Distributed Expertise and Authenticity in the Development of Design Expertise

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***Abstract* – Community is a vital part of the design process, yet most studies of design occur in isolation, such that the role of community has not been much studied and a sequestered view of the design expertise has emerged. Design commonly occurs in a distributed expertise system, with various members transferring into the problem space with different expectations, knowledge, and interests. This study takes as its unit of study teams of students learning to design in a year-long senior capstone bioengineering design course at The University of Texas at Austin. The experience of working on a design team has great potential to provoke new learning and to place students on trajectories towards adaptive expertise. This research, which is a part of the NSF-funded Vanderbilt-Northwestern-Texas-Harvard-MIT, Engineering Research Center, is grounded in the principles of How People Learn and considers adaptive expertise to be critical for those in rapidly changing fields. Two years of the design course are contrasted with implications for authentic design experiences highlighted. Pre- mid- and post-tests were completed along with surveys about learning environment, design, and community. Additionally, specific groups were followed to provide moments in design, and to examine what led to functional groups.**

Key Words- Adaptive Expertise, Design, Distributed Expertise

BACKGROUND

This study is part of the research and educational activities ongoing in the Vanderbilt-Northwestern-Texas-Harvard-MIT (VaNTH) Engineering Research Center for Bioengineering Educational Technologies. As such, it is grounded in the How People Learn framework [1], which provides lenses of learner-centeredness, assessment-centeredness, knowledge-centeredness, and community-centeredness (For examples see Petrosino et al. [2]). This research focuses on community, as students negotiate their roles as designers in design teams, and on knowledge-learner interactions, as the students become responsible for their own learning of content related to their projects.

ENGINEERING DESIGN

I. Expertise in Engineering Design

Design has been characterized as being different from other expertise, as it is not a standard case of problem solving. Design problems have been called "wicked" because the problem space is far less constrained compared to problems in science, and termed ill-structured because they have multiple possible solutions with multiple paths and require preferences dictated by the designer [3]. Commonly, design involves solving highly complex and dynamic problems [4]. Goel and Pirolli [5] introduce a framework for discriminating design and non-design problems, and for considering how design problems differ. The framework consists of the task environment, which includes the external environment in which the problem is solved and the problem space, which is the interaction of the problem solver and the environment, and which contains invariant features. Some of the qualities that differentiate design task environments from other science problem solving task environments are problem complexity, constraints, how specified the problem is, and how interconnected the sub-problems are. These qualities situate a problem as belonging to design.

The design problem space includes problem scoping, design phases, incremental and iterative decomposable steps, and individually constructed preferences and endpoints. The designer negotiates the problem space, first through a broadening process of problem scoping and then by a narrowing process of becoming solution focused. This is a difficult process to learn, and how the designer negotiates this may correlate with level of experience and level of skill. Studies of engineering design have focused primarily on contrasting novice with intermediate and/or expert designers or on categorizing design skills of experts. In most cases, these studies have occurred in isolation of other people, though resources have been available during tasks [3].

Von der Weth and Frankenberger [6] developed a model to differentiate design skill based upon performance of designers of different levels as they solved a task. In their experiment, the designers had access to various resources and took as much time as was desired, though none took more than 15 hours. The actions of the designers were categorized, and from this, the authors found that domain general heuristics were not good predictors of successful design, and domain knowledge is insufficient to explain the differences, but that style accounts for some differences. They define style as “individual characteristics, marking not only the ways of proceeding in design, but also in other complex situations.” This raises a question about what characteristics allow for the more successful designs.

Another study considers design from a cognitive stance: the dissociable nature of design expertise means that it can be partitioned into the declarative and procedural. While it is easy to teach the declarative aspects, which are readily verbalizable, it is difficult to teach the procedural. Further, far less attention is paid to procedural. Declarative aspects are insufficient for good design and this may be a major difference between levels of expertise. The author concludes with a plea for the importance of students having realistic and authentic experiences [7].

Studies of design expertise have shown that with increasing experience and skill, designers pay better attention to the Voice of the Customer, logistics, and constraints [8], are less likely to employ trial and error [9], gather more data, consider alternatives, and are more flexible in employing strategies [10]. Experts tend to rely on the procedural, using a breadth-first approach while novices use declarative knowledge and a depth-first approach [11]. While the ability to draw on experience may offer a clear advantage to the expert, the use of strategies that go beyond trial and error offer significant affordances not available to novice designers [9]. Good design is considered to be the result of good problem scoping (“identifying need, problem definition, and gathering information” [10]), being solution focused, and employing frequent cognitive switching, but not due to having considered broad alternatives [3]. A lack of flexibility can result in fixation, and novices in design are commonly described as suffering from fixation. Exposure to a flawed solution can also provoke fixation, such that designers will incorporate many aspects of the flawed solution in their designs [12]. This is problematic when one considers that much of what designers do involves redesign.

In one study looking for elements common to expert design, the authors assert that expert design is systematic, and that the designers start from first principles [13] (“fundamental physical principles” [14]). Engineers tend to take a broad approach that is informed by personal preference, then explore the problem space in a principled manner, and populate the design process with dynamic, temporary goals [15]. Strategies for solving problems may be local or global, as experts decompose an ill-structured problem into well structured sub-problems. These sub-problems may then be solved by designers within a design team.

II. Distributed Cognition

In a study of how experts view diagrammatic presentations of the design process as presented in textbooks, researchers found that experts generally did not disagree with the diagrams, but found them insufficient. Missing was a focus on tasks associated with the lens of community: communication and multidisciplinarity [16]. Few designs fit neatly into one small area, and even those that seem to may benefit from different perspectives. The idea that the expertise required to accomplish a goal may exist within several individuals, and that one individual, even an expert, could not accomplish the goal equally, is distributed cognition [17, 18].

Although other designers are one of the most important resources an engineer has during the design process, few studies have considered the design team as a unit of analysis. Studies of groups in engineering have focused primarily on promoting effective team skills or on exploring the ways in which groups interact. For example, Bossert [19] provides an overview of various types of groups (such as jigsaw groups) and Smith [20] provides guidelines for how to use groups, with descriptions of different types of groups and ways to evaluate teams. According to Smith, functional groups have Positive Interdependence, meaning that all group members cooperate to complete the task, as well as Individual and Group Accountability, meaning that each group member is accountable for the grade. In a fairly comprehensive overview of options for teaching design, Dym et. al. [21] provide a review of how teams engage in design thinking, highlighting the relevance of ABET criteria. ABET included criteria that address the social nature of design, in that students are expected to possess the following:

- 3(d) an ability to function on multi-disciplinary teams
- 3(g) an ability to communicate effectively
- 3(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

It has been argued that “design education should be refocused on teaching designers to better function in group situations” [22]. Designers greatly benefit from participating in the argumentation aspects of design and the social process of negotiation [23]. Because each team member has different technical skills and values, the resultant “design is an intersection—not a simple summation-of the participants’ products” [21].

I. Adaptive Expertise in Engineering Design

Research has shown that experts’ knowledge is organized by core principles of the expert’s discipline [24-26] and cannot be reduced to a set of isolated facts because it is deeply connected and conditionalized with respect to context [24]. The organization of expert knowledge into conceptual schema means that it is readily accessible [27, 28]. Expertise both allows the expert to recognize things that novices may miss and blinds them to aspects of problems that have previously proven to be unproductive [1, 26, 29]. This pairing is vital to developing efficient expertise when routine problem solving is called for. Additionally, expertise may involve the ability to apply knowledge to solving problems in contexts slightly, or even greatly outside those in which the expert possesses routine efficiency. This is accomplished through the recognition of underlying similarities in concepts or principles that govern situations and this ability is termed transfer [1].

Not all experts, even within the same discipline, solve problems in the same way. Just as novices may be discriminated from experts based on how they solve problems, so too may experts be discriminated based on two end-member types of behavior: routine and adaptive expertise [30]. While routine experts may be efficient and technically skillful, they may not be able to flexibly adapt to solve novel problems [31]. In a time when many people may expect to change fields, and when the fields themselves are changeable, this flexibility is critical. While adaptive experts possess the ability to efficiently solve routine problems, they are also able to adapt to new situations, are metacognitive, and are especially solicitous of new learning opportunities [1, 32, 33]. Adaptive experts not only have knowledge that is well organized, but also display the ability to transfer their knowledge, skills, beliefs, and attitudes to new situations.

While understanding initial and goal states is useful, it is not sufficient; current research must focus on the less well understood trajectories towards expertise [34]. Within this lie many questions about how to promote the development of the characteristics possessed by adaptive experts. Design problems, because they are ill-defined and contain opportunities for innovation, provide an excellent opportunity for the study of these learning trajectories. Fixation may also be a useful discriminant when considering differences between designers; while a design may satisfy the requirements, another may address them in an innovative way [12].

PARTICIPANTS AND COURSE DESIGN

The participants of this study are senior bioengineering students enrolled in the capstone, year-long (fall 2005 through spring 2006 and fall 2006 through spring 2007) design class at The University of Texas at Austin. This represents the first two times this course has been taught, as the bioengineering major is a new major. Design teams were composed of 3 or 4 students who were selected by the course instructors. The instructors made sure that non-native English speakers were distributed across groups. In accordance with common practice, the instructors also used a version of the Myers-Briggs Temperament Indicator (MBTI) to form groups [35].

Students completed the delta design game [36], which places team members into roles with conflicting goals; teams then negotiate to produce a final design. Both cohorts of design classes completed a preliminary project prior to beginning their sponsored project (See figure 1).

Fall Semester				Spring Semester	
Cohort 1 N=86	Pre-test	Mini-project	Mid-test	Sponsored project	Post-test
Cohort 2 N=82		Redesign project		Sponsored project (in progress)	

FIGURE 1

COURSE FORMAT AND COMPARISON OF PRELIMINARY PROJECTS

For cohort one, this entailed the mini design project, in which all teams designed digital stethoscopes with the constraint that they functionally incorporate a specific material. For cohort two, the preliminary projects included a redesign project, in which teams selected biomedical devices, such as nicotine patches, inhalers, and pregnancy tests and redesigned some aspect of the device.

After completion of the smaller projects, the teams were selected by sponsors to design a biomedical device or protocol. The projects came from hospitals, industry, NASA, and universities, and were tremendously varied in terms of difficulty. Teams completed various tasks for their designs, including ideation, Gantt Charts, Pugh Charts, final reports and presentations.

The class is taught in two consecutive semesters by two different professors. The four teaching assistants (who vary from semester to semester) played a large role in facilitating the students' learning; the TA's had approximately 100 contact hours with the teams and helped with assessment of students work. Additionally, teams had faculty advisors and meetings with their sponsors.

The students typically do very little group work prior to the design class. Therefore, the intense teamwork the students experience in this course has the potential to provoke new learning of "soft skills" such as interaction, communication, and team work [37]. The lens of community-centeredness [1] is an important one for understanding how the students learn in this course. Additionally, we will consider how these students negotiate their roles as they enter their communities of practice [38, 39].

MEASURES AND PRELIMINARY RESULTS

I. Initial Steps in Design

A pre-test, given in the first week of class, included a challenging design question in which the students are told that we do not expect them to complete it, but that we are interested in how they begin solving such a problem. This question is used to examine how student thinking changes with experience in design, and involves designing a device for treating hypothermia in war conditions, given several constraints. A mid-test using the same question was given following completion of the mini or redesign project, and a post-test, also using the same question, was given after the sponsored project was completed. A coding scheme based on expert performance and evaluation of student performance was developed. Coding of student work on the tests revealed a trend of students orienting to more of a design focus, meaning that over the year, their designs included more information about how the design would be constructed, increased use of and higher quality schematic views, and more attention to the Voice of the Customer. A typical response on the pretest, for example, addressed the scientific aspects related to the heat-transfer inherent in the problem. A typical response from the posttest was more likely to address concrete issues of design, including insulation, size requirements, temperature monitoring, or how blood could be warmed without damage. This reorientation in focus is indicative of an increased sensitivity to design. Particularly, it shows that over the course of the semester, the students learned to focus their attentions on the real-world interactions with their design product.

These data, though incomplete (as cohort two students are still in the design process at the time of writing), are useful for contrasting the mini-project with the redesign project. While the overall trend for the cohort one students shows an increase by the post-test, there is a sharp and troubling decrease in Voice of the Customer at the mid-test (Figure 2). This trend is not seen in at the end of the redesign project with the cohort two students; rather, there is an increase in Voice of the Customer. Both groups show an increase in Diagram, but with year two students, there is a stronger increase.

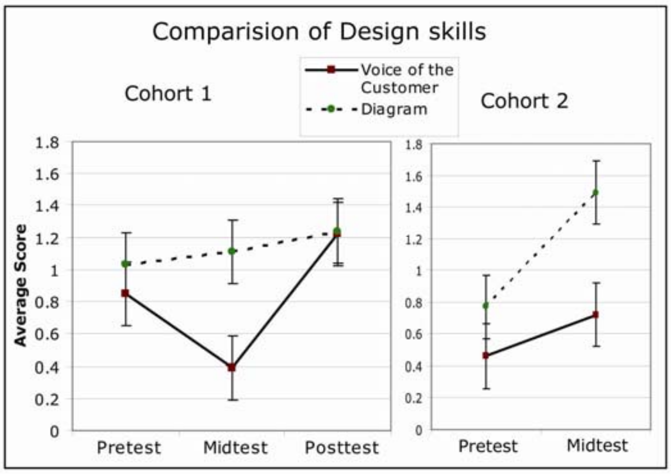

FIGURE 2
TEST AVERAGES FOR COHORT 1 AND 2 FOR VOICE OF THE CUSTOMER AND DIAGRAM

II. Adaptive Expertise

The project definitions and final projects were sorted along the adaptive expertise dimensions of efficiency and innovation by the spring course instructor, who was familiar with these constructs (Figure 3).

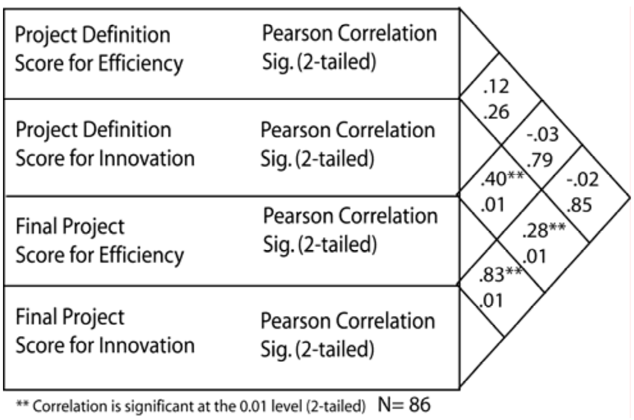

FIGURE 3
CORRELATIONS OF INNOVATION AND EFFICIENCY ACROSS PROJECT DEFINITION AND FINAL PROJECT SCORES

Project Definition Scores for Innovation are positively correlated with Final Project Scores for Efficiency and to a lesser degree, Final Project Scores for Innovation. Final Project Scores for Efficiency are strongly and positively correlated to Final Project Scores for Innovation. This supports the idea that a great deal of content knowledge is prerequisite to innovation. While there is a correlation between the Project Definition Scores for Innovation and the Final Project Scores for Innovation, the lack of strength of this relationship indicates that there are many things that impact this relationship. This finding is compelling because it indicates that early innovation may not yield innovative results, but that efficient understanding of the problem may allow for more innovative solutions.

III. Constructivist Learning Environment Survey

The Constructivist Learning Environment Survey (CLES) [40], which is composed of questions that address personal relevance, shared control, critical voice, and student negotiation, provides a picture of the practices as they exist in the classroom. The survey is a 5-point Likert scale (1=Almost Never; 2=Seldom; 3=Sometimes; 4=Often; 5=Almost Always). Six questions cover each category. This survey was administered during the Spring semester for the year one students (when the students were well into their sponsored projects) and was administered as a pre-test for year two students addressing prior coursework. At the end of this year, the year two students will complete the survey an additional time. An exploratory factor analysis indicated that the grouping of the questions was satisfactory for all but one of the questions. This question, part of the personal relevance scale, read: “In this class what I learn has nothing to do with life beyond my classroom setting” and is perhaps worded too strongly. Previous research with the CLES has not reported such findings, but that research was conducted with a more general audience; it is possible that using a more restricted sample composed of engineers led to slightly different findings. Because this question does not group with the others, it is not considered in the analysis (Figure 4).

Constructivist Learning Environment Survey (CLES)

Category	Sample Question	Cohort One: Sponsored Project Average	Cohort One: Sponsored Project Standard Deviation	Cohort Two: Prior Coursework Average	Cohort Two: Prior Coursework Standard Deviation
Personal Relevance	I learned about the world beyond the classroom setting	3.49	1.05	3.18	0.92
Critical Voice	It is acceptable for me to question the way I am being taught	3.61	1.26	3.54	1.1
Shared Control	I planned what I was going to learn	3.38	1.78	2.8	1.14
Student Negotiation	I asked other students to explain their thoughts	4.05	2.2	3.93	0.92
		N= 84		N= 73	

FIGURE 4
STUDENT REPORTED RESULTS ON THE CLES

Keeping in mind that these are two different groups of students, and that they are not snapshots taken from the most maximally separated time points (pre and post), it is still interesting to note the difference between year one's mid project scores and year two's prior coursework scores, especially on Shared Control.

While all the year one mid-project scores are higher, there is a sizable difference on Shared Control, possibly indicating that the nature of the design course gives the students greater control over their learning than their other coursework tends to. These data are extrapolations, but as the rest of the year two data comes in, we will have a clearer picture of changes over time.

III. Community

Multiple measures are needed for examining the role of community in learning how to design. Peer reviews and surveys were collected, instructors were interviewed, and observations were collected. As the peer reviews were used by the professor for grading, they have proven relatively unreliable for research purposes; students tended to give their team mates high grades, even when other indicators suggested that some team members were not contributing. This has led to the collection of peer reviews for strictly research purposes for the cohort two, and these are in the process of being administered. The relationship between individual and team grades was explored for cohort one teams. The correlation for this relationship is significant and positive ($r=.435$, $p=.01$), yet it is insufficient for predicting the team grade.

From team observations and interviews with the instructors, there seemed to be qualitative differences in how groups interacted. Some groups could be categorized as "divide and conquer" while other groups could be described as "everyone does everything." A closer look within these two categories revealed that these superficial categories could be more effectively broken up further to account for differences (Figure 5).

Some "divide and conquer" groups over-divided, meaning that early on they chose tasks and worked in isolation, meeting only when required. Members of "over-divide and conquer" groups had few opportunities to understand what their teammates had done and rarely negotiated their design. Other "divide and conquer" groups managed their tasks, dividing only during sub-problems. During their meetings, the "divide-enough and conquer" group members made sure that every group member understood the basics of what they had done, and they met frequently enough that if changes needed to be negotiated, there was still time. This model successfully takes advantage of distributed expertise and incorporates negotiation.

In the "everyone does everything" groups, some functioned as small school rooms in which every member independently accomplishes every goal. This leads to a redundancy that does not support distributed expertise, and that uses time inefficiently. For these groups, there is little advantage to being in a team. Other "everyone participates" groups identified a team member who could best accomplish a task, and could lead the rest of the team through the task, with members engaging as they were able. The leader would vary with the task, but all members participated enough to understand the impact on the design and why it might be important during negotiation. It is not yet clear what provoked the different categories described here, or how common they are, but our on-going research will address this.

Group types and affordances

Group type	Negotiation	Distributed Expertise
Over-divide and conquer	-	+
Divide and conquer enough	+	+
Everyone does everything	+	-
Everyone participates	+	+

FIGURE 5
EXPLANATION OF GROUP TYPES AND THE AFFORDANCES THEY LEVERAGE, SUCH AS NEGOTIATION AND DISTRIBUTED EXPERTISE

CONCLUSIONS

One question brought up by research on teaching engineering design, is "How authentic should [project based learning] experiences be compared to industry design experiences?" [21]. Because the students did not feel authentically invested in the mini project, they did not effectively learn to value the Voice of the Customer. The authenticity of the sponsored project helped the students value the Voice of the Customer. More authentic experiences help the students to effectively engage with the design process.

The ability to place students on a trajectory towards adaptive expertise in design may depend on more than initial success at innovation. Deep content knowledge is required, but is also insufficient. Experience with redesign, which may give students experience breaking through moments of fixation, has the potential to provide students with critical experience for thinking adaptively. The social nature of design has implications for the development of adaptive expertise in engineering; without strong communication and negotiation skills, a learner will not effectively interact with a design group.

Community is a complicated lens to study in design, yet, to understand the design process, it is vital. The success of group design is dependant on how the group interacts. There may be more than one successful way to accomplish this interaction, but without taking advantage of the group's distributed expertise and without negotiation, success will be limited. In fact, the affordances that working in a group offers may be eliminated altogether.

As data continue to come in from this on-going study, we will continue to analyze data for this research, and to refine our methods for understanding the role of community in the development of adaptive expertise in engineering design.

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REFERENCES

[1] Bransford, J. D., Brown, A. L., and Cocking, R. R., *How People Learn: Brain, Mind, Experience, and School. Expanded Edition*, 2000.

[2] Petrosino, A., Martin, T. and Svihla, V, "Developing Student Expertise and Community: Lessons from How People Learn," in *Special Issue of New Directions in Teaching and Learning*, vol. 108. San Francisco: Jossey-Bass, 2007, pp. 118.

[3] Cross, N., "Design cognition: Results from protocol and other empirical studies of design activity," *Chapter*, vol. 5, 2004, pp. 79-103.

[4] Jonassen, D. H., "Toward a design theory of problem solving," *Educational Technology Research and Development*, vol. 48, 2000, pp. 63-85.

[5] Goel, V. and Pirolli, P., "The Structure of Design Problem Spaces," *Cognitive Science*, vol. 16, 1992, pp. 395-429.

[6] Von Der Weth, R. and Frankenberger, E., "Strategies, competence and style--problem solving in engineering design," *Learning and Instruction*, vol. 5, 1995, pp. 357-383.

[7] Goel, V., "Dissociation of Design Knowledge," in *Knowing and learning to design: Cognitive perspectives in design education*, Eastman, C. and Newstetter, W. C., Eds.: Elsevier, 2000.

[8] Bogusch, L. L., Turns, J., and Atman, C. J., "Engineering design factors: how broadly do students defineproblems?," *Frontiers in Education Conference, 2000. FIE 2000. 30th Annual*, vol. 2, 2000.

[9] Ahmed, S., Wallace, K. M., and Blessing, L. T., "Understanding the differences between how novice and experienced designers approach design tasks," *Research in Engineering Design*, vol. 14, 2003, pp. 1-11.

[10] Atman, C. J., Chimka, J. R., Bursic, K. M., and Nachtmann, H. L., "A comparison of freshman and senior engineering design processes," *Design Studies*, vol. 20, 1999, pp. 131-152.

[11] Ho, C. H., "Some phenomena of problem decomposition strategy for design thinking: differences between novices and experts," *Design Studies*, vol. 22, 2001, pp. 27-45.

[12] Purcell, A. T. and Gero, J. S., "Design and other types of fixation," *Design Studies*, vol. 17, 1996, pp. 363-383.

[13] Cross, N. and Cross, A. C., "Expertise in engineering design," *Research in Engineering Design*, vol. 10, 1998, pp. 141-149.

[14] Cross, N. and Cross, A. C., "Winning by design: the methods of Gordon Murray, racing car designer," *Design Studies*, vol. 17, 1996, pp. 91-107.

[15] Cross, N., "Creative cognition in design: processes of exceptional designers," *Proceedings of the fourth conference on Creativity & cognition*, 2002, pp. 14-19.

[16] Mosborg, S., Adams, R., Kim, R., Atman, C. J., Turns, J., and Cardella, M., "Conceptions of the Engineering Design Process: An Expert Study of Advanced Practicing Professionals," *2005 ASEE Annual Conference & Exposition: The Changing Landscape of Engineering and Technology Education in a Global World*, 2005, pp. 2005.

[17] Hutchins, E., *Cognition in the Wild*: Cambridge, MA.: MIT Press, 1995.

[18] Salomon, G., *Distributed Cognitions: psychological and educational considerations*: Cambridge University Press, 1993.

[19] Bossert, S. T., "Cooperative Activities in the Classroom," *Review of Research in Education*, vol. 15, 1988, pp. 225-250.

[20] Smith, K. A., "Cooperative learning: effective teamwork for engineering classrooms," *PROC FRONT EDUC CONF*, vol. 1, 1995, pp. 208-213.

[21] Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., and Leifer, L. J., "Engineering Design Thinking, Teaching, and Learning," *Journal of Engineering Education*, vol. 94, 2005, pp. 103-120.

[22] Minneman, S., "The Social Construction of a Technical Reality." Stanford, California: </ref-type><contrib, 1991.
[23] Bucciarelli, L. L., *Designing Engineers*. Cambridge, Mass: MIT Press, 1994.
[24] Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., and Palincsar, A., "Motivating project-based learning: Sustaining the doing, supporting the learning," *Educational Psychologist*, vol. 26, 1991, pp. 369-398.
[25] Bruer, J. T., *Schools for Thought: A Science of Learning in the Classroom*: Bradford Book, 1994.
[26] Chi, M. T. H., Feltovich, P. J., and Glaser, R., "Categorization and Representation Physics Problems by Experts and Novices," *Cognitive Science*, vol. 5, 1981, pp. 121-152.
[27] Driver, R., *The Pupil as Scientist?* New York, NY: Taylor and Francis, 1983.
[28] Driver, R., Asoko, H., Leach, J., Mortimer, E., and Scott, P., "Constructing Scientific Knowledge in the Classroom," *Educational Researcher*, vol. 23, 1994, pp. 5-12.
[29] Nathan, M. J. and Petrosino, A., "Expert blind spot among preservice teachers," *American educational research journal*, vol. 40, 2003, pp. 905-928.
[30] Hatano, G. and Inagaki, K., "Two courses of expertise," *Child development and education in Japan*, 1986, pp. 262–272.
[31] Hatano, G. and Oura, Y., "Commentary: Reconceptualizing school learning using insight from expertise research," *Educational Researcher*, vol. 32, 2003, pp. 26–29.
[32] Fisher, F. T. and Peterson, P. L., "A Tool to Measure Adaptive Expertise in Biomedical Engineering Students," *Proceedings of the 2001 American Society for Engineering Education Annual Conference, Albuquerque, NM*, 2001.
[33] Hatano, G. and Greeno, J. G., "Commentary: Alternative Perspectives on Transfer and Transfer Studies," *International Journal of Educational Research*, vol. 31, 1999, pp. 645-54.
[34] Lajoie, S. P., "Transitions and trajectories for studies of expertise," *Educational Researcher*, vol. 32, 2003, pp. 21–25.
[35] Wilde, D., "Design Team Formation Using Jungian Typology," *Proceedings, National Collegiate Inventors and Innovators Alliance*, 2000.
[36] Bucciarelli, L. L., "Delta Design," *Cambridge, Mass.: Massachusetts Institute of Technology*, vol. 10, 1997.
[37] Seat, E. and Lord, S. M., "Enabling effective engineering teams: a program for teaching interaction skills," *Frontiers in Education Conference, 1998. FIE'98. 28th Annual*, vol. 1, 1998.
[38] Lave, J. and Wenger, E., *Situated Learning: Legitimate Peripheral Participation*: Cambridge University Press, 1991.
[39] Brown, J. S., Collins, A., and Duguid, P., "Situated Cognition and the Culture of Learning," *Educational Researcher*, vol. 18, 1989, pp. 32-42.
[40] Taylor, P. C. S., Fraser, B. J., and White, L., "CLES: An instrument for monitoring the development of constructivist learning environments," *annual meeting of the American Educational Research Association, New Orleans, LA*, 1994.