that identity. Figure 24 illustrates how one engineering practice-subject, data, aligned the mentoring actants' focus on different epistemic frame elements.

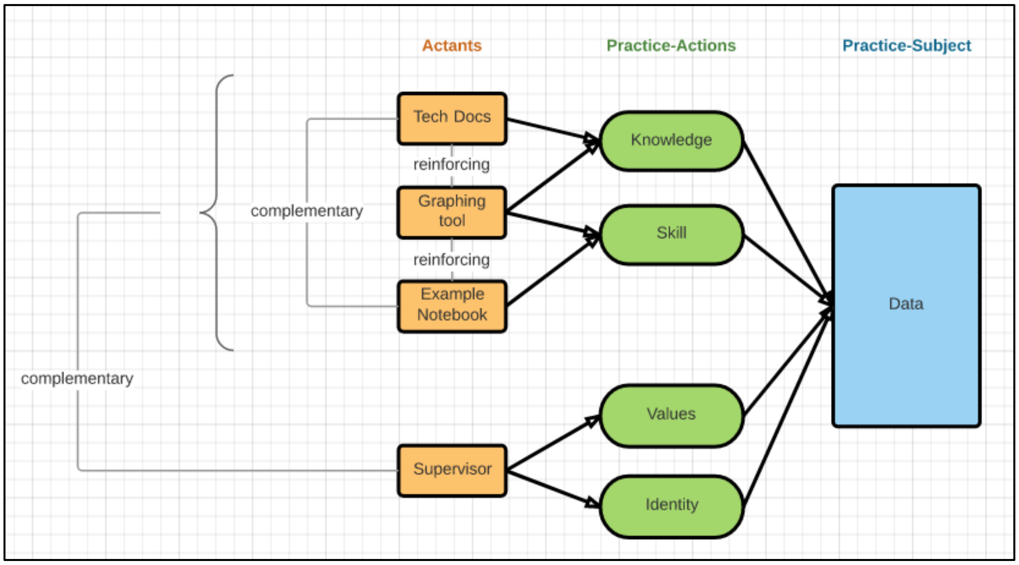


Figure 24. Actants reinforce and complement each other to connect practice-actions to Practice-subject.

These four actants, the supervisor, technical documents, graphing tool, and example notebook, combined their mentoring to teach four important engineering practice-actions: knowledge, skills, values, and identity. Some aspects of the taught epistemic frame elements were only available to Tim because of the mentoring of a single actant. While the actants taught different practice-actions, their mentoring was complementary because they shared a common practice-subject: Data.

R3.2.2 Sharing a Shared Repertoire

The surfactant research activity was learning focused. The way that the multiple mentoring actants in the surfactant research activity worked together—complementing each other's efforts—to teach the interns the engineering epistemic frame was meant to ensure that the interns would accomplish the activity's tasks in the way that engineers would. Complementary mentoring taught the engineering epistemic frame by teaching different engineering practice-actions associated with a common engineering practice-subject.

Being a member of a community means doing the tasks that the community does the way that community does it. The complementary mentoring in the surfactant activity not only taught Tim how to accomplish his task as an engineer would, but also that this method of accomplishing tasks was shared by multiple constituents of Nephrotex. The supervisor, the technical documents, the example notebook, and the graphing tool were all aligned in their focus on data, even if they approached it differently. In other words, the actants systematically coordinated their mentoring to teach the interns the shared repertoire of engineering (Figure 25).

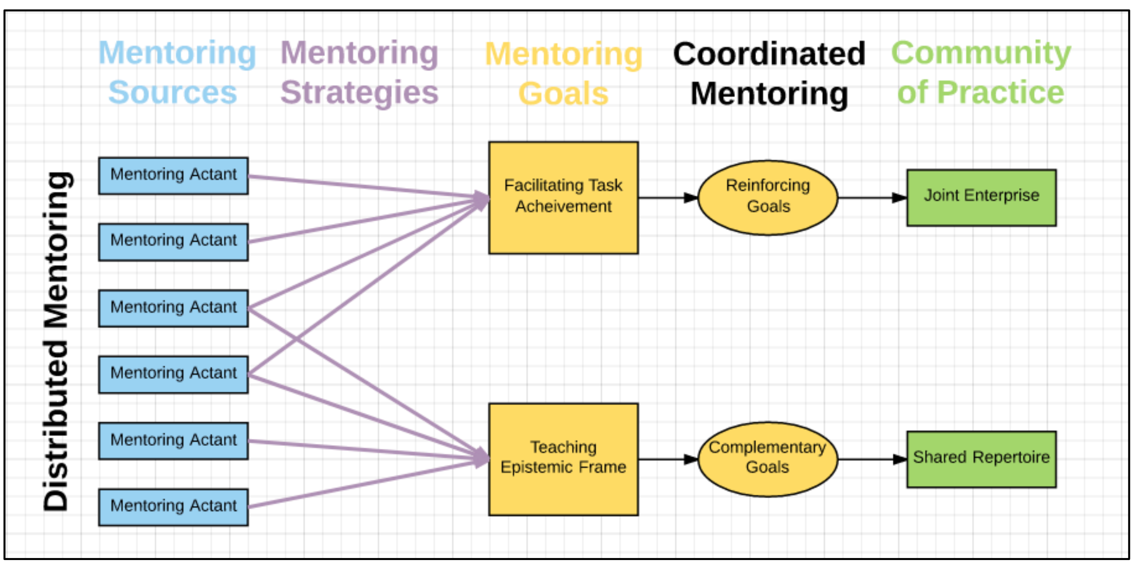


Figure 25. Distributed Mentoring actants complement each other to teach the epistemic frame, leading to a shared repertoire.

The mentoring in Nephrotex was coordinated in that the actants reinforced each other's effort to establish a joint enterprise, and complemented each other's efforts to teach the shared repertoire. When teaching the shared repertoire, the different mentoring actants taught different epistemic frame elements that were nonetheless aligned by common mentoring practice-subjects. The next section examines another way the mentoring in Nephrotex was complementary.

R3.3 Complementary Mentoring Strategies

In addition to complementing each other by focusing on different mentoring goals, the actants also complemented each other by using different *mentoring strategies*. Different mentoring strategies fostered different types of participation in the internship's activities.

R3.3.1 Modes of Participation

Different mentoring strategies facilitated different types of engagement. For example, in the surfactant research activity, the technical documents, graphing tool, and example notebook each taught Tim the knowledge of attributes, but approached teaching this important information differently. Table 18 shows just the approaches these actants used to teach this particular epistemic frame element.

Table 18

Complementary mentoring strategies for teaching an epistemic frame element

Mentoring Purpose	**Graphing Tool**	**Technical Documents**	**Example Notebook**
Knowledge of Device Attributes	Problem-Solving	Explaining	Demonstrating

The technical documents *explained* the knowledge of attributes by communicating the surfactants' effects on device attributes with test results, directly providing the information that Tim needed. The example notebook *demonstrated* the knowledge of attributes by modeling how in another internship the design advisor communicated his design parameters' effects on device attributes with test results. The graphing tool was slightly more interactive; when Tim inputted data into it, it responded with a graphical representation to improve his understanding of the attributes and to increase the amount of data he had at his disposal. It worked with Tim, albeit in a rudimentary way, *problem solving* his incomplete understanding of the knowledge attributes. Explaining, demonstrating, and problem solving each offered Tim different modes of learning key pieces of engineering thinking to help him accomplish this and future tasks. In this way the actants offered *complementary mentoring strategies*.

The surfactant research activity mainly relied on mentoring strategies that focused on delivering information. The sole exception, the graphing tool, was interactive in that it required inputs to generate an output, but this type of mentoring did not facilitate a mode of participation much different from explaining or modeling. In all three cases, Tim was expected to absorb information. Further, Tim encountered these mentoring strategies individually. While using the graphing tool (or reading a technical document or example notebook, for that matter) Tim's activity with that mentoring actant was in the horizon of observation of no one beyond him and that mentoring actant. No one could see what he was reading, or writing in his notebook, or entering into the graphing tool[7].

Other mentoring strategies facilitated different modes of participation. Different activities in Nephrotex involved not only learning different configurations of the epistemic frame—ways of thinking associated with that activity's particular task—but also different types of participation. In fact, immediately following the surfactant research activity was one of those activities: the reflection meeting.

The reflection meeting looked very different from the surfactant research activity. In it, the supervisor used the same mentoring strategies, *explaining* in his instructions email, and *monitoring* via his feedback email. The design advisor, by contrast, used a completely different strategy: *reflective questioning*.

At the start of the activity, Maria insisted that she needed "everyone to participate in this meeting." While each intern had participated in the activities previous to this one, in this activity the design advisor redefined what participation meant. She started the meeting by asking the interns about their previous activity:

Maria	9/23/14 9:39	Based on your surfactant graph, how did the surfactants perform relative to one another?
-	*9/23/14 9:39-9:42*	*Maria answered previous question from Lee about where the meeting was taking place*
PJ	9/23/14 9:42	I feel as if all of the surfactants had their strengths and weaknesses, while the Steric and Biological surfactants scored very high on the Marketability Results, they are the most expensive.
Tim	9/23/14 9:42	According to my graph most of the surfactants had a sort of "redeeming factor", that is almost every one had an attribute about it that was very desirable. For instance the biological surfactant was the least reactive to blood of all the surfactants and the Hydrophilic surfactant resisted membrane fouling for

[7] Once Tim submitted that notebook, however, that horizon of observation broadened to include the supervisor, who could then see a record of Tim's activity, and respond accordingly. His response was only seen Tim though.

		the longest.
PJ	9/23/14 9:45	I agree with Alex. When looking at the data gathered from the No Surfactant results, I strongly believe that this is the only option that doesn't compare with the others.
Ron	9/23/14 9:45	I agree with you guys. The surfactants seem to outperform each other in at least one category. However, this usually meant the surfactant did poorly in other areas. For example, having no surfactant would be the least expensive, but it was ranked lowest in all the other categories. The negative charge surfactant was the only one that did not excel in any particular category.
Lee	9/23/14 9:45	Okay, thank you. I agree each surfactant had its redeeming quality. But I think the Best qualities from some of the surfactants outweigh the best qualities of others. We need to sacrifice one factor atleast in all of them.
Lee	9/23/14 9:46	The hardest part in choosing a surfactant is deciding which factor is most important to us and which is least.

This conversation took place in Nephrotex's chat client, and as such everyone involved in the activity, including the design advisor and the entire project team of interns, was in everyone else's horizon of observation. Every question Maria asked was for the entire team, and each team member saw every other team member's answers. Maria made sure that everyone contributed, waiting for each of the interns to respond before re-voicing or asking her next question. The interns' answers indicated that they all agreed that each surfactant had, as Tim put it, a "redeeming factor" (other intern responses included similar language: "all of the surfactants had their strengths and weaknesses" said PJ, and Lee echoed that each had a "redeeming quality"). Their answers also indicated that they were reading each other's replies. For example, after Tim replied, each of the other three interns referred to another intern's reply (PJ: "I agree with Alex"; Ron: "I agree with you guys"; Lee: "I agree…"). This activity was shared in a way that previous activities had not been.

In previous activities the only indication that other interns were doing the same work came from public displays of instructions or support, such as when the design advisor offered chat messages to remind or clarify what the interns needed to be doing and when it was due, or to offer advice about how to accomplish the task. In the reflection meeting, the interns participated in an interactive conversation with the design advisor, a task in which the main activity grouped them in each other's horizon of observation. Their participation in the reflection meeting was thus a more mutual type of participation than in previous activities.

The reflection meeting featured not only a more mutual mode of participation, but it extended that mutuality beyond the boundaries of the activity. Most of the reflection meeting consisted of the design advisor asking the team questions about their previous activity. Her next four questions were:

1. Was there one surfactant that was obviously the best choice?
2. How did you choose the best surfactant?
3. How were the surfactant graphs helpful in making your final surfactant choice?
4. Did you value some attributes more than others when choosing the best surfactant?

Her questions transformed what had been an individual endeavor for each intern, the surfactant research, into a shared experience. For example, when she asked the interns how the surfactant graphs produced by the graphing tool helped them choose a surfactant (question #3), the interns' answers revealed that their experience with the tool was the same:

> PJ: "They helped by laying all of the data out so that you could compare each attribute easily."
>
> Lee: "They made it much easier to analyze the data because it was all laid out neatly and easy to interpret in comparing the surfactants."
>
> Tim: "The way the graph overlays each surfactant makes it very easy to visualize the differences between each category and determine which is best instead of looking at numbers in a grid."

The three interns' answers revealed that they had similar opinions about the role the graphing tool played in their task. Each intern could see that the others thought that the graphing tool presented the data in a way that made it easier to compare the design attributes. All three commented on how the tool simplified their task (PJ: "you could compare each attribute easily"; Lee: "They made it much easier to analyze"; Tim: "The way the graph overlays each surfactant makes it very easy to visualize…"). Maria's question created a space where the interns described their previous experience, an experience that they did not initially share, including what they did and what they learned.

After the interns answered those four questions, Maria re-voiced what she thought she heard them saying:

> It sounds like you're saying the choice of surfactant involved weighing the effect each surfactant had on the different attributes. Does everyone agree?

After re-voicing, she asked the interns, as a group ("everyone"), whether they agreed with her telling of their thinking. This process of re-voicing was focused on confirming that the experience was indeed shared, and that the interns agreed on what they did and what they learned. In this way the reflective questioning mentoring strategy was a way for the design advisor to ensure that not only was their present experience mutual, but that their previous experience was mutual as well. In other words, by making what the interns learned in the previous activity publicly shared knowledge, the design advisor established that they had been mutually engaged even when it did not seem so at the time.

The design advisor did not stop at making the previous activity mutual. Her last question was focused on the future: "What should your team's next step be?" Tim responded first:

Tim	9/23/14 10:01	I feel like analyzing/researching other parts of the dialyzer is a logical next step.
PJ	9/23/14 10:01	I agree.
Ron	9/23/14 10:01	Same.
Maria	9/23/14 10:02	If I am hearing you right, it sounds like your next steps might include conducting more research on the filtration membranes to better understand the surfactant's effects on design decisions. Does that sound right?
Lee	9/23/14 10:02	I think we should make sure we are agree on the right surfactant and then research how to use them with the nest part of the dialyzer we research.
Lee	9/23/14 10:02	Yes.
Tim	9/23/14 10:02	That sounds right!
Maria	9/23/14 10:03	Perfect!
Ron	9/23/14 10:03	Yes that sounds good

Tim's thought was that "analyzing/researching other parts of the dialyzer is a logical next step." When Ron and PJ immediately agreed with his answer, saying "I agree," and "Same," respectively, Maria re-voiced his answer[8]:

> If I am hearing you right, it sounds like your next steps might include conducting more research on the filtration membranes to better understand the surfactant's effects on design decisions. Does that sound right?

By asking the interns what they thought they should do next, Maria affirmed their participation thus far in the internship in a way that facilitated their participation moving forward. Her question meant that their opinion of the next stage of Nephrotex's enterprise mattered. The next activities the interns would do after this reflection meeting would in fact include "more research on the filtration membranes." Since the interns agreed with her re-voicing, they headed into those activities believing that it was what they should do next.

[8] Lee's response was in agreement with the rest of his peers (he thought they should come to an agreement on what the best surfactant was "and then research how to use… [it] with the next part of the dialyzer we research"), but must have come just seconds after Maria's re-voicing.

Now, when those activities started with an email from the supervisor assigning a task that aligned with what they had just decided was an appropriate next step, they would be on the same page as the supervisor. Maria's reflective questioning thus facilitated a mode of participation that involved establishing mutuality not only among the interns, but also between the supervisor and interns.

The design advisor's brand of reflective questioning that featured the revoicing participant framework, then, was a mechanism for establishing mutuality (Figure 26).

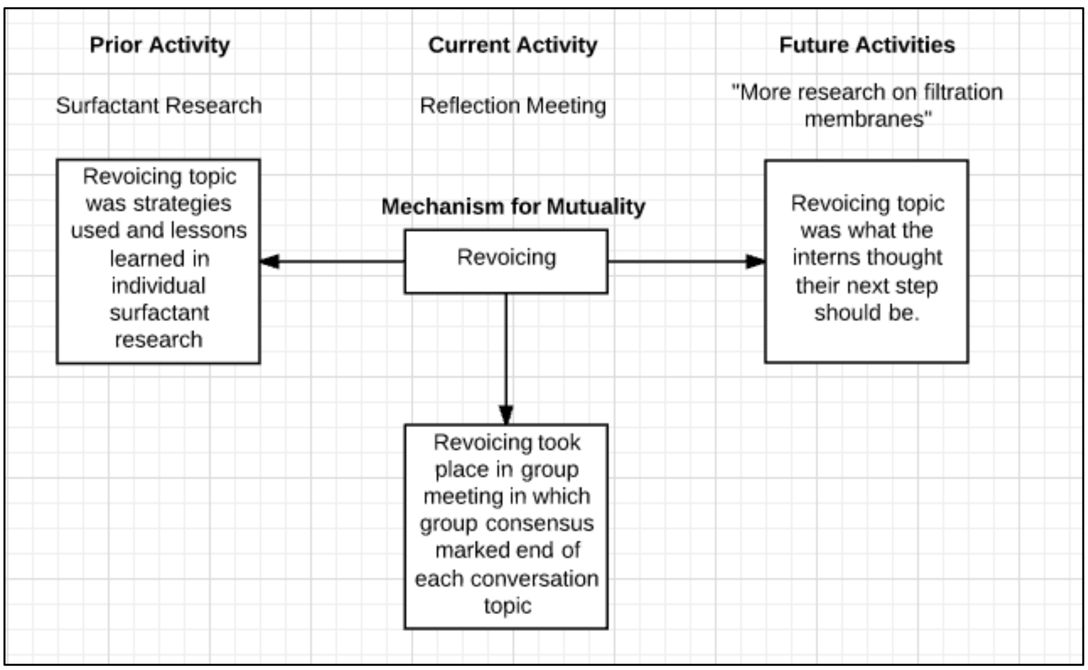


Figure 26. Revoicing as mechanism for mutuality.

Using revoicing, the design advisor facilitated an activity, the reflection meeting, in which the interns had a group discussion in which they all had to participate. In other words, their participation was required and within each other's horizons of observation. Further, the nature of their participation was focused on coming to agreement on conversational topics chosen by the design advisor, and was therefore a mutual experience. These topics extended the mutuality both into the past and into the future.

In the reflection meeting following the surfactant research activity, the mode of the interns' participation in Nephrotex shifted. As the supervisor relayed in his instructions email for the reflection meeting, an important aspect of engineering is collaboration. This activity was much more collaborative than any activity before, and the activities after it followed suit. Whereas in the preceding activities the interns did their work by themselves, starting with this reflection activity, the interns had to increasingly rely on each other.

This is not to say that the surfactant activity (or the background research activity before it) was not engaging or important; the information the interns needed to learn was crucial to their future activities and if it was not engaging, no intern demonstrated their lack of engagement by not learning it. But they did it alone. The surfactant activity was an activity that was engaging, but by itself not particularly *mutually* engaging. The reflection meeting featured the design advisor using a mentoring strategy, reflective questioning, that opened up the horizon of observation of each intern in ways that made the activity, and the prior and next activities, more mutual.

R3.3.2 Mutual Engagement

Different mentoring strategies in Nephrotex created activities that facilitated different modes of participation. Some strategies, like explaining and modeling, were less interactive, requiring interns to absorb information and practice skills. Others, like problem solving and reflective questioning, were more interactive, involving a more reciprocal type of engagement.

For example, Maria's reflective questioning increased the mutuality of the activities of Nephrotex in multiple ways. It expanded the number of co-participants in the reflection meeting activity. It retrospectively established shared lessons from the previous surfactant research activity, and prospectively established shared goals for the next activity. But reflective questioning, though one of the more interactive mentoring strategies, could not by itself facilitate mutual engagement. The reflection meetings were the only activities that featured the *reflective questioning* mentoring strategy, and in those activities, the design advisor was the only actant who used it.

The interns needed to have some common experience on which they could reflect together. Establishing that common experience was the focus of some of the other, less interactive, mentoring strategies. Mentoring actants taught particular engineering domain knowledge and skills, and why these skills and knowledge were important, by less interactive means, such as explaining and modeling. This coordination of complementary mentoring strategies, with explaining and modeling creating a shared experience, and reflective questioning confirming how and that it was shared, promoted mutual engagement (Figure 27).

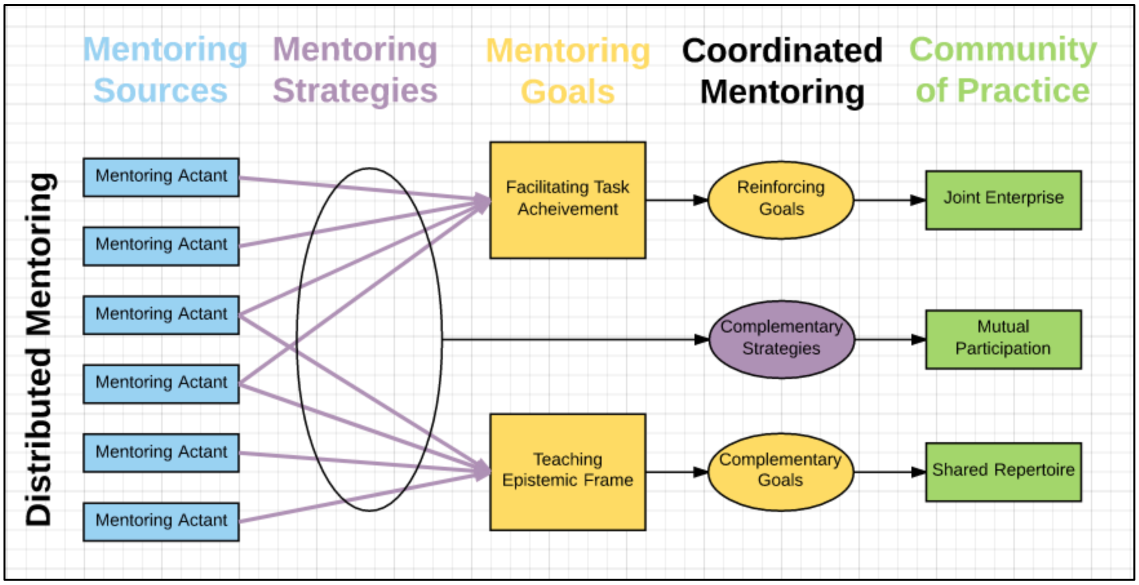


Figure 27. Complementary mentoring strategies lead to mutual participation.

R3.4 Creating a Community of Practice

A community of practice has three aspects that establish its coherence. It is a *joint enterprise*, which means all the members of the community are focused on a common goal. These goals are accomplished by means of *shared repertoire*, which is the common way that community members do their work. And the community features *mutual engagement*, which means that the various members of the community work together to accomplish the goal according to their capabilities.

The mentoring actants in the Nephrotex internship worked together to involve the interns in a joint enterprise characterized by mutual engagement and a shared repertoire. Their aligned goals for the tasks that needed to be achieved were a way of establishing a joint enterprise; their aligned goals for what interns needed to learn to complete those tasks as engineers were a way of establishing a shared repertoire. The combination and coordination of interactive mentoring strategies were a way of encouraging mutual engagement in the activities. In other words, the object of the mentoring actants' coordination was to create a community of practice.

R4. Membership

Nephrotex's coordinated mentoring system created an engineering community of practice. Communities of practice focus their activity on two endeavors: production and reproduction.

Part one of this section examines whether the community of practice accomplished one its key functions: enculturating its newcomers in such a way that they were mutually engaged in a joint enterprise using a shared repertoire. In other words, whether the interns became members of the community by participating in its productive process. This section looks at the trajectory of interns as learners in the community of practice's activity.

The second part of this section examines whether the newcomers participated in its reproductive processes. Part of what community members do is help newcomers to the community learn the ropes. This section looks at how interns transitioned from "newcomers" to "oldtimers," by looking at the trajectory of interns as teachers participating in the community's activity.

R4.1 Production

This section examines how two interns accomplished two tasks in the internship, and did so using the shared repertoire of the engineering community of Nephrotex. Both tasks were design-based. Designing, in Nephrotex, involved using FEEDS (Figure 28), a tool that gave the interns the ability to choose different options for four design parameters (including the choice of surfactant, polymeric material, percentage of carbon nanotubes, and manufacturing process).

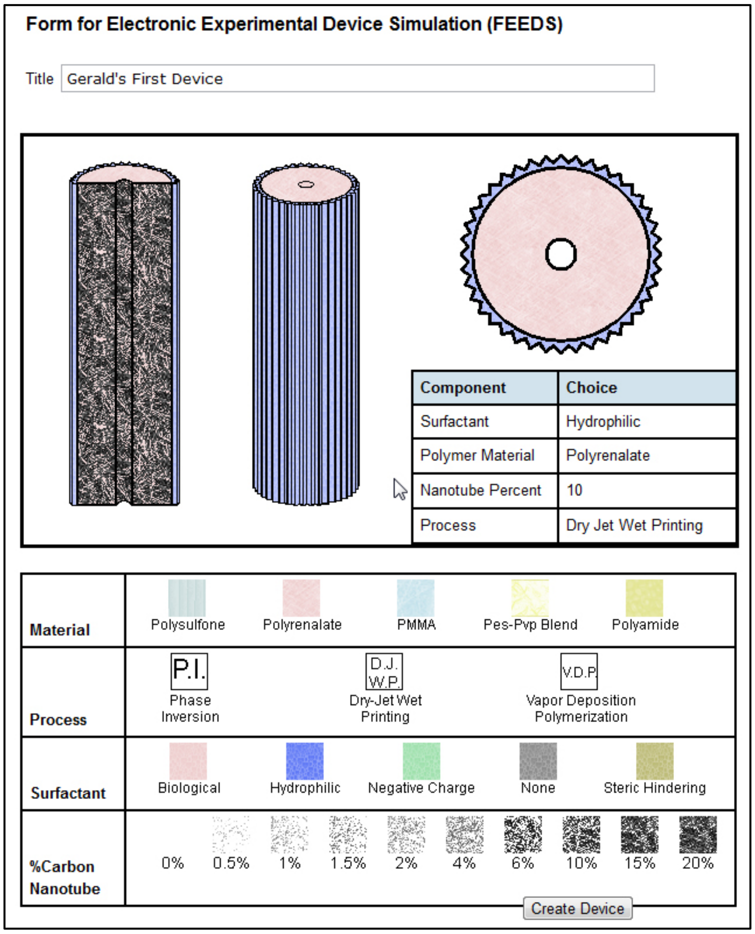


Figure 28. FEEDS interface.

The first task was the interns' first chance to design. In it, each intern individually designed five prototypes. The second task, by contrast, involved the interns' final design. After being shuffled into new teams, the team conducted another round of design testing. Once they received their test results, the team decided as a group what final prototype to recommend to the firm, discussed their decision with the design advisor, and wrote a summary of their discussion in their notebook for the supervisor.

R4.1.1 Being a team player

At the beginning of their first design task, the interns had just finished learning about the internal consultants, who were Nephrotex employees whose priorities for the dialysis devices were meant to inform the devices the interns designed. For example, one of the internal consultants, Rudy Hernandez, was the marketing manager. In an email forwarded to the interns by the supervisor, Mr. Hernandez explained what he was looking for in a device:

> From a marketing perspective, marketability and affordability are the two big factors in producing a competitive device. I don't care how great your dialyzer is: if no one can afford it, no one is going to buy it. I'd try to keep the cost of the device under $120 per unit, which would put it on par with other high-flux models. If you can keep the price under $110 per unit without sacrificing performance, then we'll certainly get a big share of the market. Carbon nanotubes are an exciting new development in our industry, and the first device to market that uses them is going to make a killing. I don't want to get scooped by our main competitor who sold 400,000 units last year. At an industry event last week, I heard a rumor that some of the new dialyzers hitting the market will have a high percentage of carbon nanotubes. If we include them in our membranes, I think we can sell 550,000 units next year.

Each internal consultant cared about two of the device's five attributes, and provided the interns with two threshold values for each attribute of interest. One threshold was a suggestion, and the other a requirement. Meeting the suggested threshold was good, and meeting the required threshold was imperative. Rudy Hernandez cared about the marketability and cost attributes; his suggested cost was less than $110/prototype, and his required cost was less than $120/prototype.

The five internal consultants had different priorities for the devices' attributes. For example, while Rudy Hernandez cared about cost and marketability, another consultant, Michelle Proctor, was a Product Engineer who cared about the flux and reliability device attributes. It was impossible for the interns to design a prototype that met every internal consultant's suggested thresholds because the internal consultants' thresholds for the different attributes were conflicting. As a result, the nature of the design task required compromise.

In the previous activity, the interns had divided up the five internal consultants, one per intern, and read technical documents that described experiments that revealed how different combinations of three parameter choices, the manufacturing process, nanotube percentage, and the team's assigned polymeric material, affected their consultant's particular prioritized device attributes. In this first design activity, the supervisor asked the interns to first share their internal consultant research with their peers, and then to individually design five preliminary prototypes that they thought their team should submit. When describing the task, the supervisor urged that they "think carefully about the designs" as the "goal" was "to test prototypes to get more information about how to meet internal consultant design requirements." The deliverable included submitting the specifications of the five designs, with a justification for each design, and a reflection in which they needed to consider how confident they were that testing their proposed designs would give them the information they needed to achieve a better final product.

Mo, an intern in the group assigned to the PSF material, had researched the parameter choices with Michelle Proctor's prioritized device attributes (flux and reliability) in mind during the last activity. Michelle Proctor suggested that the flux rate be greater than 13.5 $m^3/(m^2\text{-day})$, and required that it be greater than 12 $m^3/(m^2\text{-day})$; in terms of reliability, she suggested that the membrane operate at 75% efficiency after 8 hours, but required it operate at that efficiency after 1.5 hours.

As was typical, the design advisor had provided an example notebook that demonstrated the type of notebook entry that the interns were expected to produce.

Notably, the design advisor did not, as she often would, inform the interns that the example notebook was in the shared space for them to use. Nevertheless, Mo did in fact look at the example notebook for this activity.

<u>Example Notebook for Individual Prototype Design</u>
Title
Individual Prototype Design Example Notebook

<u>Prototype 1</u>
Design Specifications:
Aluminum, Optic Binary, NiCd, ROM 3, Electric
Justification:
I chose the factors for this prototype to be a cheap, yet functional exoskeleton. Cost was a major concern for my internal consultant and I thought choosing factors with low cost would be a good base prototype to compare the following prototypes with.

<u>Prototype 2</u>
Design Specifications:
Aluminum, Optic Binary, NiCd, ROM 2, Electric
Justification:
Prototype 2 is similar to Prototype 1 except that it uses ROM 2 instead of ROM 3. By keeping the other components constant, I will be able to see how much ROM affects the cost and functionality of the prototype as a whole.

<u>Prototype 3</u>
Design Specifications:
Steel, Optic Binary, NiCd, ROM 3, Electric
Justification:
Prototype 3 is also similar to Prototype 1 but instead of using aluminum as the material, I chose to experiment with steel. Aluminium is cheaper and lighter than steel, but also less strong. I thought it would be interesting to isolate just the material and see how the change affects the exoskeleton overall.

<u>Prototype 4</u>
Design Specifications:
Aluminum, Strain-Gauge, NiCd, ROM 3, Electric
Justification:
The difference between Prototype 4 and Prototype 1 is the control sensor. The Optic Binary sensor is cheap and performs only slightly poorer than the Strain-Gauge. With that being said, I thought it would be beneficial to test it so that I could determine if the better performance is worth the extra cost.

<u>Prototype 5</u>
Design Specifications:
Aluminum, Optic Binary, PFC, ROM 3, Electric
Justification:
My final prototype changed only the power source from my original prototype. The NiCd battery is cheapest and has good agility. The internal consultant I researched was concerned with recharge interval, and PFC has the longest interval of the power sources. Doing this test will allow me to see if the more expensive PFC is worth the money for a better recharge interval.

Reflection
I am fairly confident that testing these prototypes will give me the information I need to create a successful final design. By only changing one design input per prototype, I will be able to see exactly how the changed design input influences the device as a whole.

The structure that the example notebook modeled matched the supervisor's description of what Mo should include in his assignment. It also reinforced the supervisor's message about the purpose of the task, as it repeatedly described designs in terms of the information that testing them would provide (e.g. "Doing this test will allow me to see if the more expensive PFC is worth the money for a better recharge interval"). Finally, it modeled a design strategy that involved varying single design parameters in order to better understand the impact of specific design choices ("changing one design input per prototype… to see exactly how the changed design input influences the design as a whole").

Mo got some additional mentoring from his design advisor. While working on his individual device designs on a weekday night, Mo asked Maria a clarifying question in the chat concerning how he should design his five prototypes:

Mo	9/25/14 21:27	When designing the 5 prototypes, are we making one per consultant?
Maria	9/26/14 8:28	Consider designing prototypes that try to meet all of the consultants' requests. For information about each consultant, ask your teammates to share their consultant research with you

The design advisor's answer to his question, delivered the following morning, reiterated the instructions from the supervisor. She recommended getting his peers' internal consultant research and designing prototypes that met "all of the consultants' requests." Despite asking the question and receiving a definitive answer, Mo did not heed this mentoring.

Mo technically achieved the task that he was assigned. He submitted his completed notebook on time, and it included all of the requested items (five designs, with specifications and a justification for each, and reflection on whether these prototypes would help him learn what he needed to learn). The structure of his notebook resembled the structure of the design advisor's example notebook (Bracketed design numbers added for ease of analysis):

Mo's notebook submission of individual designs

[1] Design Specifications: PSF Material, Phase Process, Hydrophilic Surfactant, 2% Carbon Nanotube
Justification: I created this because it closely matches what my consultant wanted. She wanted the flux rate to be at 13.5m^3/(m^2-day) or above. The Ultraflux model with the Phase Process gives the largest flux at 17m^3/(m^2-day), so I decided to try this prototype out and see it it matches the flux rate that was needed. Also, I thought the Hydrophilic Surfactant would match what she wanted because this is the only surfactant that has the highest reliability rate. No surfactants can reach 8 hours or more, and this surfactant is also greater than 1.5 hours.

[2] Design Specifications: PSF Material, Phase Process, Hydrophilic Surfactant, 6% Carbon Nanotube
Justification: This prototype is just like Prototype 1, just that I changed the Carbon Nanotube percentage. I want to analyze how changing the Carbon Nanotube percentage effect the time it takes to reach 75% of the original flux. This prototype will have 1.0% Carbon Nanotube, and I want to see if this increases the time it takes to reach 75% of the Flux.

[3] Design Specifications: PSF Material, Vapor Deposition Process, Hydrophilic Surfactant, 2% Carbon Nanotube
Justification: This prototype is just like Prototype 1, just that I changed the Process. I think my consultant would want this becuase my consultant wanted the nanotube to operate at 75% efficiency after no less than 1.5 hours, but preferred 8 hours or more. The High Flux Model containing this process has the highest time to 75% performance at 6 hours.

[4] Design Specifications: PSF Material, Vapor Deposition Process, Hydrophilic Surfactant, 6% Carbon Nanotube
Justification: This prototype is different from prototype 3 because I changed the Carbon Nanotube percentage in the nanotube. A higher percentage will increase the time it will reach 75% efficiency. I want to see if this will create a longer time for the efficiencty to reach 75%. If this is the case, then this prototype will meet the consultant's specifications more.

[5] Design Specifications: PSF Material, Phase Process, Negative Charge Surfactant, 2% Carbon Nanotube
Justification: This prototype is just like Prototype 1, just that I changed the surfactant. This surfactant has the second highest reliability, and this prototype may help to support that the Hydrophilic surfactant is the best choice if we want a higher Reliability/ hours to reach 75% of the original flux.

> This process of creating test designs helped me to think about how I can create prototypes to help support my ideas that I began with (such as using Phase Process for Flux and Vapor for Reliability), as well as testing many combinations out to see which combination can fit my consultant more. By changing one design specification per prototype, I am confident that my prototypes can help me give me information on how to produce the best final product as I know how combining different choices may impact each other.

More than simply mimicking the structure of the example notebook, Mo emulated its design strategy. As he explained in his reflection in the last paragraph of his notebook, his strategy was to change "one design specification per prototype." For example, his second prototype was identical to the first but for an increased percentage of carbon nanotubes. His third and fifth prototypes were likewise identical to the first prototype but for one design parameter change. He could therefore attribute any changes in performance in the test results for those prototypes to the single change he made in each.

While his testing strategy revealed a command of data and data collection, another aspect of his strategy missed the mark. Mo focused on meeting the requirements and preferences of only one internal consultant, the one he had researched during the previous activity. As he explained in the justification for his first design, "I created this because it closely matches what my consultant wanted." In two of the four other designs (designs #3 and #4) he directly referred to his consultants' priorities. In the other two designs (designs #2 and #5), his justifications focused on the device attributes that his consultant valued, and both directly mentioned how they were "just like Prototype 1," but for one change.

It had been made clear to Mo that he needed to understand the perspectives of all of the internal consultants. Both the supervisor and design advisor had recommended that he design with all of the internal consultants in mind. His team had indeed shared their internal consultant research with each other at the start of the activity. Despite these repeated and aligned messages, Mo's notebook made no mention of either his teammates and their research or the interest of the other internal consultants.

Other interns receiving similar mentoring as Mo, but their submissions looked different. For example, Zoe, an intern in the PESPVP group, received the exact same instructions email from the supervisor that Mo did, and just like Mo looked at the example notebook as a model. One difference is that she did not have the benefit of the clarifying chat messages from her design advisor that Mo received when he asked his question about how to design the five prototypes; in this sense she received *less* mentoring than Mo. Like Mo, she submitted her completed notebook, with all of the requested items included, on time (Bracketed design numbers added for ease of analysis):

<u>Zoe's notebook submission of individual designs</u>
[1] Design Specifications:
Material: PESPVP
Process: Vapor
Surfactant: Hydrophilic
% Nanotube: 20%
Justification:
Many people in my group came to the conclusion that the overall best surfactant was Hydrophilic that is why I chose it for the surfactant in this design. In the provided information regarding CNT percentage, it was displayed that the higher percentage of CNT gave a higher flux. I chose the Vapor process because the cost is under all of the consultants prefered price, it's flux rate is over the required flux rate given by the consultants, and it has the best reliability with 6 hours to reach 75% performance.

[2] Design Specifications:
Material: PESPVP
Process: Dry-jet Wet
Surfactant: Hydrophilic
% Nanotube: 20%
Justification:
I chose the hydrophilic surfactant because my group members all agreed that this was a very surfactant, many even thought it was the best choice. I chose the dry-jet wet process because it had the lowest price which is attractive to many of the consultants and this process still meets the required blood cell reactivity of 75 ng/ml. I decided on 20% CNT because the higher the percentage of CNT, the better flux rate.

[3] Design Specifications:
Material: PESPVP
Process: Vapor

Surfactant: Steric Hindrance
% Nanotube: 20%
Justification:
I chose the steric hindrance surfactant because it has the best marketability. Many of the consultants agreed that marketability was one of the more important attributes in the design. The vapor process is also a good pick because it gives the highest reliability out of the three and is still under the desired price. 20% CNT will provide this design with the most successful flux rate.

[4] Design Specifications:
Material: PESPVP
Process: Phase
Surfactant: Hydrophilic
% Nanotube: 20%
Justification:
The hydrophilic surfactant is the overall best surfactant for membranes so this was a good chode for the design. The phase process gives the highest flux rate for a very good price. This process does not meet the blood cell reactivity standard but the hyprophilic surfactant has the best blood cell reactivity. Again. the CNT % is 20% because it provides the best flux.

[5] Design Specifications:
Material: PESPVP
Process: Phase
Surfactant: Negative Charge
% Nanotube: 20%
Justification:
I chose the negative surfactant charge becaause it has a good marketability and a good blood cell reactivity. The phase process is under the desired price and has the best flux rate out of the three processses, exceeding the desired 12(m^3/m^2-day). The CNT percentage I chose to be 20% because it also creates the best flux rate.

I am very confident that these prototypes, along with the rest of my teams, will really help in providing the information we need to create the best design possible and give us a good idea on how well we are understanding all of the steps thus far. I found it fairly difficult to piece together the best parameters because there was so much information provided that could lead to even more prototypes. but with the prototypes shared among the group should provide a range of design possbilities.

Zoe's notebook submission was notable for its poor writing. It was full of typos, misspellings, run-on sentences and sentence fragments. Mo's notebook also had a couple misspellings, but Zoe's was worse. While she was a worse writer, at this point in the internship she was a better engineer.

Like Mo, Zoe understood that the point of testing preliminary designs was to gather information. As she put it in her reflection paragraph at the end of her notebook, she was confident that the prototypes would "provide the information" her team needed. Her design strategy, like Mo's, anticipated the type of information she would get from her test results. Like Mo, she likely learned from reading the example notebook to only make slight adjustments between prototypes. For example, the only difference between her first and third prototypes was the surfactant she chose. The first design featured the PESPVP material, the Vapor manufacturing process, 20% nanotubes, and the *Hydrophilic* surfactant; the third prototype had all the same design choices except for the *Steric Hindrance* surfactant. Similarly, the fourth and fifth prototypes differed only the surfactant she chose (Hydrophilic in the fourth, and Negative Charge in the fifth); in all other respects they were identical. Her test results would therefore allow her to isolate the effects of those particular surfactant choices.

In contrast to Mo, Zoe leaned on the expertise of her teammates. Three of her five prototypes featured the hydrophilic surfactant, because her team had favored it to be, as she put it, the "overall best." When reflecting on her designs and design process, she explicitly talked about how her team was of value:

> I am very confident that these prototypes, along with the rest of my teams, will really help in providing the information we need to create the best design possible…

She specified that not just her designs but also those her peers designed would be helpful for providing information. She anticipated that the sum of the team's prototypes, "shared among the group," would provide a "range of design possibilities." In other words, she was engaging in this activity with her teammates in mind.

Zoe also designed her prototypes while thinking of all of the internal consultants, not just the one she researched. When justifying a particular design choice, she would explain that "many of the consultants" cared about a particular attribute, as she did in the second and third designs. Or, she would point out how a specific value would meet all of the consultants' preferences or requirements. For example, in her first design, she chose the Vapor manufacturing process because the resulting cost would meet "all of the consultants prefered price" thresholds. Because she considered the interests of multiple internal consultants, she also made decisions by considering how design choices affected multiple device attributes and how she could combine different attributes based on their complementary strengths. For example, as she described in the justification of her fourth design:

> The phase process gives the highest flux rate for a very good price. This process does not meet the blood cell reactivity standard but the hyprophilic surfactant has the best blood cell reactivity.

Zoe evaluated her choice of the phase manufacturing process by considering its trade-offs. It had the "highest flux rate" and a "very good price." On the other hand, it "did not meet the blood cell reactivity standard." She attempted to address this flaw with her choice of chemical surfactant, one of the other device parameters. Choosing the hydrophilic surfactant because it had "the best blood cell reactivity" meant that Zoe justified her design decisions by considering combinations of design choices to ensure satisfactory performance on multiple design attributes. Her design decisions were therefore made and justified based on more factors than Mo's decisions.

The shared repertoire of Nephrotex's community that the two interns used when designing and justifying their designs was taught to them by multiple mentoring actants, from the technical documents, to the example notebooks, to the supervisor and design advisor. The mentoring that they received let them know that they needed to design 5 prototypes, which meant they needed to understand the design parameters. They needed to design them so that testing them would provide them information about how their performance on the design attributes would meet the needs of all of the internal consultants. The example notebook, in particular, modeled a design strategy that involved using controls (e.g., varying only one design parameter). They needed to learn about how different parameters affected the attributes the internal consultants cared about from both their and their teammates' research. And they needed to do all of these things as engineers. The epistemic frame that Mo and Zoe needed to employ to complete this task thus looked like the one in Figure 29.

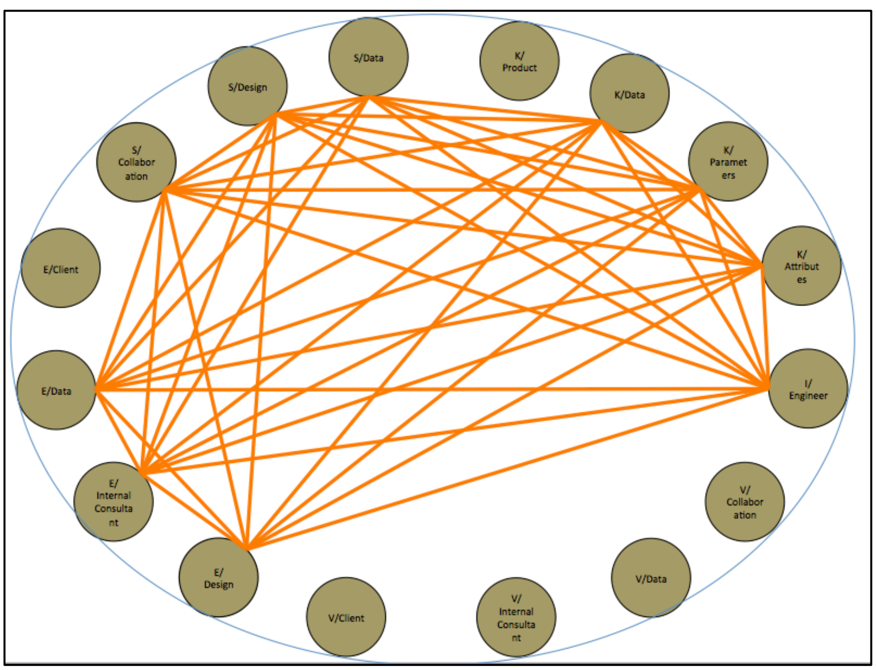


Figure 29. Mentored epistemic frame connections for individual design task.

Only one of the two interns' frames looked like this mentoring frame.

Mo used his knowledge of data, design parameters, and design attributes to design his prototypes. Further, his ability to design and use data to design demonstrated that he was adept at the skill of design and the skill of data. He had adopted an engineering identity, as he designed for an internal consultant that he viewed as his own ("my internal consultant"). He made his design decisions based on the data he anticipated he would get in his test results, and even though he did not design for all of the internal consultants, he made design decisions to meet the priorities of the one he viewed as his own (Figure 30). In other words, he used the epistemology of data, and the epistemology of internal consultants.

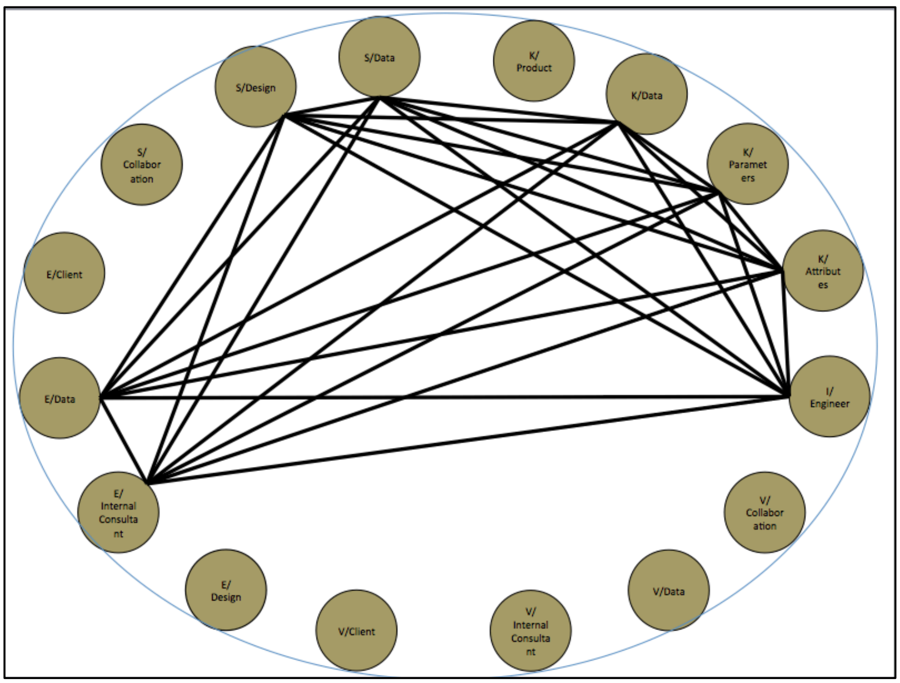


Figure 30. Mo's epistemic frame as enacted in his designs and design justifications.

Zoe made the same connections that Mo did, but her epistemic frame looked different (Figure 31), because she made additional connections:

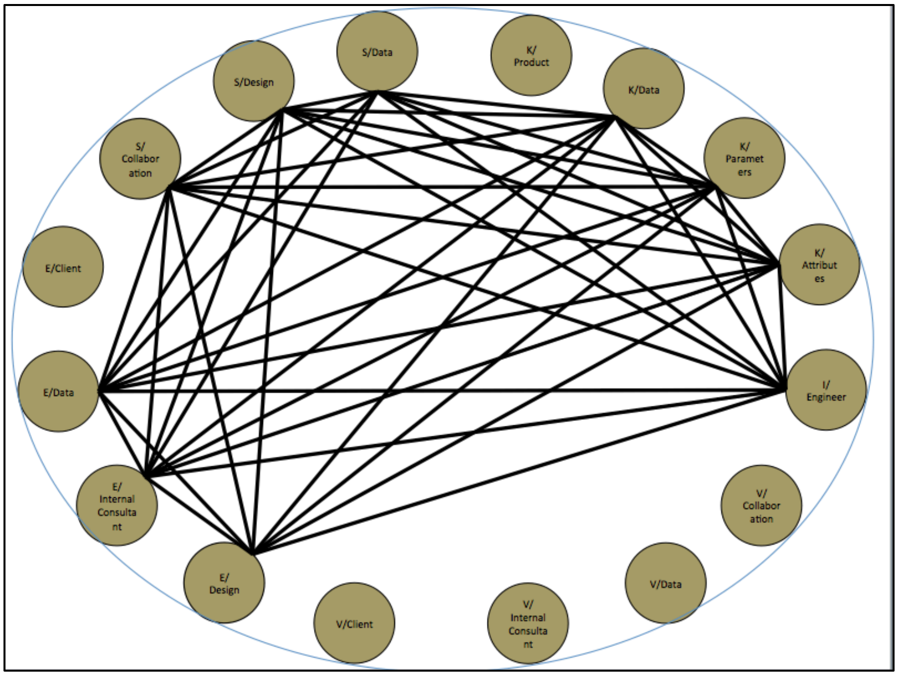


Figure 31. Zoe's epistemic frame as enacted in her designs and design justifications.

Like Mo, Zoe used her knowledge of data, design parameters, and design attributes to design prototypes. Her ability to design and use data to design demonstrated her skill of design and the skill of data. And like Mo, she made design decisions based on her anticipated test result data, using the epistemology of data.

Zoe mobilized additional aspects of the engineering epistemic frame however. Both she and Mo considered the needs of the internal consultants when designing; Mo designed for only one internal consultant, and she designed for all of them. So while they both used the epistemology of internal consultants, her thinking of the needs of multiple internal consultants meant that she had to think in terms of balancing priorities, which meant that she also used the epistemology of design.

Zoe repeatedly referred to how her team informed her design decisions, and her adoption of an engineering identity, which she shared with Mo, was tied to another key skill that Mo missed: the skill of collaboration. Zoe talked about how not just her prototypes, but her *and her team's prototypes*, would give them the information they needed. The different connections in Zoe's designs and design justifications are represented in Figure 32 (connections that she made that Mo did not are in green).

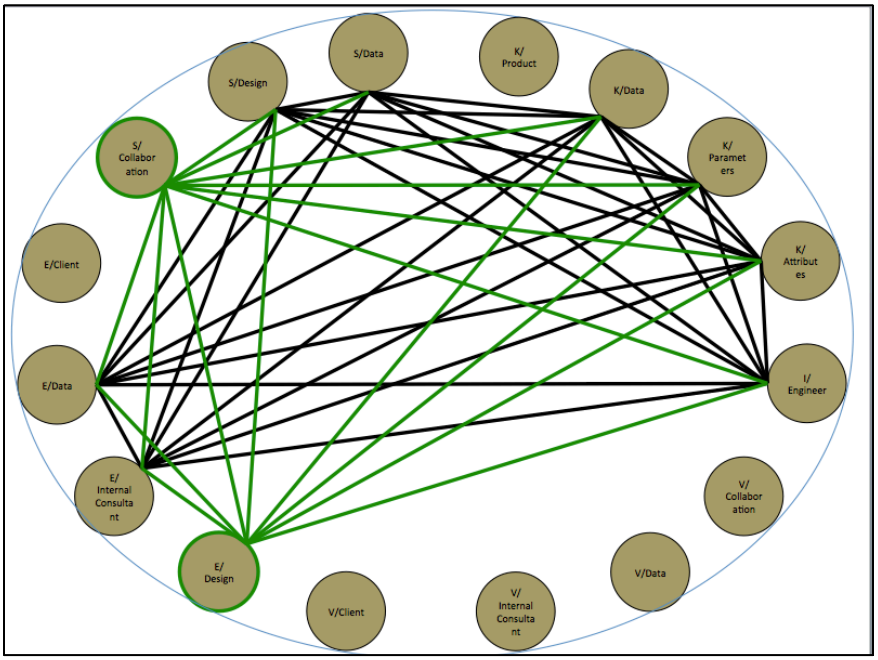


Figure 32. Zoe's additional connections in her designs and design justifications.

To summarize, during the same activity early in the internship, two interns received similar mentoring about how to complete a task using the engineering shared repertoire. While both interns completed the task, the engineering epistemic frame that they used to complete their task was different. One intern used the epistemic frame she was mentored to use, and the other did not.

R4.1.2 Mo Epistemologies

While Mo and Zoe were on different teams initially, later in the internship they were on the same final team. With the rest of their peers in their final team, they had a discussion in which they deliberated and chose a final prototype to recommend to the firm, continued their discussion with the design advisor during which they reflected on their decision, and then individually summarized their discussion for their notebook submission.

Deciding on the final prototype design and justifying it as an engineer would was the culminating goal of the internship. While after this activity the team still needed to present their choice to their peers, and engage in some assessments, in this activity they accomplished the goal set out in the very first supervisor email. They had, in previous activities in the internship, learned multiple ways of justifying design choices. As described in the previous section, Zoe had learned three different ways of making design choices: basing choices on ranking or comparing design options (E/Design), basing choices on data or the promise of data (E/Data), and basing choices on satisfying the interests of the internal consultants (E/Internal Consultants). By contrast, Mo only demonstrated that he learned the latter two epistemologies.

Before joining their new teams, the interns were introduced to one other way of justifying design choices. The final activity with the interns' first groups was a reflection meeting after the team received their first set of test results. One of the topics of conversation in that meeting was how to make decisions if you could not meet all of the internal consultants' thresholds. After asking questions about how the team decided on the five devices they tested, the design advisor summarized the interns' acknowledgment that they needed to make compromises because meeting all of the internal consultants' suggested and required thresholds was impossible: "Yes, so you're saying compromises had to be made and justified because you couldn't meet all of the internal consultants' thresholds. Is that right?" Once the interns agreed (e.g. Mo responded, "Yes because none of the prototypes are perfect"), the design advisor changed the topic of conversation. The next three questions were all focused on the role of the patient in the design process:

1. How did you design your device to address patient needs?
2. Which aspects of the design do you think the patient is most concerned with?
3. How did you address patient safety while balancing the other attributes in your designs?

The interns had a command of which device attributes the patient would care about the most. For example, Mo suggested three attributes:

> Reliability (how reliable the product is), flux (how quick the blood can flow through the product) and Blood Cell Reactivity (so that the immune system does not go off).

In terms of designing for patient safety, the interns wrestled with navigating trade-offs. As Mo put it,

> We had in mind to increase flux and decrease Blood Cell Reactivity, but as the results came out, nanotubes with low blood cell reactivity also has the highest cost. So if we go forward, we should consider these in mind.

Mo was pointing out that their test results revealed that prioritizing the attributes that patients cared about, flux and blood cell reactivity, meant driving up the cost of their devices (Mo used "nanotubes" as shorthand for the device). Nevertheless, his conclusion was that they "should consider these [attributes] in mind" in the future (posed as a conditional, "if we go forward"). The design advisor summed up this topic of conversation by re-voicing Mo and his peers:

> I believe you are saying that patients' needs should be considered, because all other things being equal, the best product is one that is best for the client or user. Does everyone agree?

All five interns agreed with the design advisor ("I agree"; "yes"; "Yes, because after all, its the patients who will buy the products"; "Yes" "Completely agree") that when it is time to decide between devices that otherwise seem equivalent ("all other things being equal"), the interns should choose the one that best meets the needs of the patient ("the best product is one that is best for the client or user”). In other words, an important way that engineers make design decisions is by considering the needs of the client (the epistemology of the client). Therefore, interns should base choices on data or the promise of data (E/Data), on ranking or comparing design options (E/Design), on satisfying the interests of the internal consultants (E/Internal Consultants), and on meeting the needs of the client (E/Client).

When it came to deciding on a final design, the team used all four engineering epistemologies. During their meeting in which they chose their design, they looked at their test results to decide which of the five devices they submitted for testing met the internal consultants’ required and suggested thresholds. Zoe counted three prototypes that met all of the requirements:

> Prototype number 5 met all the requirements, it fell short of two suggested thresholds but it met all the requirements. Prototype 4 met all the requirements and so did prototype number 1.

Another intern, Ron concluded, “I think we should pick one of those three then,” and Mo agreed: “Yeah I believe so too.” By evaluating the designs based on their test results, the team was using the epistemology of data to choose their design. As is apparent from their focus on the internal consultants’ thresholds, they were very clear that internal consultants’ interests were guiding their decision. As Mo put it, “I think we should pick the one that fits almost all consultants because consultants knows whats best.” In other words, they were also using the epistemology of internal consultants. At the same time, Mo carried his understanding of the importance of designing with the patient in mind from his previous reflection meeting. For example, when advocating for prioritizing performance of the design attribute blood cell reactivity, he reminded the team: “we dont want to make something that gets rejected by the body.” Prioritizing designs that would improve the patient's safety and comfort meant that Mo was using the epistemology of the client. Finally, when it seemed like the team was settling on a device, Mo asked his teammates to explain how it compared to another device: "Im fine with chosing zoe's if someone tells me why Ron's cant compare to Zoe's or what aspect Ron's didnt meet a consultant requirement?" In response, his teammates explained how Zoe's design (which they eventually chose) met more of the internal consultants' suggested thresholds, and the particular tradeoffs were acceptable. As Ron himself put it, "cost is better and marketability is the same. I think it's a fine trade-off." The team thus used the epistemology of design as well.

Looking at how Zoe and Mo summarized their decision making and reflection discussions in their notebook submissions demonstrates how they justified their final prototype choice using the engineering epistemic frame taught by the mentoring actants. In her notebook submission, Zoe described her team's decision-making process for choosing their final design:

> **Zoe's summary of the team's discussion**
> Our meeting today was held to choose the best and final prototype. We discussed our results and how the best three compared to each other. By comparing these designs, we gained a better understanding of the most successfu prototype along the way. We discussed the importance of the internal consultants requirements and suggestions and tried to meet as many of those as possible because meeting these thresholds guarantees a successful product.
>
> I agree that prototype number 5 performed the best overall and that it should be our final design in this process. I also agreed that the design we chose should meet as many of the internal consultants thresholds as possible. I did disagree that the BCR level was too high for prototype number 5 and I didn't agree that prototype 1 was the best design. I also didn't agree when Ali said that prototype 1 was the only design that met all of the requirements because it is clear that other designs met these requirements as well. I am clear on our conclusion.

Zoe first explained that they chose the three best designs based on their discussion of their "[test] results" and then considered "how the best three compared to each other." In other words, she reported that the team had used the epistemology of data (because they narrowed down their choices based on test results) and the epistemology of design (because they compared designs). To choose between those three, she described how they "discussed the importance of the internal consultants requirements and suggestions and tried to meet as many of those as possible…" which suggests not only that they valued the internal consultants but that their interests were what guided their choice. Zoe thus cited using the epistemology of internal consultants, the epistemology of data, and the epistemology of design when describing how her team chose their prototype.

Mo's notebook revealed he shared much of Zoe's characterization of the team's decision-making process:

> **Mo's summary of the team's discussion**
> We talked about what we thought was the best prototype, and what will help us consider what the best prototype would be. We talked about how we shold meet every consultant's requests as they know what is best, and because each consultant specializes in a specific field, but making sure their requirements are met will make us be able to find one that meets many different aspects that a customer may be looking at. At the end, we decided that PESPVP, Phase, Hydrophilic, 20.0% was the best because it met every threshold, even met the preferred thresholds too all while hving a low cost. The Blood Cell Reactivity is also at average value too.
>
> I disagreed with the fact that PESPVP, Phase, Hydrophillic, 20.0% was the best prototype. I came in thinking that PAM, Phase, Steric Hindrance, 1.0% was the best because it was even better then the best prototype in the first batch that I ran. It had a decent Reliability, Blood Cell Reactivity is low, Marketability is also decent along with flux. But it did came out being the most expensive. However, after talking to the team, I do believe that PESPVP, Phase, Hydrophilic, 20.0% is better, as each aspect met even the preferred threshold, and although the Blood Cell Reactivity is higher, it still has the average value and cost is low. I agree with my team.

Like Zoe, Mo incorporated the epistemology of internal consultants into his description of the team's choice. In a contrast from the first set of prototypes he designed individually, he talked about meeting "every consultant's request." Also, in contrast to his first designs, he was much more team focused, even describing how, "after talking to the team," he was convinced that the prototype he initially thought was the best was not as good as the one they eventually chose. Specifically, he started by simply comparing devices. For example, the first device he considered the best “because it was even better then the best prototype in the first batch…” Comparing devices is a way of using the epistemology of design. His team helped him remember that devices should be evaluated in terms of how many of the internal consultants’ thresholds they met; they chose their design because “each aspect met even the preferred threshold.” In other words, he understood that his team was best served by choosing a device by how it met the internals consultants’ requests rather than simply by comparing them to each other. He also talked about why meeting the consultants’ requirements was important. Doing so, he argued, would allow the team to “find one [device] that meets many different aspects that a customer may be looking at.” In other words, he was also making his choice based on the epistemology of the client.

There are thus four configurations of epistemologies that describe Mo and Zoe’s learning the engineering shared repertoire that they were mentored to use: the mentored epistemologies, the team’s epistemologies, Zoe’s report of the team’s epistemologies, and Mo’s report of the team’s epistemologies (Figure 33).

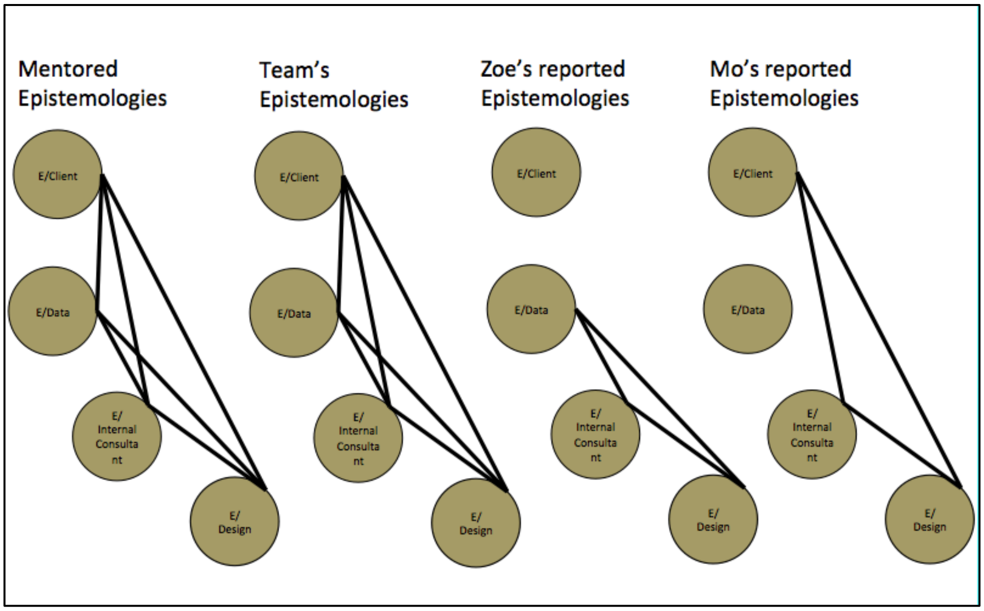


Figure 33. Taught and learned epistemologies.

While Zoe and Mo's team used all four of the mentored epistemologies in their group decision, the two interns had different takes on the same experience. Both Zoe and Mo indicated that they used the engineering epistemologies that they had been mentored to use. They both explained that comparing how the team's different designs met the needs of the internal consultants was how they made their decision (E/Design and E/Internal consultants). They each highlighted one additional way of making decisions. Zoe mentioned how the test results allowed them to compare designs in terms of the attributes that the internal consultants cared about, thus indicating that they used the epistemology of data, while Mo described how they were meeting the needs of the client by trying to satisfy the internal consultants' requirements, thus reporting that they used the epistemology of the client.

Mo showed progress from his earlier design justifications, when he failed to apply the epistemology of design that he had been taught. In this final design task, Mo paid attention to his team, compared designs both in terms of their attributes and how those attributes met all of the internal consultants' interests, and even considered the needs of the client. The epistemology of the client, especially, was an indication that Mo was learning from the mentors, as he was the intern who was advocating for thinking about the patients in the team's discussion (all of the interns were discussed the other three epistemologies), and the mentoring that addressed the epistemology of the client happened days before, back when the interns were with their previous teams. Mo's progress was thus evidence that he was becoming a more full member of the engineering community of practice of Nephrotex.

R4.2 Reproduction

Participating in the Nephrotex community of practice was about more than accomplishing all of the tasks necessary to finally achieve the overall goal of the internship, recommending a prototype dialyzer. Members of a community of practice, now matter how new they are themselves, are also responsible for helping those participants in the community who are less experienced, or less capable, than they to do the work. In other words, one characteristic of members of a community of practice is that they provide mentoring functions for other members. This section examines how interacting participant structures enable the interns in Nephrotex became sources of mentoring functions. The jigsaw, revoicing, and problem solving participant structures lead the interns to provide each other with support, promote mutual engagement and teach each other the community's knowledge.

R4.2.1 Becoming resourceful

After Tim and his team had conducted research on dialysis, dialyzers, and chemical surfactants, and had been introduced to the internal consultants and their required and suggested thresholds, they needed to learn about how the other three design parameters affected the internal consultant's interests. In his instructions email, Alex suggested that since the internal consultants' views were so important (as he put it, "the internal consultants will ultimately determine whether a final design is acceptable or not"), the team's five interns should split up the research so that each intern would be responsible for understanding how the parameter choices would affect one internal consultant's preferences.

Alex's email explained that once they had established which intern would research which internal consultant, they should:

> …focus on the how the design parameters affect the attributes that your consultant prioritizes. For example, if your internal consultant is concerned about blood cell reactivity, research how blood cell reactivity changes as the manufacturing process and carbon nanotube percentage change when using PAM as the membrane material. You have access to the company's research reports such as the report on polyamide and carbon nanotubes, and device specifications. At this stage in the design process, you are only researching one material, so you need only look through the company's literature on PAM.

Each intern needed learn specific information about how the design parameters affected the design attributes that one internal consultant cared about by reading Nephrotex's technical documents, which described experiments and data that revealed the relationships between parameters and attributes. Alex thus simultaneously emphasized the importance of knowing how to satisfy the internal consultants/interests and granted each intern the responsibility to be the carrier of this important knowledge learned from the technical documents.

As usual, there was an example notebook available to model what Tim's deliverable should include and how it might best be organized.

<u>Consultant Analysis Example Notebook</u>
Title: Consultant Analysis Example Notebook
<u>Consultant</u>: Laura Rivers - Chemical Engineer

<u>Effect of Range of Motion and Material Choice on Attribute 1</u>:
Attribute: Recharge Interval
Effect of Range of Motion: According to tests on Electric Actuators conducted by RescuTek, the recharge interval is inversely proportional to the number of degrees of range of motion. The best recharge interval is greater than 12 hours for ROMs 1, 2, and 3. For ROMs 4, 5, and 6 there is a steep decline, the recharge interval dropped quickly to 6 hours [1].
Effect of Material: According to RescuTek's resources, there does not seem to be any correlation between the material choice and the recharge interval. More testing is needed to understand the effects of material on recharge interval.

<u>Effect of Range of Motion and Material Choice on Attribute 2</u>:
Attribute: Cost
Effect of Range of Motion: RescuTek's resources do not specifically cite how ROM influences cost. However, it would make sense that an increase in ROM would push the cost higher--due to the addition of more active joints. More research would need to be conducted to see a more specific correlation between ROM and cost. I think ROM 3 would be good for Laura Rivers because it has a good recharge interval and would likely be less expensive than ROMs 4, 5, and 6.
Effect of Material: I think aluminum is the best choice for a material that would be effective and cost efficient. With a price of $120/unit it is the cheapest option and is fairly light [2]. However, it has the worst maximum tensile strength of the available materials.

<u>Works Cited</u>:
1. Malik, V., Edwards, D., Henriquez, P. (2012). The Effect of Exoskeleton Range of Motion on Electric System Level Performance Metrics (RescuTek Experimental Testing Report No. 2013-217). Retrieved from http://www.rescutek.com.
2. "Materials Descriptions and Technical Specifications." RescuTek. N.p., n.d. Web. 6/23/2012

The example notebook included data to support claims about how design choices might affect the design attributes that the internal consultant ("Laura Rivers - Chemical Engineer") prioritized. For example, when describing the effect of increasing range of motion ("ROM") on the "Recharge Interval" attribute, the example notebook explained that for "ROMs 4, 5, and 6 there is a steep decline, the recharge interval dropped quickly to 6 hours." It also included references in a "Works Cited" section. As the particular attributes and parameters in Maria's model were not relevant to Tim's task, the main purpose of the example notebook was to teach him how to write a certain type of analysis.

In other words, the technical documents would teach Tim the knowledge of design parameters, design attributes, and data, while the example notebook would teach him the skill of data. The supervisor oriented his research by making sure he was learning it for the important purpose of understanding how to meet the internal consultants interests. The coordination of these mentoring actants would help him produce his own consultant analysis (Figure 34).

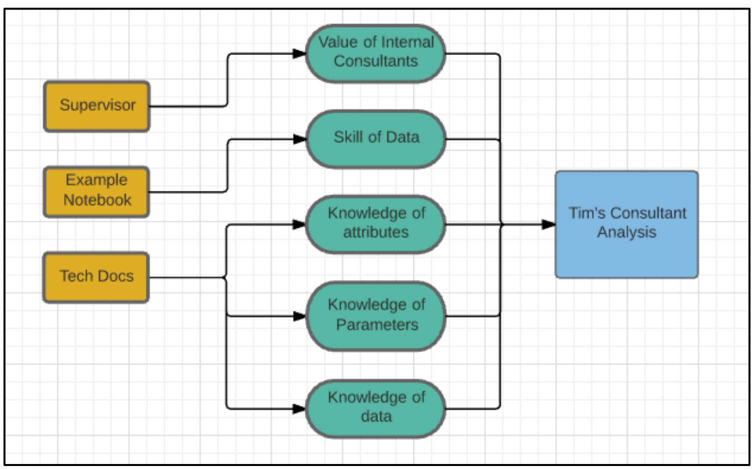


Figure 34. Tim's consultant analysis guided by complementary mentoring.

Tim's internal consultant was Michelle Proctor. He read the technical documents and the example notebook, and wrote and submitted a notebook summarizing his research:

> **Tim's consultant analysis**
> Michelle Proctor
> **Attribute:** Flux
> **Effect of CNT Percentage:** The CNT percentage in the Polyamide nanotube blends has a marked effect on flux levels. At no levels of CNT to slightly under 1% CNT flux levels remain at about 20m^3. At levels of 1% to 2% flux increases rapidly then levels off at 22 m^3. After 2% flux levels rapidly fall to levels below the original flux level.
> **Effect of Manufacturing Process:** The engineering process also has a profound effect on flux levels. The phase inversion manufacturing process has the highest flux rate at 17m^3 and also benefits from costing only $30 per unit.

Attribute: Reliability
Effect of CNT Percentage: According to Nephrotex's experimentation into the effects of CNT dispersion within polyamide/nanotube membranes the inclusion of carbon nanotubes in the dialyzer directly increases fouling resistance. With no CNT inclusion the devices only lasted for 2 hours before reaching 75% flux while the device lasted 4 hours at a CNT concentration of 4%.
Effect of Manufacturing Process: The manufacturing process has a large effect on the reliability of the membrane. While the Phase Inversion manufacturing process has the benefit of retaining high flux this unit also only extends time to 75% performance to 3 hours. Of the three processes the Vapor deposition polymerization process keeps the dialyzers the most reliable; it extend the time to reach 75% to up to 6 hours.

Montino, Victor, et. al. Enhancement of PAM Membrane Performance via CNT Dispersion (Nephrotex Experimental Device Testing Report No. 2013-21). Retrieved from Nephrotex, Inc. website: http://nephrotex.com. Date Accessed: September 26, 201

"Polyamide Device Specifications". Retrieved September 26, 2014 from http://nephrotex.com

Tim's submitted notebook described how the "CNT Percentage" and "Manufacturing Process" design parameters interacted with his team's material "Polyamide," to affect the two design attributes that Michelle Proctor stated were her priority, "Flux" and "Reliability." In doing so, he used data from the technical documents to back up his claims. For example, when he claimed that the "CNT percentage in the Polyamide nanotube blends has a marked effect on flux levels," he explained that at "no levels of CNT to slightly under 1% CNT flux levels remain at about $20m^3$." Tim thus followed the mentoring cues that the supervisor, technical documents, and example notebook provided him to produce a consultant analysis that focused on the how design parameters affected the attributes that his consultant prioritized. In other words, his consultant analysis communicated the knowledge of design parameters, design attributes, and data.

Just as with the mentoring that took place in other activities, the information the interns learned in the internal consultant research activity was necessary for their ability to complete the tasks in the next activities. In the upcoming individual and group design activities, interns needed to know about all the design parameters and attributes, and their relationship to all of the internal consultants' interests, including those consultants that they did not personally research.

The next activity was the individual design activity (described in greater detail in the previous section). The first thing the supervisor told the interns to do was to share their consultant analysis notebook entries with their peers. In terms of mentoring, this individual design activity required the interns to know about all of the internal consultants' interests and what design choices would be best to satisfy them. Each intern's notebook entry, modeled after the design advisor's example, contained the type of data about the design parameters and attributes that the interns would otherwise get from the technical documents. Rather than have the interns go to the technical documents for this information, the supervisor instead had the interns go to their peers' consultant analyses (Figure 35).

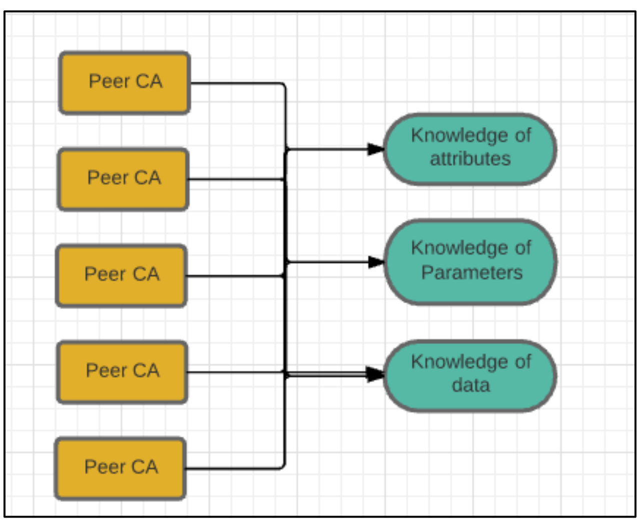


Figure 35. Peer consultant analyses teach epistemic frame elements.

Nephrotex featured a jigsaw participant structure in which learners conducted independent research and shared that research for the purpose of accomplishing a consequential task, design. The consequence of the jigsaw was that interns began to serve mentoring functions associated with membership in the Nephrotex community of practice (Table 19).

Table 19

Tim's adoption of mentoring actions focused on teaching engineering knowledge

Mentoring Purpose	**Original Activity**	**Original actant**	**Original use of mentoring strategy**	**Tim's use of mentoring strategy**	**Activity in which Tim provided mentoring**
K/Data	Internal Consultant Research	Technical Documents	Technical documents explained results of experimental studies.	Tim's research summary explained results of experimental studies	Individuals design 5 devices
K/Design attributes	Internal Consultant Research	Technical Documents	Technical documents explained how design parameters affected design attributes.	Tim's research summary explained how design parameters affected design attributes	Individuals design 5 devices
K/Design Parameters	Internal Consultant Research	Technical Documents	Technical documents explained how design parameters affected design attributes.	Tim's research summary explained how design parameters affected design attributes	Individuals design 5 devices

A mentoring function that was typically the purview of the technical documents became the responsibility of the interns' consultant analyses. Tim's consultant analysis, and those that his peers created, thus carried out a mentoring function focused on teaching the shared repertoire of the Nephrotex. The interns were becoming members of the community of practice by virtue of their roles as reliable sources of the Nephrotex way of doing things.

R4.2.2 Problem Solvers

In the group design activities, the interns adopted even more mentoring functions. After their individual design activity, where the interns individually designed five prototypes using FEEDS, Tim's team (and each of the other teams) was tasked with deciding on five prototypes that they would submit for testing. The only group activity of the internship before this group design activity was the reflection meeting facilitated by the design advisor. While the design advisor was available for questions and did interject with advice and reminders, the interns needed to decide on their five prototypes on their own.

As the supervisor had instructed, the purpose of these tests was to determine how different combinations of design parameter choices would affect a prototype's attributes. Each intern came to the meeting with the five prototypes they had individually designed in the previous activity. At the start of the discussion, there was no foregone conclusion as to which of those designs, if any of them at all, would be the ones they chose.

Over the 60 minutes of the design meeting, Tim and his teammates settled on their five devices to test. They started by establishing the process by which they would decide.

Tim	10/2/14 9:29	How about everyone describes one of the devices they submitted for the last notebook and we'll go from there.
PJ	10/2/14 9:31	How do we want to go about deciding which prototype to send?
Tim	10/2/14 9:32	If everyone chooses one they feel strongly about from their own list we can try those and go from there.
PJ	10/2/14 9:32	That sounds good.
Ron	10/2/14 9:32	That works.
Lee	10/2/14 9:33	sounds good!

Tim suggested that they each "describe one of the devices they submitted for the last notebook" and then they would "go from there." The first decision they made about their decision making process involved each intern contributing a design that they felt "strongly about from their own list." His teammates agreed.

Having established that each intern would contribute one of their own designs, the team continued to discuss their process. Tim started by volunteering one of his devices.

Tim	10/2/14 9:34	For example I had a design whose specs. were PAM, Vapor, None, and 0.0% CNTs. I figured a device that utilized the cheapest components and no surfactant would serve as a control to compare our test devices to and relate how a change in each attribute (process, surfactant, CNT%) affects the performance of the device as a whole.
PJ	10/2/14 9:34	I am in favor of using that as one of our choices.
Ron	10/2/14 9:35	My device uses a phase inversion process, a biological surfactant, and 4.0% carbon nanotubes. This gives the lowest blood cell reactivity based on the numbers given for each component.
Ron	10/2/14 9:35	I like having a control device.

Tim did not volunteer his device because he thought it was the best, but rather because he thought it would be a good device to use as a comparison. In other words, he suggested they create a "control" device. Tim almost certainly got the idea for this design strategy from the example notebook from the previous activity, in which the interns designed their first five devices. As described in the previous section, this model explicitly called out its use of a control device: the cheapest, most minimally outfitted prototype that was possible, in order to make it easier to determine the relative effects of the design choices from the test results. PJ and Ron, Tim's teammates, agreed with this strategy, replying, "I am in favor of using that as one of our choices" and "I like having a control device," respectively. Tim then followed his own suggestion with an example, complete with the specific design parameters and a justification. The design he used as an example simultaneously set the expectation for how his peers should share their own designs, and set forth a specific method for meeting the goals of the activity: using a control.

Tim started the meeting by mimicking mentoring actions. Like the design advisor, Tim offered an example of the type of product that the interns were expected to produce. Like the example notebook, Tim's example taught the skill of design by modeling a type of design that could be characterized as a "control." In these ways Tim carried out mentoring strategies that focused on facilitating his group's task achievement using an engineering epistemic frame (Table 20).

Table 20

Tim's adoption of mentoring actions in the group design meeting

Mentoring Purpose	**Original Activity**	**Original actant**	**Original use of mentoring strategy**	**Tim's use of mentoring strategy**	**Activity in which Tim provided mentoring**
Define task	Reflection Meeting	Design Advisor	Design Advisor told interns they all need to participate in discussion	Tim suggested that each intern participate by offering a favorite design.	Group design activity
Support effort	Individuals design 5 devices (and others)	Design Advisor	Design Advisor provided a model to help interns understand how to complete their task.	Tim provided a model of a control device when designing with his team.	Group design activity
S/Design	Individuals design 5 devices	Example notebook	Example notebook modeled the use of a control device when designing a set of devices	Tim modeled a control device when designing with his team.	Group design activity

			for testing		

Tim was not the only intern who adopted these types of mentoring actions. Typically, when an intern asked a question in the chat, the design advisor would respond with some type of support. She had, after all, identified herself as the person who was available to answer questions. Sometimes, however, other interns would beat her to it. For example, in one group's (the group focused on the PESPVP material) surfactant research activity, Zoe was confused about where to find the data she needed to summarize:

Zoe	9/18/14 10:13	Where can I find the data? It is not attached in the e-mail
Bob	9/18/14 10:13	Its in the shared section
Bob	9/18/14 10:19	My notebook is shared if you guys have any extra questions or don't find something I can help too!
Bob	9/18/14 10:20	Is there anything else that is due for today?

When Zoe asked where she could find the data, one of her teammates, Bob, immediately came to her assistance, letting her know the information could be found "...in the shared section." He went even further, however, and addressed his next chat to the whole team: "My notebook is shared if you guys have any extra questions or don't find something I can help too!" He volunteered his own notebook for his teammates to use as a model, and volunteered his services if they needed help. In other words, he was offering himself and his work as resources to help his teammates. The design advisor had offered these same kinds of resources to help the interns in every activity of the internship at that point, so

Bob had definitely encountered the design advisor's "help" mentoring, which suggests that he was emulating the design advisor.

In Tim and his team's group design activity, Tim continued to imitate the mentoring that he had encountered thus far in the internship. After his teammates agreed with the idea of using a control, they built on this idea by thinking of other "types" of devices they should test.

Lee	10/2/14 9:35	That's a good idea for a base model to test our others against. I think for the process we should use phase inversion because it has the highest flux rate and lowest blood reactivity
Lee	10/2/14 9:36	Also for the actual device I think we should use steric hindrance and 2% nanotubes
Tim	10/2/14 9:37	Yeah, I think one of the devices we submit should be our "ideal" device like Lee is describing
Lee	10/2/14 9:37	Maybe we should go through each component and discuss which we all agree on for the "ideal" model

Lee offered his opinion of a couple specific choices of design parameters the team should use in their "actual device." Tim followed up Lee's suggestions about specific parameter choices for what he called the actual device by suggesting another type of device, an "'ideal' device like Lee is describing" This device would be one that they thought would do the best job meeting all of the internal consultant's preferences. Lee then suggested a strategy for building this "'ideal' model": going through each "component" (by which he meant design parameter) and deciding as a group what choice would be best for it.

In this exchange, Tim again mimicked the design advisor, this time by successfully utilizing a variation of another mentoring strategy that the design advisor had used in a previous group meeting. In the team's reflection meeting, the design advisor used the revoicing participant framework as part of her reflective questioning mentoring strategy. Tim used revoicing in this group design meeting. After the team agreed on Tim's idea of a control device, Lee switched the topic of conversation by suggesting choices for an "actual device." It was unclear exactly what he meant by "actual device." He may have been referring to the device that they would ultimately choose at the end of the internship, or possibly a device that they thought would be the best, by some unnamed metric. Whatever he meant, Tim picked up Lee's suggestion. He revoiced Lee by agreeing with what he said ("Yeah"), stating what he thought the team should do ("I think one of the devices we submit should be our "ideal" device") and then attributing the idea to Lee ("like Lee is describing"). While he didn't form his revoicing in the form of a question or ask Lee to confirm whether he was representing his idea faithfully, as Maria did while using the reflective questioning mentoring strategy, his revoicing nevertheless worked. Lee accepted Tim's re-voicing by adopting the term that Tim attributed to him, the "*ideal* device," when he suggested a strategy for designing it, the "*ideal* model."

Tim's reformulation of the revoicing participant framework in the context of the design activity illustrated how the participant structures in Nephrotex led the interns not only to adopt mentoring strategies for the purposes of helping each other accomplish the task or teaching each other the shared repertoire, but also to foster mutual participation. When the design advisor revoiced as part of her reflective questioning mentoring strategy, she reformulated the interns' words into the proper register of the community of practice by literally replacing their words with terms that belonged to the shared repertoire and then attributing her words to the interns. Her intention was to reframe their past and future activities so that the interns would view them using the shared repertoire, but also to situate the interns as mutual partners in them.

Tim's use of revoicing was also in the service of a mentoring strategy. Rather than *reflective questioning*, however, Tim and his team were engaged in *problem solving*. The sustained interaction between the interns in the group design activity was in service of a task that none of them knew exactly how to achieve at the outset. Unlike the design advisor or the example notebooks, Tim didn't have any formal authority that his peers did not also have. Yet the interns shared common experiences prior to the task, and each had proven that they had something of value to contribute.

Once the team decided the parameters for the "control device" and "ideal device," they chose to design their remaining three devices by "focusing on an important aspect to maximize," as Lee put it. In other words, they chose to create devices that they thought would maximize performance on at least one of the design attributes, They chose to create devices that they thought would perform well on blood cell reactivity, reliability, and marketing. The interns were aware that each member had done research on the attributes favored by particular consultants that the rest had not, and therefore relied on each other's expertise. For example, when considering what design parameters to choose for the device focused on reliability, Tim asked, "which aspects increase reliability the most?" Lee immediately answered, "For reliability, Vapor Deposition with the hydrophilic surfactant and 4% nanotubes," and then checked in with the team, "Does anyone agree or disagree?" Indicating the confidence that the interns placed in each other, Ron replied, "I trust whomever did the research for it." Ron's trust was not based on an individual assessment of the expertise of any specific peer; he trusted "whomever" had the expertise. In other words, the trust was based on the acknowledgment that his peers had participated in the same joint enterprise he had ("did the research"), and thus had a command of an aspect of the shared repertoire (the knowledge of design parameters and design attributes, or, "which aspects increase reliability the most") to bring to the current task. Moreover, he trusted that each team member had as much as authority as the original source of the research, the technical documents.

Problem solving in the group design activity, like revoicing in the reflection meeting, thus functioned as a mechanism for establishing mutuality, in the form of a participant structure (Figure 36).

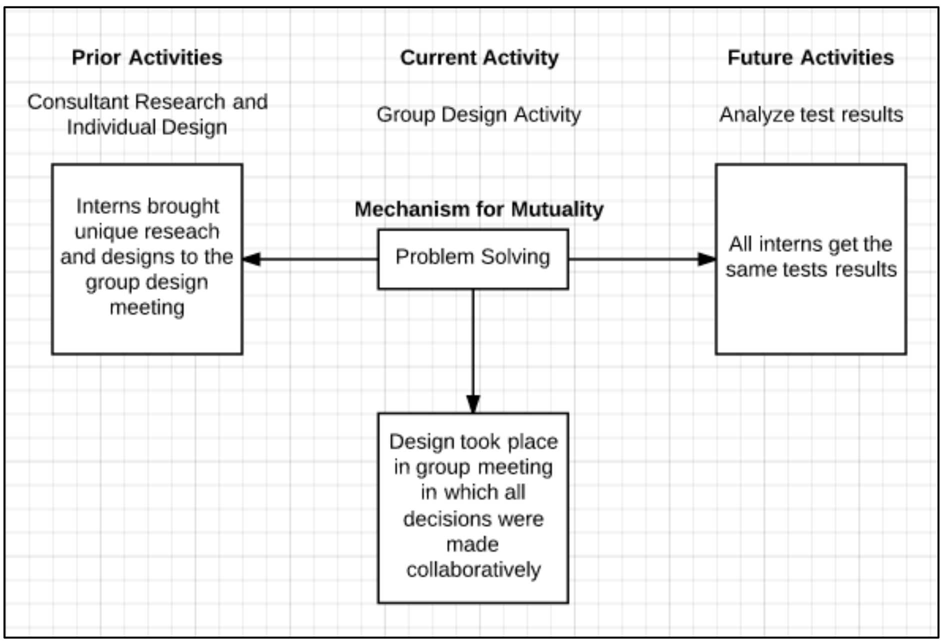


Figure 36. Problem Solving as a mechanism for mutuality.

Each intern brought unique research and a set of personal designs to the activity. Once in the activity, the interns collaborated to make decisions that relied on the team's distributed expertise in the shared repertoire that had been gained by their shared experience in the joint enterprise. Moreover, instead of the design advisor leading the conversation, the interns themselves facilitated their accomplishment of the task. In the context of this self-facilitated problem solving, the interns adopted mentoring strategies to help them accomplish the task. In the following activities, the team would receive a set of test results that reflected their group decision-making accomplishment. Like revoicing, problem solving was a participant structure that created a social arrangement that promoted membership in a community of practice by foregrounding the interns' participation in the current, past, and future activities as activities and by framing this participation as integral to each intern's task, the team's task, and to Nephrotex's task.

R4.2.3 Summary

The interns not only mutually engaged in the joint enterprise using the shared repertoire. They also served the same types of mentoring functions as the other actants. The internship facilitated this by asking the interns to serve mentoring functions for each other in the context of completing their tasks. This was an inherent characteristic of the structure of some of the internship's activities, such as in the group design activity the interns engaged in a group problem solving discussion, where each intern worked with the others to come up with the five design solutions, and in the repeated jigsaws, where interns came to hold knowledge that their peers needed to complete the internship. A key characteristic of the coordinated mentoring system was that it extended its coordination to include the interns themselves.

Discussion

In this qualitative study, a virtual engineering internship was examined in order to understand the role mentoring could play in enrolling learners into a professional community of practice. This study offers a theory of distributed mentoring to explain how a coordinated system of mentoring actants and actions created, and assimilated the participants into, a community of practice.

This chapter consists of four sections. The first section summarizes the results and discusses how they address the research questions of the study. The second section further considers the implications of the results. The third section describes this study's limitations, and the fourth section suggests areas of future research.

D1. Summary of Results

D1.1 Mentoring in Nephrotex

This study first looked to see whether one intern participating in the Nephrotex the virtual internship encountered five workplace mentoring strategies. The three common strategies relied on an information transfer model. Explaining, monitoring, and demonstrating, all involve providing information that the young person presumably does not have. Two other mentoring strategies, problem solving and reflective questioning, operate under a different model, seeking rather to facilitate a reciprocal interaction.

Section one of the results chapter revealed that all of the mentoring strategies were used in Nephrotex. Starting with the first instructions email from the supervisor, the interns had things explained to them. Explaining was not limited to explaining how and why, as the supervisor explained what to do and by when to do things. This type of explaining occurred in every activity of the internship. The supervisor not only provided instructions, but he also always provided the interns with information about whether their submitted notebooks were meeting Nephrotex's standards of performance. The monitoring mentoring strategy, then, also happened in every activity. In nearly every activity of the internship, the interns had an example notebook that functioned as a model for the deliverable they were assigned. These activities all featured the demonstrating mentoring strategy.

The other two mentoring strategies appeared as well, though true to Hamilton and Hamilton's characterization of them being rare and challenging, they happened less frequently, in activities specifically dedicated to them. In their design activities, the interns used an interactive tool, FEEDS, to test their hypotheses about the relationships between the design parameters and design attributes. While FEEDS was not a person, and therefore was not obvious candidate for providing an interactive mentoring function, it contributed to the interns' design process by allowing them to manipulate the design parameters into differently configured devices that then could be tested. In other words, it worked with them to complete a task that neither could complete themselves.

The other interactive mentoring strategy, reflective questioning, occurred in three reflection meetings at key moments throughout the internship. The reflection meeting described in the first Results section illustrated how the design advisor asked the interns questions about the work they had just completed to prompt them to think about their tasks and what they learned from them. Her questions then turned to what the interns thought they should do next, so that lessons of their past activities informed the way they approached the activities to come.

Notably, these mentoring strategies were not all offered by a single mentor. Nor did a "mentor" necessarily offer them. The person whose role most resembled that of a traditional mentor, the design advisor, was only one of the sources of Hamilton and

Hamilton's mentoring strategies. The next section of the Results further examined the different sources of mentoring in Nephrotex.

D1.2 Distributed mentoring

This study's proposed theory of distributed mentoring suggests not only that mentoring is better characterized as a function rather than a role, and that therefore mentoring can be offered by multiple non-mentors, but that mentoring functions can also be provided by nonhumans. In other words, mentoring can be provided by multiple actants.

Section two of the results chapter demonstrated how the mentoring in Nephrotex was distributed. The interns received mentoring from a variety of sources. A close examination of one particular activity early in the internship, in which the interns conducted background research on topics related to their overall design task, revealed that different mentoring sources were focused on different mentoring goals and, in some cases, used different mentoring strategies to accomplish them.

The supervisor had a central role in facilitating the interns' task achievement, as his instructions email defined the interns task, set the deadline, and provided information intended to help the interns accomplish the task. In the same email, he also explained important aspects of engineering thinking. By describing why what the interns were doing was important, he communicated engineering values. His other email in the activity was also focused on task achievement. Sent to the interns' in response to their submitted notebooks, this email indicated whether the interns had successfully completed the task. If they hadn't, then it provided suggestions about where to get help or how to do it again so that they would succeed on a second attempt.

The design advisor was barely involved in this activity. Her one act was to help the interns by informing them of the existence of another source of mentoring, the example notebook. The example notebook showed the interns how the design advisor, when she was an intern, accomplished a task similar to their background research. In other words, it modeled engineering skills involving data. To complete the task the interns had to read technical documents, curated resources containing the specific engineering content that the interns needed to learn in order to carry on with the internship. So while the example notebook modeled data skills, the technical documents described a specific body of engineering knowledge.

The mentoring in the background research activity was thus distributed in multiple ways. The multiple mentoring actants not only used different mentoring strategies, but they employed those strategies for multiple purposes, including different aspects of facilitating the interns' task achievement, and teaching the interns the different epistemic frame elements that represented the particular way that engineers would accomplish that task.

This distributed mentoring structure was not limited to the background research activity. Mentoring was distributed in all of the interns' activities, though the distribution changed activity by activity. Even as the activities changed, some of the mentoring sources were a constant presence, with constant goals. The supervisor, for example, was the regular source of direction when it came to defining the interns' tasks and the deadlines for those tasks. Similarly, the calendar tools were always available and also presented task information. Other sources of mentoring only played a role in specific activities. For example, the graphing tool was used in only one activity (the surfactant research activity) and discussed in another (the reflection meeting following it). Similarly, FEEDS was used in design activities and the following team meetings in which the interns discussed their test results. Still other mentoring sources were always present but played different roles depending on the activity. In some activities, the design advisor simply reiterated information from the supervisor's instructions emails, while in others, such as the reflection meetings, the design advisor played a more important role in the facilitation of the interns' learning.

This theory of distributed mentoring thus adopts the perspective of Hamilton and Hamilton about the nature of mentoring being best described as a function. However, like Campbell and colleagues (2016), it recognizes explicitly that these actions can be taken by both human and non-human actants within the mentoring environment. In Campbell and colleagues' (2016) framework, distributed mentoring is an approach to examine aggregated mentoring functions that emerge in an unplanned learning environment. In Nephrotex, distributed mentoring is offered in the context of a particularly designed set of activities. When mentoring is unplanned and emergent, as it was Campbell and colleagues' study of an online fan fiction community forum (2016), there is an open question about how the various mentoring forum participants encounter hangs together. The same question can be asked in Nephrotex, where the mentoring was provided by multiple sources, but those sources are designed by a single developer and controlled by a few internship managers. With such variation of mentoring purposes and strategies distributed across multiple mentoring actants in Nephrotex, as there were in the background research activity, there would be potential for the mentoring to be confusing, or worse, contradictory. The next section of the Results section examined how the mentoring in Nephrotex was coordinated, how that coordination worked, and to what purpose.

D1.3 Coordinated mentoring for a community of practice

This study examined distributed mentoring in the context of a designed learning environment intended to teach young people how to think like a certain kind of professional. The proposed theory of distributed mentoring that this study investigates suggests that when distributed mentoring is coordinated, it can simulate a community of practice, complete shared tasks, shared ways of accomplishing those tasks, and mutual modes of participation that organize their activity. Further, it suggests that it can demonstrate how it accomplishes those feats.

Section three of the Results chapter illustrated that what made distributed mentoring an effective mechanism for the construction of a community of practice was that it was *coordinated*. An examination of the surfactant research activity, demonstrated three ways the actants' mentoring was coordinated.

First, some actants reinforced each other's mentoring because their distinct mentoring actions shared the same task achievement goals. For example, in the surfactant activity, the different aspects of task achievement were addressed by multiple mentoring actants. Two actants, the supervisor and calendar tools, defined the task. Three actants, the supervisor, calendar tools, and design advisor, communicated the deadline and provided support to help the interns complete their task. Receiving confirmatory messages regarding the current work that needed to be accomplished established a joint enterprise.

Reinforcing mentoring was not a phenomenon that occurred in the surfactant research activity only. The mentoring actants reinforced each other's efforts to facilitate the interns' task achievement in every activity. The calendar tools, for example, were always present and available to inform the interns what their current deliverable was and when it was due. Those tools and the supervisor, who always assigned the task and deadline in his instructions email, therefore always reinforced each other's messages about the task. In nearly every activity, the design advisor reminded the interns of the deadline, joining the calendar tools and the supervisor in sending those messages related to task achievement. Similarly, she very frequently reiterated or clarified what the task was, thereby reinforcing the supervisor's mentoring functions of defining the task. The design advisor sent the interns to an example notebook that they could use as a model in most of the activities, and likewise regularly offered herself as someone who could answer any questions in the chat client. In other words, like the supervisor and calendar tools, she was a constant source of support for the interns' task achievement.

Other mentoring was aligned in a more subtle fashion. Different actants taught different ways of thinking associated with the engineering profession. In the surfactant research activity, the actants taught different epistemic frame elements that nonetheless shared a common practice-subject. For example, the supervisor focused on teaching the value of data, while the technical documents provided the interns with particular data they would need, and the example notebook modeled how to write about data. The different mentoring actants thus served complementary functions when it came to teaching the epistemic frame.

But more than simply teaching different epistemic frame elements, they stitched the epistemic frame together by providing a manifold approach to an engineering practice-subject, data. For engineers, it's not enough to know data, or value data, or be able to use data; they need to be able to do all three, and as demonstrated later in the internship, they also need to be able to justify claims using data. What's more, this complementary approach was also reinforcing in the way that it emphasized the role data plays in engineering practice. Nephrotex's coordinated teaching efforts were thus complementary in the service of establishing an engineering shared repertoire.

Nephrotex's coordinated teaching efforts were complementary in one other important way. Not only did the mentoring actants distribute teaching epistemic frame elements in an effort to help the interns develop that practice's shared repertoire, but they also distributed the types of mentoring strategies that they used in order to foster mutual forms of participation. While some mentoring actants were limited in the type of mentoring strategies they could use, others used different strategies in different activities to create particular forms of participation in the engineering practice. For example, most of the artifacts that provided mentoring in Nephrotex simply delivered information: the calendar tools provided details about the task and deadline, and the technical documents provided key engineering content. The design advisor, by contrast, used different mentoring strategies to different effect. While in some activities the design advisor played a literal supporting role, in others she facilitated interactive group discussions that granted interns ownership of the lessons of previous activities, and the goals of forthcoming activities.

The interns' experiences focused on accomplishing engineering tasks and learning engineering ways of thinking initiated the interns into the firm's joint enterprise and shared repertoire, respectively. When interns participated in more interactive activities like the reflection meetings, they relied on already having engaged in the joint enterprise and having some traffic with the shared repertoire. They needed to have something to reflect on, after all. Interns learned some engineering skills, knowledge and values from actants that modeled and explained these frame elements; having acquired these ways of thinking gave the interns common experiences and ways of thinking and talking that allowed them to participate in ways that affirmed these acquired aspects of the engineering frame in terms of the shared experience, language, and ability to participate in future activities. In other words, the coordination of mentoring actants facilitating different modes of engagement with engineering practice created a setting of mutual participation.

Rather than an aggregated collection of disconnected mentoring actions, the distributed mentoring in Nephrotex was a set of reinforcing and complementary mentoring actions, including reinforcing actions that facilitated the interns achievement of tasks for the purposes of establishing a joint enterprise, complementary actions that that taught the interns an engineering epistemic frame in order to equip them with a shared repertoire, and complementary actions that promoted reciprocal forms of engagement that created a environment of mutual participation. This set of reinforcing and complementary mentoring actions were therefore a coordinated mentoring system that worked to accomplish a particular goal: to simulate a professional community of practice into which the interns could obtain membership.

Thus, this theory of distributed mentoring builds on previous distributed mentoring theories by emphasizing way that multiple actants coordinate their mentoring. Further, it describes how actants' coordination of different mentoring goals and strategies can create a community of practice. The next section describes whether the participants joined this created community.

D1.4 Becoming community members

The proposed outcome of participating in a coordinated mentoring system that has simulated a community of practice is that participants adopt both the community's productive and reproductive practices. In terms of the community's productive practices, participants join the joint enterprise by accomplishing tasks, share the shared repertoire by using the epistemic frame they were taught to use, and participate in mutually participatory practices. At the same time, they also take on some of the community's reproductive practices by guiding other new members into the community's way of doing things.

The final section of the Results chapter, section 4, examined whether the interns did indeed become members of Nephrotex's engineering community by looking at how they participated in both its productive and reproductive practices.

Interns did adopt an engineering shared repertoire as the internship proceeded. Examining two interns' activity at two points in the internship, one early in the internship and one closer to the end, revealed progress in one intern's ability to use the mentored epistemic frame to complete his task. In the early activity, the two interns individually designed and justified their first prototypes of the internship. One intern, Zoe, was able to learn from the mentoring she received the appropriate ways to justify her designs. She designed for all of the internal consultants and relied on her team's expertise to do so. The other intern, Mo, despite having the same mentoring as the first, failed to design for all of the internal consultants, and instead designed for only the consultant that he had researched in a previous activity. He did not use the research conducted by his peers. In some ways, Mo had received even better mentoring than Zoe because when he directly asked his design advisor about how he should design, she informed him to design for all of the internal consultants.

Later in the internship, the two interns were in the same final design group, which meant that they and their peers decided as a group what prototype they would recommend to their firm. After the team decided, every intern wrote and submitted a notebook entry that explained how they decided on their design. Part of what it means to be a professional is the ability to make decisions based on multiple considerations. In the Nephrotex design task, data from test results provided information by which interns could determine whether a prototype met the requirements of the internal consultants (E/Data and E/internal consultant). But since those requirements were conflicting, compromising and considering trade-offs became an important method of making decisions (E/design). And when choosing among trade-offs, considering the client was an important priority (E/client).

In their notebooks, the two interns told slightly different stories about how their team decided on their final design. They both articulated that their team had decided on their device by attempting to satisfy the interests of all of the internal consultants, and they both described that they had to go through a process of comparing different designs from this lens to do so. In other words, they both indicated that that their team had relied on the epistemologies of internal consultants and design to make their decision. After that, their stories diverged. While Zoe emphasized the team's use of test results to make their decision, Mo explained that prioritizing the needs of the client was an important factor in their decision. Again, these were their accounts of how their team made a decision, so the particular epistemologies they chose to highlight may reveal more about each intern's individual interests than anything else. Either way, these two different epistemologies were equally legitimate, as both were epistemologies that had been taught by the mentoring actants. The important development was that Mo, who had previously struggled to learn Nephrotex's mentored shared repertoire was now able to do so.

More than just adopting the shared repertoire of Nephrotex, interns adopted other functions characteristic of members of such a community of practice; namely, the role of community members in facilitating the community's reproduction by providing mentoring to new members. In the case of Nephrotex, of course, the interns were mentoring their own peers, who had the same amount of experience in the community as they had. They were all new members of the community. But they did imitate the mentoring that the mentoring actants used, including all three types of coordinated mentoring that constructed the community of practice. They helped each other achieve tasks in the joint enterprise, taught each other elements of the engineering epistemic frame to share the shared repertoire, and promoted mutual participation.

Nephrotex facilitated the interns' adoption of these mentoring functions through interacting participant structures. The jigsaw participant structure provided the interns with legitimate community knowledge. The group design meetings featured the interns using a problem solving participant structure, which relied on the interns shared experiences and trust in each others' legitimate knowledge to accomplish the consequential task of engineering practice. Designing using FEEDS involved simply selecting from the different options for each design parameter, but choosing which combinations of design choices were the best to test required some professional discernment, and coming to a consensus on those five was more complicated still. This was an activity that consisted of a sustained interaction between interns, in which they were all on equal footing. Within the context of this "problem solving" participant structure, interns were provided the means and opportunity to solve a problem related to the overall goal of the internship by collaborating with each other. The way they worked together had been set up by the coordinated mentoring system so that they too would be a part of that mentoring system for each other.

Building on previous theories of distributed mentoring (M. A. Hamilton & Hamilton, 2002; S. F. Hamilton & Hamilton, 2004), theories of distributed cognition and actor-network theory (Hutchins, 1995; Latour, 2005), epistemic frame theory (Shaffer, 2006b), and positive youth development (Larson, 2006), distributed mentoring offers a new theoretical and methodological approach to understand mentoring. It is a framework for understanding how actants in a learning environment coordinate to draw learners into a community of practice. Distributed mentoring is a theory of learning which argues that the interaction between a learner and a mentoring system, rather than a learner and an individual mentor, is the proper unit of analysis for analyzing mentoring.

The theory of distributed mentoring examined in this study builds on Hamilton and Hamilton's claim that mentoring is a function that can be provided by non-mentors, and using theories of distributed cognition, extends it to argue that nonhumans can provide mentoring as well. If mentoring can be provided by multiple actants, what matters is how mentoring is coordinated. Using epistemic frame theory, distributed mentoring theory can show how multiple mentoring actants can coordinate their efforts to do something that even a super-mentor cannot do: simulate a community of practice. Distributed mentoring is thus a way of explaining how mentoring actants work together in a coordinated fashion to simulate—and shepherd newcomers into—a community of practice.

D2. Implications

D2.1 A theory of distributed mentoring

This section defines distributed mentoring, situates the theory of distributed mentoring in the context of mentoring theory generally, describes how it is treated in this study, and suggests some of the limitations of the theory.

D.2.1.1 Mentoring as a distributed function

This study takes a view of mentoring that is distinct from the more traditional view, in which a non-parental concerned adult provides guidance in the context of a special relationship. This study proposes and explores a systems approach to defining mentoring, where particular kinds of interactions, taken together, establish a mentoring system. This approach defines mentoring not by the presence of an adult with a particular kind of role or relationship with the youth, but rather by the presence of multiple aligned mentoring interactions. While the particular kinds of actions that could be defined as mentoring are wide-ranging, they can be identified by their purpose. Mentoring actions are focused on facilitating task achievement, and/or teaching the necessary and transferable ways of thinking to accomplish those tasks. Doing so in a manner that affirms the young person's autonomy is what makes the mentoring "quality" (Larson, 2006) and more likely to be successful (Karcher and Nakkula, 2010).

Defining mentoring in this way thus opens the possibilities for mentoring actions to originate from distal figures, as Hamilton and Hamilton (2004) suggest occurs, but also from non-humans. This view of mentoring, then, is particularly broad. The argument is not that any time some person, tool, or resource, facilitates a young person's achievement of a task or teaches a young person something, that mentoring is occurring, but rather that a collection of actions with these purposes that a set of persons, tools, or resources take, together comprise mentoring. In this view, the unit of analysis for mentoring is at a higher level than individual relationship actions or relationships; it is rather, in the way of theories of distributed cognition (Hutchins, 1995) and actor-network theory (Latour, 2005), at the level of *activity*. From this perspective, judging whether an action is mentoring or not requires not just whether it has mentoring goals (task achievement and learning), but also looking to see how it is aligned with adjacent actions performed by adjacent actants.

D.2.1.2 This study's treatment of distributed mentoring

Using a distributed mentoring lens, this study looks at how a group of adolescent learners experienced something like "structured voluntary activity" (Larson, 2006), where the source of the structure was distributed among multiple external adults, tools, and resources. This structure was created using the same types of actions that human workplace mentors used in previous studies of mentoring, and the purpose of this structure was aligned with how mentoring theorists describe quality mentoring structure: in terms of a joint activity. The findings of this study suggest that a systems view of mentoring can reveal, at the very least, that multiple human and nonhuman participants in an apprenticeship-like setting can have a cognitive impact on its participants. The study demonstrates teaching and goal achievement mechanisms, in the form of reinforcing mentoring goals associated with task achievement, and complementary mentoring goals focused on teaching a way of accomplishing those task achievement goals.

D.2.1.3 Limitations of distributed mentoring

Mentoring is theorized to operate on more than just a cognitive level. As Rhodes and others (2005; 2006) describe, mentors also promote socio-emotional and identity development. A theory of mentoring in which relationships are not central to the definition or outcomes of mentoring necessarily downplays this process of development. For example, it is unlikely that the distal relationships that exist in Nephrotex would lead to improved relationships with a significant other or a parent, as some long-term mentoring relationships have (Rhodes et al., 2000). However, the collaborative nature of Nephrotex meant that interns had instrumental relationships with the other employees of the engineering firm. While these relationships could not be characterized as close, and were likely not based on anything other than the shared identification of tasks and the shared way of accomplishing them, these distal relationships perhaps have the potential to lead to improved distal relationships in other contexts. Future work could investigate such effects.

A theory of distributed mentoring that uses epistemic frame theory as its measure for learning treats cognitive and identity development together. The nature of the tasks of Nephrotex is such that accomplishing them satisfactorily means learning an epistemic frame. In other words, learning in Nephrotex means adopting a particular kind of identity.

In this way, distributed mentoring situated in a context where learning to be a member of a community of practice is the outcome suggests that cognitive and identity development could be intertwined.

Thus distributed mentoring has limited utility in describing mentoring relationships characteristic of mentoring pairs with younger children: those that are more developmental, relational, or playful in focus. In other words, this theory of distributed mentoring may not be able to illuminate the particular value of relationships that are not organized around a joint activity.

D2.2 Membership as a strategy for navigating the intentionality paradox

Hamilton and Hamilton (2004) challenge a model of mentoring contingent on a long-term relationship with a mentor by claiming that mentoring can in fact be offered by distal figures in a young person's life, and that mentoring could thus be viewed as a distributed function rather than a particular relationship role. The open question that their challenge poses is how Larson's intentionality paradox (2006) is navigated without the trust built up by the consistent quality mentoring in a long-term relationship. Even if the distal figures offer quality mentoring, the consensus in the mentoring literature is that trust is an essential ingredient in successful mentoring relationships. How then could youth not be threatened by the structure of Nephrotex?

This study examined late adolescents participating in a virtual internship that was only weeks long. This apprenticeship-like experience featured mentoring functions distributed among multiple, sometimes non-human, sources. The results suggested that these mentoring sources coordinated their mentoring to construct Nephrotex, an engineering community of practice, and that the interns acted as members of that professional engineering community.

Trust did not seem to be a particularly salient factor in the interns' activity. The one explicit mention of trust came when an intern remarked that she trusted her teammate's research, which brings up a question implied by positioning mentoring as a function. This study demonstrated that artifacts and peers, not just concerned adults, could provide mentoring functions. This is not to suggest that mentoring is something that can be accomplished without adults, as clearly the role of the design advisor and supervisor were central in both structuring the interns' tasks and teaching them the community's way of doing them. But the point is that there was no functional difference between mentoring from an adult or from some other source. There may have, however, been a difference in the response to that mentoring. The interns increasingly serving mentoring functions for each other could have possibly negated some of the autonomy challenges associated with the formal authority carried by non-peer roles.

The various sources of mentoring did however have something in common: membership in the Nephrotex community. Perhaps, then, the success of mentoring functions in the context of a community of practice is not based on relationships of assumed authority and care but rather based on the existence of shared membership. The shared membership in a community of practice that the mentoring actants in Nephrotex established and the interns joined was possible because of the way that the mentoring was coordinated. It's possible that the coherence of the community of practice, as established by the coordination of its sources of mentoring, provided an alternative to the consistency of the relationship in a dyadic mentoring model. In other words, a possible alternative to the power of a relationship with a mentor is the power of a relationship to a community, otherwise known as *membership*. As developmental theorists (Larson, 2000) suggest that productive relationships with a youth's community—thriving—are a useful measure of healthy development, finding and providing communities to which young people can access and join may be a worthy option for fostering positive youth development.

D2.3 Analyzing legitimate peripheral participation

In describing how newcomers to a community of practice become members, Lave and Wenger (1991) explain that they engage in legitimate peripheral participation. As Lave and Wenger describe it, legitimate peripheral participation is always conceived as an inseparable whole; there is no such thing as illegitimate peripheral participation, and no way of talking about what constitutes or does not make participation more or less peripheral, or more or less participatory, for that matter.

This study argues that the interns in Nephrotex become part of a community of practice, but it also attempts to explain how that happens. In particular, it demonstrates how multiple actants worked together to facilitate and support the developmental work of adopting the community's shared repertoire. In other words, this study suggests that legitimate peripheral participation is not really inseparable analytically. We can think of it using epistemic frame theory, and see how the coordinated actions of individual mentoring actants built an epistemic frame by coordinating their messages to the interns. By distributing the teaching of epistemic frame elements among multiple actants, the shared repertoire becomes the property of a community rather than a single interaction or relationship; the coordination of those elements achieved by the actants' complementary approaches to a single subject that is important to the community, like data or design in the case of engineering, legitimizes that repertoire as shared.

D2.3.1 Teaching an epistemic frame

While previous studies on the development of epistemic frames have investigated how frame elements are connected to one another in practice, this study highlighted how those epistemic frame elements were themselves constructed for learners in practice. A critical component of coordinated mentoring is complementary mentoring, which can be understood in terms of the way that two actants link different practice–actions by connecting them to the same practice-subject. This contribution to epistemic frame theory suggests that the coordinated mentoring actants can be a crucial component in the teaching of epistemic frames.

Complementary mentoring is a participant structure that distributes complex ways of seeing and solving problems among multiple actants so that they are more easily learned. In this way, it uses a similar process to learning reflection-in-action. Reflection-on-action distributes reflection and action across time: reflection is separate from but connected to action, and multiple cycles of reflection-on-action develop learners' ability to reflect-in-action. Complementary mentoring for the purpose of teaching a shared repertoire distributes aligned ways of thinking not across time, but across mentoring actants. The act of drawing the multiple elements of professional practice from these multiple actants is the process by which those elements occupy distinct but aligned (or *connected*, in the parlance of epistemic frame theory) positions in the learner's mind.

D2.3.2 Participant Structures

The results highlighted the importance of particular participant structures to the coordination of mentoring, and thus to the process of becoming a member of a community of practice. Just as epistemic frame theory can be used to analyze the process by which newcomers to a community of practice learn its shared repertoire, examining the participant structures that organize the learners' and mentoring actants' activity can reveal processes of adoption of community practices.

Whereas Hamilton and Hamilton describe problem solving as a mentoring strategy, it may be useful to examine it as a participant structure through which a variety of other mentoring strategies may be employed. In Nephrotex, problem solving takes place as a design activity shared by peers who have the same relative position to the community of practice, rather than a process between a learner and mentoring figure with more established community authority. The interns' ability to problem solve together rested on the success of the other participant structures. The complementary mentoring participant structure ensured that the interns had learned the way that interns should approach design, including what they should know, what was important, design strategies, and ways of making decisions. The revoicing participant structure made sure that the interns knew that they shared this way of thinking with each other and with the rest of the Nephrotex community. The jigsaw participant structure ensured some aspect of community knowledge that each intern brought to the activity was unique.

The complementary mentoring participant structure that teaches the epistemic frame is coordinated with other participant structures like revoicing, problem solving, and jigsaws. Examining these other participant structures can highlight processes by which learners can come to see themselves as part of a community. Despite the fact that these latter three participant structures operate at different levels of activity (revoicing takes place at the level of conversational turns, problem solving takes place at the level of a single activity, and jigsaws take place across multiple activities), what they have in common is the way that they organize learner's social arrangements in relation to the community of practice.

D2.4 Human development problems, learning science methods

There are many calls for studies that focus on what makes for quality mentoring interactions. Qualitative studies like this one can fill that gap. While the type of mentoring here is of the particular sort that occurs in apprenticeship settings, and not the sort that is typically found in formal mentoring programs like Big Brothers/Big Sisters, the types of mentoring interactions that mentoring theorists recommend are nonetheless similar in both contexts. Thus lessons from mentoring in Nephrotex should not be dismissed out of hand as irrelevant to mentoring in other contexts. For example, many of Larson's "working models" of quality mentoring (2006), such as instrumental scaffolding and supporting cycles of real-world learning, align closely with the types of participant structures and mentoring strategies in Nephrotex.

The results here suggest that it may be important to look for mentoring actions, influences and effects not just in the context of important relationships with quasi-parental figures, but also in contexts across many relationships. For example, a workplace supervisor telling a young person what to do would not be likely considered to be an instance of quality mentoring. Telling a young person what to do is not a particularly reciprocal action, and could be construed as authoritarian, if it was even considered mentoring at all. The results of this study suggest that such a supervisor could be acting in coordination with other actants who, viewed together, provide mentoring actions that are more mutual in nature. In any case, it is worth looking.

On the other hand, there are ways in which looking at rich developmental activities can help us understand the key issues that learning scientists care about. There is a huge body of learning science research focused on expert problem solving. For example, Chi describes how when solving problems, novices tend to stay focused on the surface features of a task, while experts hone in on the task's "deep structure" (1991). This study uses a sociocultural lens to examine a learning environment that features multiple tasks with associated learning goals, and in particular the coordinated mentoring mechanism by which the interns accomplish those tasks in a way that is aligned with a community of practice's way of doing things.

This study demonstrates that reinforcing mentoring and complementary mentoring are forms of coordinated mentoring, whose overall function to communicate *alignment*. By virtue of the duplication involved, in reinforcing mentoring the alignment is more obvious (e.g. two mentoring actants say the same thing: "do X" or "do X by Y o'clock" or "here are some things to help you do X"), whereas the alignment in complementary mentoring is more subtle (One mentoring actant says "*n* is important," while another demonstrates "here's a way to do *n*" and another says "here's lots of *n* for you to understand" and still another asks "how did *n* help you decide *o*?"). In other words, reinforcing mentoring for task achievement communicates the surface features of a task, while complementary mentoring for learning the epistemic frame communicates the task's deep structure. If both the surface features and the deep structure of a task reflect the sociocultural context of that task (which sociocultural theorists would argue), then the surface features might reflect the joint enterprise of the community of practice who is engaged in that task, and the deep structure would reflect the shared repertoire of that community of practice.

D2.5 Recommendations for the field

This study's findings suggest different recommendations based on the mentoring context of interest. In the sense that true apprenticeship opportunities are rare, and comprehensively designed virtual internships are, at this point, even more rare, this study's setting was, in the overall context of mentoring, atypical. Nonetheless, taking Hamilton and Hamilton's concept of mentoring-as-function seriously means that mentoring happens not just in the context of formal mentoring programs and natural mentoring relationships, but in a variety of settings, including the workplace, and other structured voluntary activities. Thus for those who are interested in the positive effects of mentoring, the first recommendation is simply that it may be useful to expand the search criteria. Rather than starting the search with a definition of mentoring that is *a priori* limited to contexts involving a special relationship, or even the potential of a special relationship, this study shows distal figures using mentoring strategies to achieve the types of things that quality mentors do.

This systems view of mentoring can explain important aspects of the more traditional mentoring contexts. Even in a long-term dyadic primary relationship with a mentor, the youth and mentor are at some point engaging in joint activities. In the context of those activities, the tools and resources involved need to be coordinated, in the sense that they should reinforce or complement each other in terms of characteristic mentoring strategies and characteristic mentoring purposes. For those who define mentoring as an action that mentors do, a distributed mentoring framework suggests a useful way of understanding how a mentor structures a joint activity is in terms of the coordination between the mentor and other tools and resources used in the activity.

Part of what helps a mentor become a trusted ally in a young person's life is the consistency achieved in interaction after interaction. A distributed mentoring framework could be used to understand what it means for a mentor to be consistent. If young people trust mentors who consistently approach their joint activity with the appropriate balance of structure and mutuality, then analyzing how each meeting reinforces or complements previous ones could be a useful strategy to understand that consistency. These approaches, of understanding coordination in terms of latitude (across tools and resources) and longitude (across meetings over time) may also be a useful way to explore how distal figures become more important developmental allies.

For those interested in better understanding how communities of practices enculturate new members, or exploring how it is that structured voluntary activities are promising developmental and cognitive contexts for adolescents, distributed mentoring offers a perspective on how to identify the different facets of the activity structure of those settings. Further, it suggests that considering how these facets, which may include but are not limited to tools, resources, mentors, non-mentor adults who are nonetheless involved, and peers, are coordinated or not should provide some insight into the process by which young people are enculturated into communities of practice, or adopt the norms of the particular structured voluntary activities. In other words, this distributed mentoring framework offers a way of measuring membership, and the mentoring that attracts young people to adopt the right roles in those settings.

In short, the primary contribution of a distributed mentoring framework is the way it offers an analytical tool for understanding—and defining—mentoring in multiple contexts.

D3. Limitations

The results presented here have several limitations. The ethnographic nature of this study necessarily means that any conclusions are limited to what one particular group of students did in the context of one virtual internship. Greater generalizations about mentoring are therefore not possible.

This study focuses on a particular view of mentoring, in which a long-term relationship is not necessary for mentoring to take place, and examines a short-term environment in which a long-term relationship is not possible. It therefore explores a type of mentoring that may or may not have direct relevance to types of mentoring more focused on the development of a primary relationship. In addition, its focus on mentoring interactions that involve non-mentors, and even non-humans, means that it does not directly address issues related to mentoring relationships.

This study offers no comparison case. For example, to best understand the benefits of a coordinated mentoring system it would be necessary to compare participation in a coordinated mentoring-rich environment to participation in a long-term mentoring relationship.

This study did not measure of the impact of the internship on participants using pre or post measures, and thus can make no claims that the internship definitely changed the interns' way of thinking.

This study likewise does not investigate the surely relevant individual differences between learners. Just as a host of individual and demographic factors influence one-on-one mentoring relationships, so too would they moderate mentoring effects in distributed mentoring contexts.

Although Nephrotex captured a tremendous amount of data associated with the interns' activity in the internship, it did not capture any information about what they did outside of the internship. Some of that information likely had an impact on their activity. For example, at the end of the internship, the interns prepared for their group presentation for their peers in person, offline rather than through WorkPro's chat client. Likewise, the PowerPoint files and presentations themselves were created and conducted offline. Of more interest were any communications the interns had with their professor, who was playing the "internship coordinator" role. While nearly all of their activity took place through interactions with the fictional Nephrotex employees (the supervisor and design advisor), it is possible that some of the students had correspondence with the internship coordinator that influenced their activity in the internship. Similarly, there is no way of knowing the extent to which students interacted with each other offline, and how much of that interaction was focused on the content of the internship. Since all of this correspondence and any of these interactions would have occurred via personal email accounts or in person, it was not available for this study.

The hope is that this study offers a type of proof of concept for further research with larger samples of learners. Given the increasing scalability of interventions like virtual internships that could offer distributed mentoring, and other wide variety of learning environments with multiple mentoring sources, this hope does not seem unreasonable.

D4. Future Research

As always, there are countless ways this study could have altered its focus in order to answer different questions about mentoring, or answer the same questions differently. The following avenues of potential future research had to be tabled for reasons related to time, resources, accessibility, and other factors of necessity.

The role of affect in motivation, and particularly in mentoring relationships and interactions has been shown to have a positive impact on young people (Halpern, 2010; Larson, 2006). In Nephrotex, the amount of encouragement the interns get is limited to an end of the day "good job," from the design advisor, or a "nice work" from the supervisor in the feedback email. The design advisor did demonstrate enthusiasm in the chat window, at least in terms of the frequency of her use of exclamation points, and the interns did seem to mirror that enthusiasm. Future research into distributed mentoring could take into account the affective actions mentors use to encourage learners to persevere through the challenges they face in accomplishing difficult tasks.

Nephrotex is a learning setting designed specifically to teach an engineering epistemic frame. Other settings are also great candidates for examining how distributed mentoring works. The obvious choice would be to look at workplaces, as the conversation about the benefits of adolescent employment is both contentious and mostly limited to studies of impact rather than examining the specific processes of guidance in those settings. In terms of examining distributed mentoring settings, it is apparent that the structure of the joint activities that are so important for the young person's feelings of mutuality are worth further investigation.

As this study was strictly qualitative, future areas of research would involve quantifying the impact of different sources of mentoring on learners. My previous work has used mixed-methods approaches, particularly using epistemic network analysis (ENA) to measure the learning and mentoring trajectories in epistemic games and elsewhere (Nash & Shaffer, 2011, 2013). ENA could be used to examine the relative emphasis different mentoring actants placed on aspects of the epistemic frame in respect to each other, or in different activities. Further, it could be used to examine the direct impact certain mentoring actants had on the interns' learning trajectories through the internship.

This study treated mentoring actions that shared both a mentoring strategy and mentoring purpose as equivalent. For example, both the supervisor and the calendar tools used the explaining mentoring strategy to define the task. It could be argued, however, that these mentoring actions differ in amplitude. The supervisor defining the task involved a much more in-depth explanation. It may be useful, then, to code for strength of mentoring actions. Examples of ways of varying the "strength" of mentoring actions in the design of the virtual internship in order to investigate their impact are plentiful. In every instructions email, the deadline was boldfaced and every tool and resource was directly available via provided hyperlink. Understanding whether these design choices improved the impact of the mentoring would involve omitting or varying the presence of these design touches.

A distributed mentoring framework could investigate those scenarios where those different pedagogical roles are distributed among persons or tools (Shaffer et al., 2015). For example, lecturers and teaching-assistants in university settings share pedagogical goals but have different functions and authority statuses in relation to their students. At the secondary school level, blended learning curricula, where students learn content from video lectures and then discuss and apply that content under guidance of teachers, upend traditional pedagogical roles. Conflicts that can arise when one person is responsible both for teaching and for evaluating is a well-described problem in teacher professional development, where administrators like assistant principals do class visits to help and evaluate new teachers. From the perspective of secondary and post-secondary students, when teachers are responsible for both instruction and evaluation, there is the issue of students performing for the teacher as evaluator, rather than performing for teacher as instructor. Learning environments designed from the perspective of a distributed mentoring framework could potentially unpack these motivational conflicts.

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