

The Center for LIFE: Learning in Informal and Formal Environments

We propose to establish a Center that will work toward an integrated science of learning that combines neuroscience, psychology, education, and technology to understand and foster learning in a fast-changing, technology-rich world. Directed by U. Washington (UW) Professor John Bransford, LIFE is a collaborative center developed with Co-PI's at UW's Institute for Learning and Brain Sciences (Kuhl & Meltzoff), Stanford University (Pea), SRI International's Center for Technology in Learning (Sabelli), and affiliated faculty and senior researchers from diverse disciplines.

Given the exceptional complexity of learning phenomena and the disparate levels of analysis that can be used to study them, we have assembled scientists and an innovative design that teams research scholars and traditions that rarely work collaboratively. Our expertise spans neurobiological, psychological, and socio/cultural approaches, and incorporates pioneering work in augmenting human learning through technologies such as visualization, simulations, collaboration and new media tools.

Our strategic management plan mirrors and supports the connections among these research areas and across institutions. Furthermore, it fosters productive "conceptual collisions" among the research perspectives, and creates an infrastructure to ensure ongoing and productive interactions with research and practice communities beyond the LIFE Center. Partnerships with these communities will be crucial to achieving and sustaining our vision. We have attracted a well respected and diverse External Advisory board and four additional review boards to guide our work, and propose an evaluative research component to understand how to best document and measure our broader impact.

Intellectual Merit: Through deliberate juxtaposition of diverse concepts, methodologies, and research traditions on learning, we will make progress toward a coherent, integrated perspective that is theoretically sound and has clear and far-reaching implications for improving people's abilities to learn.

Basic research will be conducted through three intersecting and multidisciplinary strands of inquiry. *The first strand* will document learning in the brain over the lifespan and discover from empirical and modeling work the underlying neural processes and principles associated with *implicit* forms of learning in the domains of cognitive, linguistic, and social learning. *The second strand* will conduct studies of STEM-related learning in *informal* settings to develop comprehensive and coordinated accounts of the cognitive, social, affective, and cultural dimensions that propel learning and development outside of school. *The third strand* will conduct experiments using principled *designs for learning* in formal educational and other settings that attempt fundamental improvements in the design of high performance learning environments.

The three Research Strands will collaborate on *Signature Projects* — inter-strand empirical initiatives that serve as capstone projects for LIFE. Signature Projects deliberately seek a common testable framework that has the potential to orient a new science of learning.

Broader Impacts: Our Center will support boundary-crossing research at a basic scientific level while forging close practical connections with the world beyond our work. Field-oriented activities are organized as an infrastructure that facilitates, documents, and coordinates education, collaborations, and outreach (ECO) with the broader research and education community.

We will engage our community of research scientists, engineers and designers to work with counterparts outside the Center to use the Center's human and technological resources. Undergraduate, graduate and postdoctoral students will be invited to spend time at LIFE, engaged in research in the areas framed by our goal. By working with a ECO Program Board that is representative of relevant outside communities, we will initiate, facilitate and cultivate strong and lasting partnerships with formal and informal education institutes, schools, and professional communities involved in science, mathematics, technology, and learning research. These partnerships will sustain the Center for LIFE.

The LIFE Center: Learning in Informal and Formal Environments

Toward an integrated Science of Learning that combines neurobiological, cognitive, and socio-cultural theories and methodologies to understand and propel learning and transfer in a fast-changing, technology-rich world.

1.0 Vision

We propose to establish a Center that provides strong national leadership to develop an integrative and transformative science of learning that has powerful applications for education, training, and other issues of societal importance. Given the exceptional complexity of learning phenomena and the disparate levels of analysis that can be used to study learning, we argue that such a transformation will not occur by proceeding with “research as usual.” We have assembled an outstanding research team, advisory boards, and management plan that allow us to bring together research traditions that have tended to work separately rather than collaboratively. Our plan for moving these traditions beyond common practice includes ways to encourage productive “conceptual collisions” among them by deliberately juxtaposing their prevailing assumptions, theories, and methodologies. The conceptual collisions are designed to spark efforts toward synthesis which lead to new levels of understanding that help unlock the mysteries of successful learning.

Our expertise spans neurobiological, psychological, and social/cultural approaches, as well as pioneering work in augmenting human learning through technology innovations including visualization, simulations, collaboration and new media tools. Guided by our strategic management plan, world-class board of advisors, and innovative evaluative activities, we will coordinate work across these areas—both through research that takes place within our Center and by means of focused knowledge-building activities and partnerships with the field. Within 10 years, our vision is to have played a catalytic role in establishing a transformed “sciences of learning” that combines bio-, psycho-, and socio-cultural theories and methodologies with studies of media and technology to provide a solid foundation for advancing processes of learning and development in ways responsive to the changing demands of work and life.

1.1 Introducing our Focus: LIFE

Our proposal is to establish a Center dedicated to LIFE—Learning in Informal and Formal Environments. A central premise of LIFE’s work is that successful efforts to understand and propel learning require a simultaneous emphasis on informal and formal (e.g., K-16) learning environments, and on the implicit ways in which people learn. To date, most research on learning has explored learning in laboratories and formal educational settings (e.g., NRC, 2000), yet most human experience is spent in informal environments. The 2000 NRC report, *How People Learn*, indicates that, in a calendar year, students with perfect attendance spend only 14% of their time in school. How people spend their time out of school is important for their overall development and has an impact on their success in school. LIFE’s emphasis on exploring learning in informal as well as formal educational environments has major implications for rethinking (a) *who can learn*, (b) *the kinds of learning and transfer* required for success in today’s world, and (c) *methods for promoting productive interdisciplinary work*.

Rethinking assumptions about who can learn: LIFE will search for principles of learning that allow society to overcome common assumptions that some people “get” mathematics and science and can succeed in STEM disciplines, whereas others cannot. For example, many people who do poorly in formal educational environments often learn effectively in informal contexts (e.g., McLaughlin et al., 2001). Active ingredients for these successes appear to include social arrangements that leverage knowledge in peer networks and mentors, and increases in motivation and interactivity made possible by new technologies such as simulations and games. Research in the neurosciences is clarifying processes of *implicit* as well as explicit learning, and many informal environments may provide a confluence of important variables (motivation, attentional focus,

optimal levels of complexity, social interactions) that are more conducive to effective implicit learning than the typical confluence of variables found in formal learning contexts (as discussed later). Empirical work demonstrates that, except in extreme cases such as severe neurological impairment, children can learn complex STEM-relevant knowledge effectively and fluently in *some* settings and supported by some forms of new media (NRC, 2000). STEM knowledge is relevant not only for future STEM professionals, but to help create informed citizens (e.g., Project 2061 from AAAS). All citizens need the capacity to understand and analyze issues of science, ethics, technology, and other factors that affect our democracy and the quality of lives of future generations. Our sciences of learning need to make explicit the principles that underlie the successes of learning, in whatever contexts they may occur.

By the same token, LIFE resists over-optimistic assumptions of the superiority of informal over formal contexts. Children outside of school do often appear resourceful, curious, capable, and creative—learning under their own agencies how to do complex things. Nevertheless, schools as formal learning environments often confer special advantages such as more consistent concerns for equity and special needs, for rigorous content and accountability for student learning, and for explicit attempts to provide the kinds of learning experiences that support transfer. Overall, to seriously rethink who can learn, we must transcend the artificial boundaries between informal and formal learning and creatively design environments that promote new learning synergies.

Re-conceptualizing the nature of learning and transfer: LIFE’S focus on learning within and outside schools also helps us rethink what successful learning in today’s world needs to look like. We live in a different world than the one for which most of today’s schools are ready (Partnership for 21st Century Skills, 2003), and this highlights the need to develop a science that explains and fosters robust learning and transfer in the face of fast-paced change (e.g., Drucker, 2001; Graham & Stacey, 2002; Marshall & Tucker, 1993; Reich, 2002). People’s increased need to adapt raises important and intriguing questions, such as: How do people develop the efficiency of processing necessary for effective action, yet remain sufficiently flexible to adapt to change?

LIFE’s attention to flexible adaptation to change highlights the need to re-conceptualize transfer of learning. Measures of transfer are among the most important tools used by researchers to evaluate the quality of learning experiences. Most transfer measures and studies (since Thorndike, 1901) have involved a learning phase and then an application phase where learners engage in “sequestered problem solving” (SPS) without access to resources (access to technology, people, information), and are asked to apply what they know to a new transfer problem. LIFE’s research will explore a new “preparation for future learning” (PFL) view of transfer as the ability to enter an unanticipated setting with the skills, knowledge, and dispositions to make sense of the structure of a problem, quickly locate and use relevant resources (ranging from other people to information and tools), actively create opportunities to test one’s thinking by getting feedback, and reflect on one’s efforts so as to continually learn to “work smarter” (Bransford & Schwartz, 1999). We note later how PFL measures of transfer can reveal strengths of diverse learning experiences whose advantages are invisible from an SPS point of view.

The need to re-conceptualize what it means to learn for transfer is motivated further by the assumption that technology will play increasingly central roles in both informal and formal aspects of people’s lives. For LIFE, transfer includes the ability to learn to “work smart” by adopting, adapting, and sometimes inventing anew tools and social practices that facilitate problem solving and future learning. Overall, we need a much broader and more coherent look at technology—especially as it is used to work smart in the workplace—in order to understand its potential for PFL transfer.

Multiple perspectives on implicit, informal, and formal learning: We noted earlier how our expertise spans neurobiological, psychological, and social/cultural approaches, as well as pioneering work in augmenting human learning through technology innovations. Each of us has studied learning in informal and formal learning environments, but not with equal emphasis. LIFE members from the neuroscience and social/cultural traditions have focused mainly on implicit and informal learning in out-of-school settings (e.g., workplaces, parent and peer interactions, after-school

communities, and playing video games). LIFE researchers from the cognition and technology tradition have more often studied learning occurring in formal settings such as schools, colleges, and universities (e.g., CTGV, 1997; NRC, 2000).

In preparing our LIFE Center, we repeatedly found that the contrasts among implicit, informal, and formal learning led to rich conversations. And when we talk with colleagues outside of LIFE’s immediate circle and with Advisory Committee members, we find that our focus readily energizes and engages them, leading us to believe that our design has broad potential to engage diverse scientific fields. We also believe that LIFE studies of implicit, informal, and formal learning will define a research agenda that the public, policymakers, teachers, and parents can understand and support; ultimately resulting in a new science of learning that will be more readily understood, supported, and put to use throughout society.

1.2 Introducing our Structure: The Elements of LIFE

LIFE’s emphasis on learning in both formal and informal environments optimizes the ability of each of us, and our research traditions, to learn from one another. Yet rigorous boundary-crossing research that we are proposing will not “just happen.” We have thus given extensive thought to LIFE’s organizational structure and developed plans to collaborate both within LIFE and broadly with the learning sciences field.

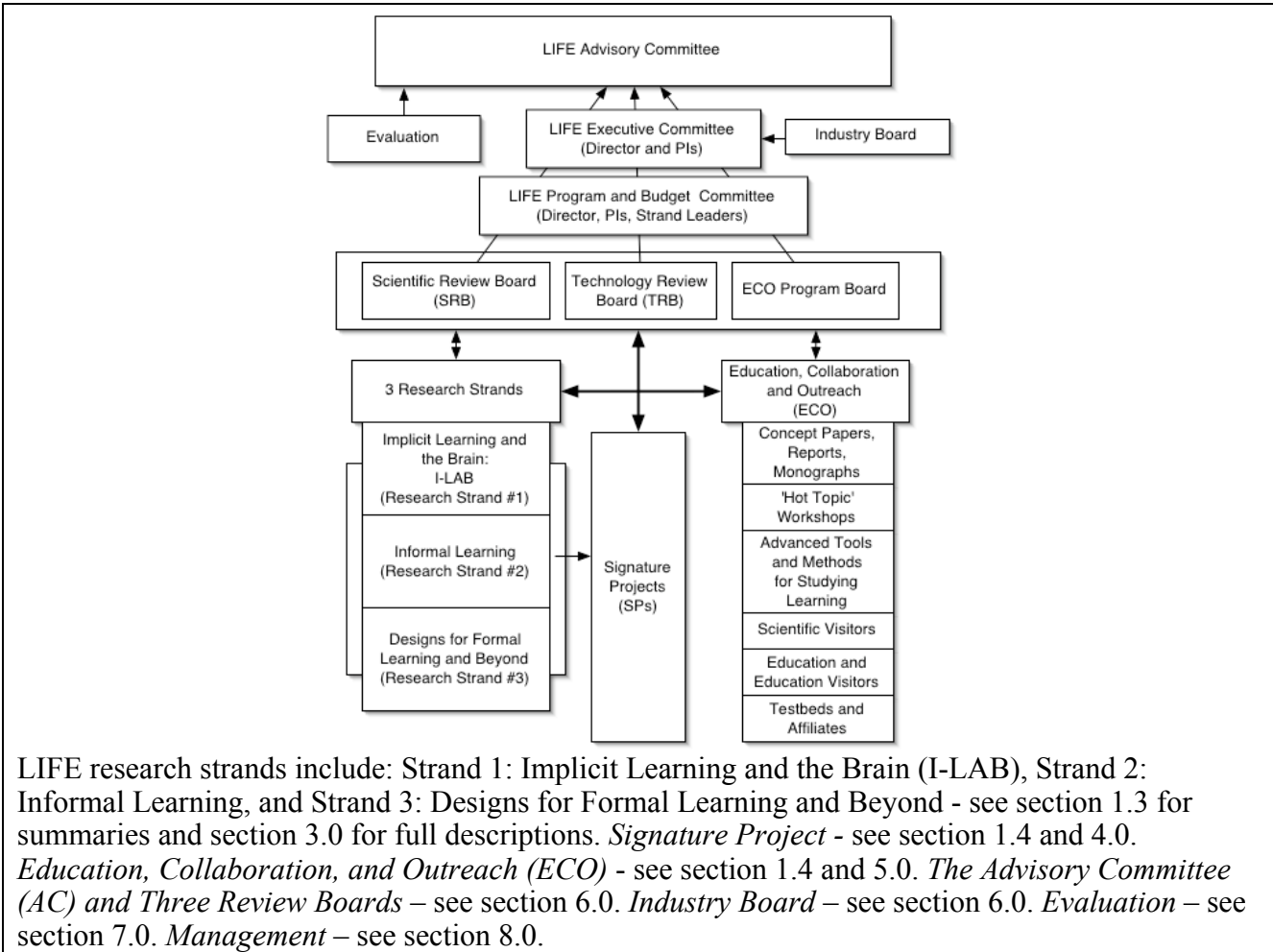


Figure 1. Structure of the LIFE Center

1.3 LIFE’s Research Strands

Consider first the three research strands in *Figure 1*. Each explores fundamental research questions in its area, but researchers will also work across the strands to create “conceptual

collisions and synergies,” resulting in integrative Signature Projects (SPs). As we discuss, SPs involve the design of environments that allow LIFE (and the broader field) to test ideas that emerge from the conceptual collisions. All three strands, through LIFE’s Program and Budget Committee, will play major roles in the decisions for SPs, and we have specific mechanisms for making these decisions (see Section 1.4 for more discussion).

LIFE’s first strand — Implicit Learning and the Brain, or I-LAB — represents cognitive neuroscience, and will document learning in the brain and discover from empirical and modeling work the underlying neural processes associated with learning throughout the lifespan. I-LAB focuses on implicit learning, the kind of learning that has been found to occur whether we want it to or not. Implicit learning is especially prominent in childhood but occurs throughout life, and investigators in the I-LAB strand will examine implicit learning in cognitive, linguistic, and social domains in infants, school-aged children, and adults. These domains are especially rich for understanding implicit learning and its cumulative effects. Studies of implicit learning will help us understand the fundamental dynamics of learning, showing how experience alters our perception by establishing mental sets that reflect our experiential histories. Our mental sets function as “filters” on future learning, providing the benefits of expertise, as well as certain limitations on the ability to take a completely new view. Hence, learning *from* experience changes our future ability *to* experience. Our specific culture and language “attune” us, altering our perceptions and actions. What we learn *from* experience alters the brain, structuring our ability *to* experience in a particular way. Understanding our implicit filters is critical for dealing with issues ranging from conceptual changes in scientific thinking, to second-language learning, to social attitudes and views, even stereotypes about diverse races or ethnic groups.

Three major themes link this strand to the others: (1) how the brain can increase efficiency in processing while simultaneously maintaining optimal levels of flexibility to adapt to change (to transfer); (2) how our understanding of principles of implicit learning can help us design environments that optimize the ability of novices to learn to act effectively in complex situations; and (3) how learning in virtual settings (e.g., games, simulations, with computer agents) might capitalize on natural implicit learning mechanisms. An interesting point here is that we already know from research that there are differences in the degree to which implicit learning occurs in simulated versus actual environments (e.g., Kuhl et al., 2003). Strand 1 research will attempt to understand these similarities and differences.

LIFE’s second strand—Informal Learning, representing the socio-cultural tradition—will conduct studies of learning of technological fluencies, science inquiry, and mathematical practices in informal settings so as to develop comprehensive and coordinated accounts of the cognitive, social, affective, and cultural dimensions that propel human learning and development outside of school. Especially relevant is the fact that many students who do poorly in formal educational settings learn well in informal settings—especially settings augmented by modern technologies (such as game communities). We need to understand the confluence of social, motivational, and cognitive issues that make learning successful in some settings but not in others. Work in this strand is also important for understanding how professionals in the field adopt, adapt, and design and use tools and social practices to work smart, and how and why transitions from formal educational to more informal workplace environments (and vice versa) are often so difficult (e.g., BHEF, 2003).

Key themes connecting this strand’s work with others include issues of transfer of knowledge and practices, the use of tools to work smart, and the possibilities that (a) neuroscience can reveal whether successful learners tend to think in terms of these tools even when they are not available (e.g., imagining a spreadsheet-like representation of new problems) and (b) this component of their expertise can be measured behaviorally to develop more precise indicators of “preparation for future learning” (PFL). Another major theme is the degree to which particular constellations of motivational, contextual, and social variables can provide guidance for the redesign of formal educational environments that will help all students succeed.

LIFE's third strand—Designs for Formal Learning and Beyond, representing the cognition and technology tradition—will conduct experimental studies of theory-based principles for the design of high-quality learning environments, with a special focus on environments that are explicitly designed to prepare people for STEM-relevant learning and transfer. The work will be guided by insights from the other two strands. Strand 3 research will place special emphasis on studying powerful roles for new technologies.

A major focus for Strand 3 will involve theories and measures of transfer. Transfer is one of the gold standards of an educationally relevant science of learning (e.g., Bransford & Schwartz, 1999; Detterman & Sternberg, 1993; NRC, 2000; Mestre, 2002) and assumptions about its effects on the educational design process (Wiggins & McTighe, 1997; Bransford, et al., in press). Both Strands 1 and 2 are concerned with issues of transfer and make assumptions about how to define and measure transfer. Transfer is an issue for productive conceptual collisions among strands.

Strand 3's work on transfer will be organized around a paper on "rethinking transfer" that won the 2001 AERA award for best research paper (Bransford & Schwartz, 1999) and was one of the major papers discussed at an NSF conference on transfer (Mestre, 2003). This paper defines transfer as the degree to which people are well prepared for future learning (PFL transfer) vs. simply being prepared to directly apply what they are learning to new problems in "sequestered problem solving" (SPS transfer — the kind used in the majority of all transfer studies since Thorndike & Woodworth, 1901). At one level the differences between SPS and PFL transfer seem so simple as to be obvious. However, if one plays out the implications of the differences, insights emerge with potential to change how the field thinks about, and measures, the effects of various educational experiences.

Strand 3's work will also be organized around a new design framework that defines a problem space for thinking systematically about designs that support transfer. The need for this framework has emerged as LIFE members have discussed cross-strand ideas and hypotheses. The need also exists outside of LIFE. Strand 3's framework for organizing thinking and research is presented later (Figure 2), and we discuss studies to test its value. Overall, Strand 3 has purposely chosen themes—transfer and a way to think systematically about a space of design possibility that can help support transfer—that are relevant to all three of LIFE's strands.

1.4 Mechanisms for Promoting Crosstalk among Research Strands

The foregoing discussion described some links between Research Strands, but we realize that a more explicit emphasis on cross-talk is necessary to achieve the LIFE vision of a transformative effect. LIFE has developed three mechanisms for promoting intellectual exchanges: (a) conceptual collisions — spontaneous debates that arise regarding topics of interest across Research Strands due to the different approaches we bring to the same problems; (b) Hot Topic discussions and workshops — scheduled discussions that occur weekly on specific interdisciplinary topics, coupled with formal annual workshops that are organized by LIFE's Education, Collaboration, and Outreach group (ECO); (c) Signature Projects—inter-strand, collaborative research projects (often but not always experimental in nature) that emerge as a product of conceptual collisions and/or hot topic discussions and workshops. Signature Projects develop ways to empirically test major new insights and hypotheses that arise as a function of cross-research-strand interaction in conjunction with input from the field as a whole. They are LIFE's engine for transformation and will lead to increased opportunities to interact with the field.

Conceptual collisions happen spontaneously, but we aim to prime the pump to ensure discussion. Research demonstrates that providing opportunities to contrast similar but differing viewpoints not only highlights commonalities but also illuminates critical differences that previously were invisible (e.g., Bransford, et al., 1989; Bruner, 1996; Gibson & Gibson, 1955; Garner, 1974; Schwartz & Bransford, 1998). Consider the juxtaposition of proverbs such as "Too many cooks spoil the broth" vs. "Many hands make light work;" and "He who hesitates is lost" vs. "Haste makes waste;" or "Absence makes the heart grow fonder" vs. "Out of sight, out of mind." Each contrasting proverb has a semblance of truth, and each is often accepted without question (e.g., Bransford &

Stein, 1993). So it is with research paradigms. Epistemological and methodological assumptions often go unquestioned, when juxtapositions can help deepen thinking. Similar juxtapositions can help deepen thinking about education. LIFE's search for conceptual collisions is designed to uncover fundamental assumptions and issues that warrant exploration from different points of view.

Hot Topics are chosen at the beginning of each year of LIFE. The topics are sufficiently timely and important to generate interest across all three research strands and the field broadly. Hot Topics will provide a touchstone for integrating LIFE's ongoing discussions. We videoconference weekly, and at least one meeting a month will be devoted to the Hot Topic. Interested people from outside the field will be invited to join and participate from remote sites. Engaging summaries of the monthly discussions will be provided on LIFE's web site, and the site will provide opportunities for the field to actively make suggestions relevant to the topic. The Hot-Topics function of LIFE culminates in two deliverables: (a) an annual Hot Topics workshop with broad field participation; and (b) an annual National Academy-like report synthesizing research and summarizing current thinking on the topic, to be made available to the field for use in courses, springboards for new research, and so forth.

Signature Projects are research initiatives involving all three Research Strands working in collaboration. Choosing the right Signature Project is important, and LIFE has a process in place. PIs and Strand Leaders, with advice from our advisory boards, will use several selection criteria for topic: (a) it must be relevant to fundamental issues within each of LIFE's Research Strands; and (b) it must be one on which the three Research Strands provide contrasting theoretical, empirical, and/or theoretical perspectives with the potential to produce significant novel work that transcends what's possible within a single Research Strand. In each year of LIFE, candidate Signature Projects will be offered and discussed. We have not yet finalized the Year-1 project. Three (nascent) Signature Project candidates that all three Research Strands are excited about are described in Section 4.0. In the coming months, our weekly meetings will focus on fleshing out these candidates, and we plan to announce LIFE's Year-1 Signature Project if we have an NSF site visit. LIFE has budgeted annual money for these Signature Projects, but we will work to make them exciting and valuable enough to attract additional funding from industry, foundations, and other sources.

1.5 Qualifications for Success of the LIFE Team

Our vision of integrating perspectives and evolving a new learning science is demanding in terms of time and expertise. Our team's qualifications for engaging in this task include the management of many very large programs, projects, and centers, and a history of work beyond the confines of our own projects and disciplines. Our overall team (researchers and advisory board) is diverse with respect to gender and ethnicity and includes outstanding early- and mid-career as well as senior scientists. ECO and its board will be concerned from the start with building capacity in new communities and bringing into our work their own research and insights so crucial to any study of the contexts of learning.

PI Bransford is an internationally renowned scholar in cognition and technology. Work by Bransford and colleagues in the 1970's helped shape the "cognitive revolution" in psychology. He was founding director of Vanderbilt University's Learning Technology Center, and served as Co-Chair of a National Academy of Science committee on "New Developments in the Science of Learning" (Bransford, Brown & Cocking, 1999) to synthesize findings from research leading to a theory of human learning. He has co-chaired two other NAS reports (Donovan, Bransford & Pellegrino, 2000; Donovan & Bransford, in preparation), and is co-chairing a National Academy of Education Report (with Linda Darling Hammond) on teacher knowledge. He is a member of Microsoft's International Advisory Board for Learning.

PI Kuhl has extensive experience managing large inter-institutional research groups, as Co-PI of a \$15M Consortium funded by The Santa Fe Institute that unites brain and behavioral research at four institutions, and as PI of an international research consortium funded by the Human Frontiers Science Program to integrate research in four countries. She is founding Co-Director of the Institute

for Learning and Brain Sciences (along with Co-Director **Meltzoff**). This Institute has faculty affiliates across the Colleges of Medicine, Arts & Sciences, Education, and Engineering & Computer Science, and has multiple international students and collaborators. Kuhl has played a lead national role in disseminating scientific findings on childhood learning and brain development at two White House conferences.

PI Meltzoff has served as PI/Co-PI on federal research grants totaling approximately \$12M. Meltzoff was PI and director of an interdisciplinary 10-year NIH Pre- and Postdoctoral Training grant, including faculty and trainees from the School of Medicine and Arts & Sciences. Meltzoff serves as a Board Director of the Foundation for Early Learning and is a member of the Program Committee that oversees expenditures for research, outreach, and teaching. He served on the Board of Directors of the University Child Development School, an independent school for students from pre-K to 5th grade.

PI Pea has extensive research management experience in working with large awards on STEM learning with technologies. His grants received as PI or Co-PI exceeded \$20Mil during the previous ten-year period. While at SRI International's Center for Technology in Learning (CTL), he developed strategic plans, grants, and new ventures in K-12 learning sciences and technologies and grew CTL from eight staff and \$1M per year in funding to 55 staff and \$10M per year, with many partnership projects engaging leading researchers and institutions throughout the U.S. He directs Stanford's Center for Innovations in Learning and a doctoral program in Learning Sciences and Technology Design.

PI Sabelli was Senior Program Director for the NSF Directorate for Education and Human Resources prior to joining SRI International. She worked for a decade to develop and procure funding for many NSF-wide and cross-agency initiatives on research, education, technology, and science, such as Learning and Intelligent Systems and Interagency Education Research Initiatives, and came to manage \$24M annually in research programs. While at the NSF, Sabelli worked on education issues at the Office of Science and Technology Policy, which serves as a source of scientific and technological analysis for the President on policies, plans, and programs of the Federal Government. Her research career as a computational chemist led to her vision of technology uses in science education and to her role in NCSA's pioneering educational programs before she came to NSF.

Strand Leader **Bell**'s research focuses on the design and study of classroom learning experiences that make use of novel learning technologies to promote an understanding of complex subject matter. He has conducted this design-based research in pre-college science and history classrooms. His second line of research examines the influence of pervasive technologies (e.g., mobile phones, instant messaging, chat) on the social learning practices and cognitive development of children and young adults. He has served as PI/Co-PI on federal research grants totaling over \$4.3Mil.

Strand Leader **Reeves** leads interdisciplinary teams that administer \$10M+ annually in research across university disciplines, and his research links to industry projects relevant to the LIFE Center. At Stanford, he is Director of the interdisciplinary Center for the Study of Language and Information (CSLI) and a Co-Founder of the Media X Program, described below. Reeves' prior relevant work includes pioneering the use of physiological assessment of human responses to interactive media, and work with successful start-up ventures on innovative new media relevant to entertainment and learning.

Strand Leader **Roschelle**'s research examines the design and classroom use of innovations that enable more people to learn complex and conceptually difficult ideas in mathematics and science. Persistent themes in his work are the study of collaboration in learning and the appropriate use of emerging technologies in education (e.g., simulations, component software, and wireless handhelds).

Strand leader **Schwartz** examines the role of visual representations in transfer, communication, and the development of advanced reasoning. His work combines laboratory, computer-modeling, and technology-driven classroom experiments. He has a pending NSF project with the Sackler

Institute on the neurological basis of alpha-numeric learning that involves the use of technological interventions in after-school settings.

Strand Leader **Stevens**' research compares how people learn and think in everyday settings (such as classrooms, workplaces, and museums), focusing on how people learn to interpret and represent the world in discipline-specific ways. His studies of learning, technology use, and interaction combine participant observation, video analysis, and video-based elicited interviews. He designed a widely-used collaborative digital annotation medium (VideoTraces) that supports new ways of reflection and assessment. He has served as PI/Co-PI on federal research grants totaling over \$12.4Mil.

1.5.1 Other LIFE Researchers

Decety is an internationally known neuroscientist with extensive experience with brain imaging techniques, particularly functional magnetic imaging. **Imada** is an internationally known expert in magnetoencephalography who has applied the technique to visual and auditory information processing by the brain. **Rao** is a computer scientist whose prior work focuses on deriving algorithms for learning from rigorous statistical principles and who works in robotic learning and human-robot interactions. **Rivera-Gaxiola** is a neurobiologist with expertise in electroencephalographic measures that can be safely used from infancy to adulthood to study brain activation.

Barron's research focuses on collaborative learning, learning ecologies that include technology, and equity in the development of technological fluency. **Goldman**'s work focuses on anthropology and education, mathematics education, qualitative research methods, and technology in teaching and learning. **Nasir** work in the areas of access and equity in mathematics education, studying how adolescent and cultural identities shape math practices for inner city youth.

Bassok's research examines how people understand mathematical situations and transfer their understanding to analogous problems. **McCutchen**'s research has examined how linguistic and content knowledge—frequently acquired via implicit or informal means—influences literacy acquisition in formal school settings. **Herrenkohl**'s research focuses on children's social and cognitive development in educational settings, and understanding what makes educational environments more inviting and engaging. **Atman, Adams and Turns** are the leadership team of the UW's Center for Engineering Learning and Teaching. They take multiple approaches to understanding engineering student learning and methods to bring research into practice. A specific research focus is on engineering design processes.

1.5.2 PI's Relevant Prior Awards

We show here the few most relevant large research awards made to the PIs, to document their management and leadership expertise. The results of this work, and of the many grants received by the PIs, Strand Leaders, and other researchers, appear as references to published work in the appropriate section of the text.

PI Bransford's most relevant awards for this proposal are: (1) *Teachable Agents: Computer Environments for Supporting High Achievement in Science and Mathematics* (with Gautam Biswas, and Daniel Schwartz: KDI-9873520-\$800,000) extended to a ongoing grant on (2) *Exploring the Value of Learning by Teaching* (with Daniel Schwartz, Nancy Vye & Gautam Biswas: REC-0231771, \$899, 812); (3) *The Challenge Zone: Using the Internet to Support High Standards in Mathematics and Science* (with Robert Sherwood and James Pellegrino: ESI-9618248, \$694,369).

PI Pea was from 1997 to 2002 Director and PI of (1) *The Center for Innovative Learning Technologies* (with J. **Bransford**, M. Linn, B. Means, R. Tinker; LIS CDA-9720384, (\$5,835,000). **PI Sabelli** has joined them for CILT's Achievement Based Renewal for 2002-2003, LIS-0124012 (\$1,679,930). Dr. Pea is PI on several research projects that create innovative software for digital video analysis and collaboration tools to be used for LIFE: (2) *A Digital Video Collaboratory to Integrate IT Innovations in Video Analysis, Sharing and Collaboration into Scientific Research Communities* ITR-0326497 (\$615,783); (3) *DIVER: Distributed Collaborative Analysis of Video*

Records in the Human Sciences REC-0234456 (\$97133); and (4) *Development of a High-Performance Digital Video Collaboratory (DVC) for Learning Sciences Research* BCS-0216334 (\$455,684).

PI Kuhl's most relevant awards for this proposal are: (1) *Increasing Human Potential* (with Co-PI John Mazziotta, funds a 4-institution collaborative project, The Santa Fe Institute, SFIC-W-01, \$2,467,200 current year), (2) *Developmental Speech Perception and Brain Plasticity* (PI, NIH-HD37954, \$1,855,559), (3) *The Bilingual Brain—Brain Plasticity Over the Lifespan* (PI, Human Frontiers Science Foundation, funds a 4-country collaboration, HF-0059, \$1,039,955).

PI Meltzoff's most relevant awards for this proposal are: (1) *Infant Imitation and the Understanding of Persons* (PI; NIH-HD22514-17, in its 17th year; current 5 yrs. as a MERIT award, \$1,558,260), (2) *Brain-Behavior Relations in Autism* (Co-PI with G. Dawson, NIH-HD35465, Project #1, \$1,477,704), (3) *Perceptual Development Pre- and Post-doctoral Training Grant* (PI; NIH-T32HD07391, \$1,944,930).

2.0 Literature Review

Note: Relevant research literature is integrated throughout the proposal.

3.0 LIFE Research

3.1 Research Strand 1: Implicit Learning and the Brain (I-LAB)

3.1.1 Why Use Brain Measures? An important feature of the LIFE proposal is the inclusion of a neuroscience component. LIFE investigators will use the tools of modern neuroscience to examine the footprints of learning in the brain, to see learning in progress, and to optimize the stimuli and sequences used in learning. Adding neuroscience to LIFE's study of learning in informal and formal settings will advance our understanding of human learning by grounding it in biology.

The addition of neuroscience is possible because the 1990's produced a revolution in our understanding of human cognitive abilities largely attributable to advances in neuroscientific techniques used to study the brain. Modern neuroscience has begun to document learning in an alive, awake brain, revealing the impact of experiential learning before it was observable in behavior.

These new measures of mental activity were quickly noted by educators. In 1996, the Education Commission of the States and the Dana Foundation held a conference entitled *Bridging the Gap Between Neuroscience and Education* which brought together leaders in the two fields (including PI Kuhl) (Denver Colorado, July 26-28 1996). The conference sparked a heated debate. The gap between the neuron and the chalkboard was acknowledged as substantial — many agreed it was perhaps a “bridge too far” — and scholarly articles and books resulted (Bruer, 1997, 1999 — who has agreed to chair LIFE's Advisory Board).

Policymakers instituted high-profile conferences to expose Congress, the Cabinet, and the public to the potential contribution of neuroscience to education. The first conference was convened by President and First Lady Clinton at the White House in 1997 — *What New Research on the Brain Tells Us About Our Youngest Children*. Six scientists (including PI Kuhl) were invited to the White House to speak. In 2001, President and First Lady Bush convened a second White House conference, *Early Childhood Cognitive Development*, focusing on learning, with special emphasis on literacy (including PI Kuhl). In the last six years, most of the 50 states convened their own “governors' conferences” bringing neuroscience to the attention of local policymakers and educators. Educators and neuroscientists had by now become familiar with sharing the podium, but little work was going on in the nation's laboratories to bring the two together.

Two facts bear on the LIFE Center. First, we are not naïve about the limitations of what brain studies have to offer the science of learning. Brain science will not, for example, generate a new math curriculum or tell us how to structure a high school student's day to optimize learning. Second, LIFE seeks to combine educators and neuroscientists to study learning across settings — and this will take work. We believe this work is critical. Cognitive neuroscience adds biology to the science of learning and will uncover basic principles of learning with broad applicability. Spanning

from the neuron to the chalkboard/workplace may have been a "bridge too far" in 1996; it may even be "too far" at the present snapshot in history, but our vision is that, over the next ten years, discoveries relating learning to the brain should and will impact our educational systems. This is where the science of learning is headed, and LIFE has a team with the capacity, training, and good will, to build the necessary bridges.

3.1.2 Theoretical Insights from Implicit Learning: Traditional research on learning often focuses on the results of explicit instruction — instruction that takes place in formal educational settings. The "Implicit Learning and the Brain" (I-LAB) Research Strand focuses its attention on *implicit learning* — learning that takes place automatically, whether people want it to or not (e.g., Greenwald & Banaji, 1995; Schacter, 1987). Prior work by I-LAB and other investigators indicates that the neural capacity for implicit learning is powerful and ubiquitous (Kuhl, 2000a). Implicit learning is especially potent in early childhood, where it may predominate (Meltzoff, 2002), but occurs throughout the lifespan. Implicit learning occurs without conscious attention, and is long lasting. Many argue that it is highly adaptive and produces excellent transfer. These assumptions about transfer for implicit learning will be examined by members of LIFE's other two strands in the context of formal and informal learning — and will likely produce a fruitful "conceptual collision." Overall, work in the I-LAB Strand seeks to uncover the fundamental principles of implicit learning, with the belief that natural/effortless learning, based on how brains evolved to learn, strongly biases learning in both informal and formal settings.

Several principles from the I-LAB neuroscience group are relevant to the LIFE Center work as a whole. We briefly describe these principles, and then show how they motivate I-LAB Strand research.

(1) Learning is computational. Infants, children and adults (and animals as well) are strongly affected by the distributional frequency and probabilistic nature of their experiences (Goodsitt et al., 1993; Saffron et al., 1996; Gallistel, 1999). Statistical learning offers an alternative to the classic notion of the critical period as to why learning is more successful in early development than later life. In this view, critical periods are governed as much by experience as time. There are not strict maturationally-determined windows for learning. The new idea based on statistical learning is that once we have experienced a large variety of information regarding a category or event, additional new stimuli do not affect the underlying statistical distribution. In order to change an underlying distribution, a massive number of instances have to "go against the grain," that is, fall outside one's normal experience. For example, to learn a second language or reverse a social stereotype (e.g., that blondes are academically challenged), a large number of counter-instances must occur to alter the underlying distribution. This principle may help explain why it is difficult later in life (but not early in life, when statistical distributions contain relatively few instances) to learn a new language, reverse a stereotype, or give up one's pet theory (Kuhl, 2000b). Understanding how our perceptions, concepts, and theories change with our distribution of experiences will advance our understanding of how people learn over their life span.

(2) Learning produces neural commitment to the properties of the stimuli we see and hear. Exposure to a specific data set alters the brain by establishing neural connections that "commit" the brain to processing information in an ideal way for that particular input (e.g., one's first language but not for other languages). Detailed experiments have shown that *neural commitment* functions as a kind of "filter" that affects future processing (Kuhl, 1991; Kuhl et al. 1992; Näätänen et al., 1997). This results in highly efficient processing of learned material (Zhang et al., 2003). The most well studied example is language, but it is only one of many examples. In language, our neural filters affect processing at all levels, from phoneme to grammar, making native-language processing highly efficient and foreign-language processing nearly impossible in adults (Strange, 1995). Neural filters focus our attention on the relevant features, increasing efficiency. However, this precision comes at a cost. We are no longer as open to new language learning as we were as young children. Learning *from* experience causes brain changes that lead us *to* experience in a particular way. Broadening this discussion to the overall study of LIFE learning, the neural commitment concept can be thought of

as a neural instantiation of “expertise” in any domain. Expertise in many areas may reflect these kinds of filters on our experience — filters that focus our attention, and structure perception and thought, so that we work more efficiently, while also limiting our abilities to do things in completely novel ways. Learning algebraic principles or mastering the scientific method also changes our filters (our concepts and theories), leading us to perceive the world in a new way. This learning alters the brain’s future processing of information. A fundamental question relevant to all of LIFE’s strands is how the brain can form neural commitments while simultaneously remaining open for adaptive change. This is a fundamental issue relevant to ideas such as the differences between “routine expertise” and what Hatano (1990) calls “adaptive expertise,” and is highly relevant to all of LIFE’s work.

(3) Social interaction enhances learning. A variety of studies suggest that people learn more readily and efficiently when engaged in real social interactions than when in artificial, media-driven settings. One reason social environments may enhance learning is that real social interactions provide more complex and variable training that (nonetheless) highlights the critical parameters necessary in mastering a task. Initial learning that takes into account the full complexity of situations seems likely to improve transfer and generalization, but there is also evidence in the cognitive literature that too much complexity can make initial learning more difficult (e.g. Bransford & Nitsch, 1978; Simon & Bjork, 2002). Appropriate social interactions may help reduce complexity to manageable proportions. For example, the idea that statistical learning and social learning are both operating may appear to be contradictory, but the combination of a “computational brain” that computes statistical patterns along with a “social brain” that provides constraints on learning may explain how humans evolved to ensure that learning focused on what was important in their environments. An unchecked computational brain would have been overly sensitive to the ever-changing contingencies in the world, indiscriminately calculating all events — an inefficient and time-consuming activity for the brain. If social interaction placed constraints on random statistical learning, it would have allowed the brain to focus on gathering statistical data when social cues indicated relevance. In other words, a social constraint would have enhanced learning speed and efficiency over blind calculations (Kuhl, 2003).

(4) Complexity and variability, not “stripped down” stimuli, enhance learning. Variable stimuli provide a wider range of instances to the novice learner, which in turn improves transfer of learning to novel situations. Studies show that initial learning with a complex stimulus results in more effective learning and transfer than learning with a simple idealized stimulus. Many more experiments need to be conducted to understand why this is the case. One idea is that setting our “cognitive filters” may rely on statistical principles; that is, learners may require optimum variability, a diversity of input that covers the full range they will eventually experience, in order to show transfer of learning. Of interest will be how age and experience affects the need for a rich, complex stimulus as opposed to a more stripped-down stimulus. Our hypothesis is that with age and/or experience the need for a rich stimulus is reduced because people develop mental models that allow them to operate on less information — their brains “fill in” the missing information. On the other hand, this returns us to the issue of how people can learn to process efficiently and remain flexibly adaptive in new settings. An important point for guiding our research is that learning is not identical at all points in time. I-LAB investigators will examine learning across the lifespan, highlighting transitions between: early learning (which is largely informal and implicit), learning in K-12 settings (more formal and explicit), and learning in adulthood.

3.1.3 Research Theme 1: Implicit Learning and the Social Brain

Experimental question. The brain’s ability to learn implicitly is powerful and ubiquitous, yet new data indicate sharp differences in implicit learning when it occurs “live” versus through media. Why is learning enhanced in the presence of a socially interactive human being? Findings from this line of research may help in the design of machine-based learning programs[RP1].

Approaches taken. Work by I-LAB investigators in the first year will focus on the domains of language and social cognition. New research shows that infants readily learn a new language from

live social interaction but not from DVDs (Kuhl et al., 2003). We will examine the learning of foreign languages across the lifespan using brain and behavioral measures, with stimulus presentations from live human beings, DVDs and other digital media. The focus will be on Spanish (USA's the fastest-growing language group), Chinese (the world's largest language group), and English (the language used internationally in business and government). Kuhl's collaborators in China and Taiwan will conduct parallel studies in English learners in these two countries. Major projects are now underway between the U.S. and China to create games that teach English, efforts connected to LIFE investigators. Another line of studies will examine the power of the social brain using observational learning and imitation. In 1996, neuroscientists discovered *mirror neurons* (Rizzolatti, et al., 1996) that fire for both the execution and observation of an action. This discovery ignited interest in the neural bases of imitation and social understanding (e.g., Blakemore & Decety, 2001; Frith & Wolpert, 2003), and suggests neural grounding not only for imitative learning but also for empathy, intersubjectivity, and understanding the commonality between self and other (Gallese, 2003; Iacoboni et al., 1999; Meltzoff & Decety, 2003; Meltzoff & Prinz, 2002). We will conduct studies examining the neural bases of imitation in adults using fMRI techniques, including direct motor imitation and tasks where the observer infers the actor's goals and intentions. Once the neural systems involved in imitation have been identified, further work will extend to perspective taking and other theory-of-mind tasks involving reasoning and understanding about the beliefs, emotions, and intentions of others, and the role that mirror neurons may play in language and communication.

3.1.4 Research Theme 2: Impact of Real vs. Simulated Stimuli on Learning

Experimental question. What are the psychological and brain reactions to “actual” versus “simulated” stimuli, and where is the threshold between them? Research by I-LAB investigators and others suggests that the naturalness of the stimulus impacts learning and transfer. Basic research is needed on the continuum between real and simulated and its impact on learning and the brain.

Approaches taken. Experiments are planned using brain and physiological measures as we systematically vary face/voice and motor actions using state-of-the art technology to create test stimuli. In one set of studies we will explore perceived naturalness and speech understanding using Massaro's animated talking head (called “Baldi”). Baldi's facial and articulatory movements can be altered systematically and will be compared with real human speakers. Speech synthesis will be used to alter the naturalness of the voice. Both the facial features of the talking head and the vocal stimuli will be manipulated from a monotone, unanimated machine-like face/voice to a facially and vocally animated natural face/voice. In the same vein, a second set of studies will explore the brain's reaction to a hand that varies along a real-simulated continuum with respect both to its physical appearance and to the actions it performs, ranging from mere physical movements to intentional goal-directed actions (Perani et al., 2001). Further studies concern the influence of television on children, investigating their learning via television as compared to live interaction (e.g., Meltzoff, 1988). We will also explore interactive media and other state-of-the art technologies in language and other learning to see whether altered contingencies affect learning. Taken together, this research explores our attributions of humanness, agency, and intentionality to a stimulus and how this affects learning (e.g., Meltzoff, 1995; Reeves & Nass, 1996). In all cases we will explore top-down influences — expectations, instructions, and point of view — on the way the stimuli are interpreted. Such studies have practical value in the creation of learning environments that elicit response from the “social brain.”

3.1.5 Research Theme 3: Simplicity, Complexity and the Formation of “Mental Filters”

Experimental Question: What kinds of data sets optimize learning and transfer, and why? Both simplicity and complexity can be shown to assist learning — what drives the balance that optimizes learning and especially transfer? How do we form *mental filters* that are both efficient and flexible?

Approaches taken: The concept of mental sets or filters — how they are acquired and ways to modify them — is a theme that pervades work in the LIFE Center. They can be studied in a variety of learning settings, from language learning and visual categorization tasks (Strand 1) to biological taxonomies and popular games (Strand 2), to academically oriented technology that teaches

mathematical concepts (Strand 3). The simplicity/complexity theme is a candidate Signature Project (see Section 4.1). Work in the I-LAB strand on the efficiency/flexibility trade-offs for learning will focus on communicative interchanges that aim either to teach language or simply to communicate a message, and capitalizes on previous work of I-LAB investigators (Kuhl et al., 1997, Kuhl et al., 2001). Communicative interchanges are relevant to learning in a variety of settings. The approach adopted here examines how learners comprehend linguistic messages using computer-synthesized utterances that vary in simplicity (the degree of separation between the instances representing the to-be-learned categories) and complexity (the variability and overlap between categories). Learning and transfer will be assessed with both behavioral and brain measures using novel data sets. The test subjects in these initial experiments will vary from expert listeners (pilots who have to contend with messages delivered by a variety of talkers, i.e., responding to air traffic controllers), to infants and children listening to a new language. The hypothesis is that simplicity and complexity serve a common goal, to maximize the statistical separation of the items to be learned/understood while providing learners with a true representation of real-world variability. Optimizing learning may involve understanding these basic principles. LIFE investigators approach the simplicity/complexity issue using a variety of theories and approaches; it may be one of our earliest conceptual collisions.

3.1.6 Research Theme 4: Learning, Games, and the Brain

Experimental question. Videogames are an economic force and a growing part of childhood socialization. How do they affect the learner? An understanding of the neural processes linked to interactive media will help maximize the design of effective games for learning and provide a window into how game use influences users.

Approaches taken. The research proposed here links directly to “Games as Research Environments” (see Signature Projects, Section 4.2) and will likely involve collaboration across all three Research Strands, with Strand-1 providing an experimental framework for neuro- and physiological measures. Toward that goal, research in Strand 1 envisions a series of studies involving both functional magnetic resonance imaging (fMRI) and physiological assessments (skin conductance levels and responses, and heart rate acceleration and deceleration) that can be linked with game-play. Examples of game features of interest include: (a) variations in the emotional content of the material and (b) physical parameters of interactivity including speed of exchanges, range of choices in the interaction, and vividness of the media stimuli (see Reeves & Nass, 1996, for an analysis of critical parameters of interactive realism). A caveat is that commercially available games often require motor responses that are correlated with the type of game activity, and these motor actions themselves affect the neuroscience measures. In order to overcome this, we will develop new MRI-compatible games involving short visual sequences and controlled motor responses. A more ambitious effort will be to build a virtual reality presentation system that allows us to control the sounds and images used to present game play that will be compatible with the magnetic properties of fMRI technology (see Hoffman, et al., 2003, for one successful effort). Finally, we will compare game play against a computer vs. another person (with interactivity controlled). In some conditions subjects are instructed that their opponent is a human whereas in others that it is a computer. The prediction is that conceiving of the game as involving a person will recruit specific brain areas (Gallagher & Frith, 2003). Brain studies provide measures that may be useful for designing games that assist learning (e.g., Green & Bavelier, 2003); results from this program will feed into and be enhanced by the work in the other two Research Strands and the Signature Project described in Section 4.2.

3.2 Research Strand 2: Informal Learning

3.2.1 Why Focus on Informal Learning? Just as the last two decades of research on learning in formal contexts have reshaped our understanding of human cognition and influenced educational practices (NRC, 2000), a program of research focused on *learning in informal settings* can be similarly transformative in the coming decades. Our work builds on foundational studies at the intersection of cognition and culture (e.g., Cole, 1996; Goodwin, 1994, 1995, 2000; Inagaki &

Hatano, 2002; Hutchins, 1996; Lave, 1988; Ochs et al., 1992; Resnick, 1988; Rogoff & Lave, 1984; Rogoff et al., 2003; Scribner, 1984; Stevens, 2000; Stevens & Hall, 1998). It is noteworthy that the learning sciences have contradictory perspectives concerning the nature, effects and value of informal learning for STEM subject-matter learning (e.g., Smith, diSessa, & Roschelle, 1993). Informal learning has been championed as a romantic alternative to schools, where productive proto-forms of STEM knowledge can develop with minimal effort. An opposing perspective argues that informal learning leads people to form naïve and misconceived ideas at odds with STEM disciplinary knowledge (e.g., Driver et al., 1985).

A related issue centers on the long-standing challenges of transfer—an issue of fundamental importance to all three of LIFE’s strands (e.g., Bransford & Schwartz, 1999; Pea, 1987). Some argue that informal learning produces ungeneralizable knowledge, with people able only to solve problems specific to a local situation, group or cultural niche (Anderson et al., 1996). Others argue that schools produce ungeneralizable knowledge, equipping people to “do school,” subject by subject and chapter by chapter, suffering once they transition from school/university to the unstructured, messy problems encountered in work and life (Brown et al., 1989; Greeno, 1998; Lave, 1988). Another contrast concerns views of informal learning opportunities as the wellspring of new knowledge and productive cultural developments, especially among young people (e.g., Gee, 2003), or as problematical conveyors of contemporary popular culture (e.g., Elkind, 2001). These and other open questions about informal learning argue for a sustained program of research in this area, and set the stage for exciting conceptual collisions (as well as synergies) with the other strands.

Even if one believes that STEM knowledge requires formal education in order to be developed effectively, recall that young people spend 53% of their time engaged in non-school activities, compared to 14% of their time in school (NRC, 2000; Carnegie Corporation, 1992). To understand and facilitate the extended STEM learning, we must understand with specificity the resources that young people bring to school from these informal activities as well as how school-based knowledge is utilized to further informal learning. Work on leveraging the cultural “funds of knowledge” that people develop from their learning contexts outside school is highly relevant to our goals (e.g., Brice-Heath, 1983; Lee, 1995; Moll et al., 1993).

3.2.2 Overview of Strand 2 Research. We propose to study basic processes of informal learning through an integrated program of research across multiple settings relevant to STEM learning, where children and adults learn by working, playing and organizing their daily lives—without structured educational interventions. This work is highly relevant to the work in both Strands 1 and 3. For example, the design endeavors of Strand 3 require analysis of what it is important for students to know and be able to do once they leave school (e.g., Wiggins & McTighe, 1997; Marshall & Tucker, 1993; Partnership for 21st Century Skills, 2003; Reich, 2002). Directly relevant to this is Strand 2 research on transitions from school to the workplace, and research on how people adopt, adapt and invent tools and social practices that help them “work smart.” Our program of research is organized to address two related questions concerning informal learning experiences: one involving youth, the second focusing on adults.

3.2.3 Research Question 1: What are the technological, mathematical, and scientific competencies and dispositions that young people develop in informal contexts?

We propose to systematically extend prior work on informal learning on this question in three interrelated analytic dimensions: context, content, and process. Our first research goal is to identify *exceptional informal contexts* in which young people are in control of advancing their own substantial new knowledge and forms of participation in activities, especially where there are substantive and likely bridges to STEM disciplinary knowledge and communities. As with any field-based scientific discipline, we need to understand the distribution of “ecological niches” in which children are most actively engaged, and study how the problems arising in these non-school settings make new knowledge necessary and certain kinds of thinking and action adaptive. We also know that these distributions vary widely by gender, ethnicity and socio-economic status, and believe that understanding this variation will be important for developing more equitable learning environments.

To identify these exceptional contexts we will study, we will create a nationally publicized website for parents to share descriptions of their children's activities and the exceptional learning that occurs therein. Parents are in the best position to help us identify these productive contexts for children. Across a wide sample of these descriptions by parents, we should have clear contexts to begin our research. By closely examining these contexts, we will document the *content* of what is learned and the *processes* by which it is learned.

What conditions do these self-motivated learners assemble to advance what they are able to know and to do? Examples of *processes* to be studied include: imitation of successful action patterns (linking to Strand 1); leveraging friendships, family ties, mentors and other relationships for learning by sharing interests, knowledge, commitment, and attention; taking advantage of socially safe contexts for sustained practice and incremental refinement of performance; and accessing social and technological supports in completing tasks too complex for one to achieve alone. Children also collaborate in sophisticated social arrangements to pursue their projects and interests (e.g., as they learn to play competitive sports or participate in on-line video games). The kinds of social arrangements that children prefer and that emerge from their interactions is important both for increasing the range of social interactions studied in the I-LAB strand and for understanding ways to generate designs for learning that enable all to succeed (Strand 3).

Our approach to Question 1 is to conduct *context studies* in a range of field settings that we expect to be consequential to STEM learning in the foreseeable future and where exceptional learning is taking place. In these investigations, we seek to understand how people advance their own learning by assembling and orchestrating different "learning configurations," i.e., uses of social resources, symbolic systems (including texts, new media), computing/communication tools, and physical artifacts. Our approach is broadly ecological (Stevens, 1999, 2000a, 2000b, Barron, to appear) in the sense that we regard socio-cultural contexts as presenting a) redundant situations that create common problems and b) clusters of conventionalized material and social resources with which to solve these problems. Our goal is to understand the problems that these contexts present and how learners assemble configurations of resources in both collective and idiosyncratic ways to resolve them. This work is especially relevant to Strand 3's emphasis on the importance of "quasi repetitive activity cycles" and the use of them to create educational designs that help people learn to "work smart."

We will select contexts for our research to address Question 1 in three thematic areas: (1) Technological Fluencies and Digital Literacies, (2) Science Inquiries, and (3) Mathematical Practices. Prior research leads us to expect that the contexts we select will *not* cleanly divide between these themes (e.g., not technology *or* math, but technology *and* math); this interdisciplinarity is a characteristic feature of learning and cognition in informal settings. However, we will select contexts in which we expect one or another of the themes to be dominant and therefore most strategically studied.

(1) Technological Fluencies and Digital Literacies. New technologies are rapidly changing people's abilities to learn informally through continual access to distributed resources and networks of peers who share interests and can offer expertise whether at home, school, in community contexts, or on-line. The term "technological fluency" was defined in a recent NRC report (1999) as the ability of people to use technology for expressive purposes, to reformulate and generate new knowledge, to constantly adapt to change, and to organize their use of technology to enhance both work and personal life. How are youth using new technologies to learn for their purposes? How do emerging technological fluencies provide young people access to informal learning opportunities in their communities and homes? Our research will investigate learning contexts supporting the development of technological fluency and digital literacy as youth use such new technologies as creative and communicative tools (video production, blogging, musical composition, robotics, instant messaging) or as sources of entertainment (e.g., games). We have chosen these activity contexts as they are highly motivating for youth and likely to offer unique insights about the self-initiated learning of this new generation of learners. Our studies will also document trajectories of

learning between informal and formal contexts—e.g., when an interest in game-playing leads to the decision to take programming in high school (Barron, Martin, & Roberts, 2001), or when the dynamic mathematic representations of a computer game are used as “funds of knowledge” when school algebra is encountered.

(2) Science Inquiries. Many reform efforts in science education have focused on supporting students in sustained, authentic inquiry as a means of promoting conceptual change toward valued scientific understanding (Bell, 2002, in press-a; Bell & Linn, 2000; Brown & Campione, 1994; Driver et al., 1996; Herrenkohl & Guerrero, 1998; Hawkins & Pea, 1987; Linn, Davis & Bell, in press; Pea et al., 1997; Reiser et al., 2001). Most often, these efforts have only indirectly taken into account the influence of children’s informal experience, knowledge, and practices (for exceptions: Chi & Koeske, 1983; Hatano, 1990). Better theoretical and empirical accounts of processes by which children engage in substantive inquiry into their personal interests and hobbies hold important insights for educating students in science — while also providing fundamental insights into informal learning processes. With a rotating focus on particular science content, we will study the learning configurations associated with children’s knowledge of subject matter and of intellectual inquiry as it develops across their activities. Our research will first focus on contexts influencing young children’s knowledge of biological systems and related forms of thinking, including understanding characteristics of specific plant species and conditions of growth developed through gardening activities or engagement with mass media, as well as dimensions of taxonomic thinking that result from the extensive play of games like Pokémon (Lavin et al., 2001), which have parallels to biological classification systems and concepts. This research will extend foundational work on children’s biological understanding (Carey, 1985; Inagaki & Hatano, 2002) by examining contemporary influences on children’s biological conceptual development. It is also the case that children encounter radically different images of scientific inquiry in their informal/formal settings (e.g., structured logical inquiry in science class, fantastic and whirlwind accounts of scientific breakthroughs in popular culture; Bell, in press-b; Bell & Linn, 2001; Hammer & Elby, 2003). Our context studies will document how children piece together an understanding of the nature of science from this multitude of discrepant images. Coordinated work with Strand 3 will explore the educational entailments of our insights.

(3) Mathematical Practices. Prior research in the learning sciences documents how participation by children and adults in non-schooled activities leads to development and use of important mathematical concepts and practices (e.g., Beach, 1995; Lave, 1988; Nunes et al., 1993; Saxe, 1991; Scribner, 1985; Nasir, 2000; Hall & Stevens, 1995; Stevens & Hall, 1999; Stevens, to appear). These capacities extend beyond the “intuitive, naïve mathematics” of basic whole-number addition and subtraction that Gelman (2001) argues is universally acquired. Building on our prior work, we will explore the wider distributions of mathematical activity in society at large and its consequential uses in young people’s activities. Some promising contexts for these studies across the years of the LIFE Center include children’s participation in games (our likely first year focus), sports, design, and consumer spending. Our studies will document how these contexts *generate* problems that need to be solved with mathematical tools (e.g., graphs, calculators) and concepts that provide occasions for just-in-time informal learning. We expect these studies to significantly expand our understanding of young people’s knowledge of ratio, direct proportion, probability, averages, and rate of change—typically untapped in schools. We will also study how these informal contexts engage the learning of mathematics in ways that appear different from schools, where motivating math learning is often seen as an intractable problem.

We plan a four-phase research strategy in our context studies, drawing on both naturalistic and quasi-experimental methods. First, we will collect ethnographic and video data to carefully analyze the organization of people’s activity (i.e., discourse and action; e.g., Barron, 2000, 2003) in representative contexts. Second, we will conduct elicited interviews (e.g., Stevens & Hall, 1997; Barron et al., 2003) using materials gathered in the field to explore hypotheses about youth experiences that emerge from our analyses of video-ethnographic data. Third, we will conduct

simulations of critical tasks identified in the two early phases of research (e.g., Scribner, 1985) to bring quasi-experimental methods to bear on our questions. Fourth, we will return to the field to see if our more well specified hypotheses about the content and processes of informal learning in particular contexts are confirmed or disconfirmed.

3.2.4 Research Question 2: What is the nature and degree of the mismatch between what is learned in school and what is needed in later occupational life?

This question arises from the nearly ubiquitous refrain from employers in our nation—and especially in scientific and technical professions—that people come to them woefully unprepared to do the work that needs to be done (e.g., Partnership for 21st Century Skills, 2003; CEO Forum). It is difficult to imagine the gap ever being wider in the past between the K-12 curriculum and the frontiers of STEM knowledge production, particularly for the increasingly complex knowledge work in engineering and the natural sciences. We will systematically study this mismatch between STEM education and workplace needs to gain an understanding of how knowledge work in school, at different grade levels, compares with knowledge work in the scientific and technical professions (Bell, in press; Lemke, 1992; Hall & Stevens, 1995; Stevens, 1998, 1999, 2000). Research in the field of science and technology studies (Biagioli, 1999; Hess, 1997) has provided a rich and challenging corpus of images of STEM work, but does not provide a parallel corpus of studies in educational settings, nor does it provide studies of transitions across the boundaries of school and work. Our research will provide us with more authentic and comprehensive images of STEM work that will be used to guide formal education efforts investigated in the Designs for Learning strand.

To address Question 2, we will conduct *transition studies* that will initially focus on engineering, in order to build upon current expertise and research underway as part of the NSF Center for the Advancement of Engineering Education (CAEE), the UW Center for Engineering Learning and Teaching (CELT), and the VaNTH Engineering Research Center. We will follow people across developmentally relevant institutional boundaries known from the learning sciences to pose significant problems for transfer of learning. We will study the continuities and discontinuities that are involved in making transitions from school to work, such as when a senior engineering student graduates and takes her or his first position in a firm, or a graduating computer science major takes a corporate programming job in a large collaborative design project. We seek to learn what resources people carry with them into new contexts and how these resources are adapted for the new context. We will also study what ways existing skills have *not* prepared people for the challenges—social and cognitive—that they face in new contexts. In subsequent years, we will expand our transition studies to natural science and other technical fields.

3.3 Research Strand 3: Design of Formal and Other Learning Environments

3.3.1 Why focus on linking theories of learning to principles of design? We noted earlier that most of the cognitive research on learning has taken place in either laboratory or school settings. A great deal has been accomplished, both theoretically and in terms of enhanced learning outcomes for students (e.g. Bransford, Brophy & Williams, 2000; Darling-Hammond, Bransford et. al, in preparation; Donovan & Bransford, in preparation; Harris, Bransford & Brophy, 2002; NRC, 2000; 2001; Schwartz, Martin, & Nasir, in press;). Nevertheless, we believe that opportunities exist to take work on designs for learning to a new level. Working on this proposal with LIFE's members has prompted us to look across all the strands in order to find issues that are fundamental to each of them. Several will be the focus of Strand 3 during the initial phases of LIFE.

3.3.2 Theoretical Issue 1: Theories and Measures of Transfer: We noted earlier that a fundamental cross-cutting issue involves theories and measures of transfer. The research plans for both Strands 1 and 2 discuss the importance of transfer and make assumptions about how to define and measure it. Transfer is an issue for productive conceptual collisions among strands.

One of Strand 3's major goals will be to conduct more detailed studies of an approach to transfer that was discussed in the introduction: namely, an approach that re-conceptualizes transfer as the degree to which people are well prepared for future learning (PFL transfer) as opposed to simply

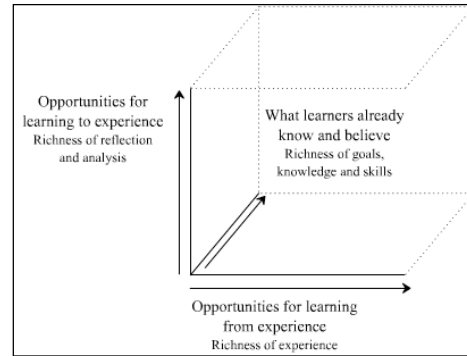
being prepared to directly apply what they have learned to new problems in a context of “sequestered problem solving” (SPS transfer — the kind used in the majority of all transfer studies since Thorndike et. al, 1901). In the introduction, we discussed some of the essential differences between SPS and PFL theories and measures of transfer. At one level, the differences seem simple. In the SPS case, evaluators do not want to “contaminate” estimations of learning by letting students have access to learning resources during a test, whereas in the PFL case, evaluators want to know if students are prepared to learn from resources provided during an assessment. If one plays out the implications of these differences, a number of ideas emerge that have the potential to change how the field thinks about, and measures, the effects of various educational experiences. As an example, there are long-standing arguments about the value of “discovery learning,” “hands-on learning,” “learning by design,” and other activity-rich environments (e.g. see Barron et. al, 1998; NRC, 2000). Some researchers and practitioners argue that these are typically a waste of time and less useful than direct instruction (see Boaler, 2002 for discussion). In some of our initial work on PFL transfer, we have found that the right combination of these two approaches (action vs. telling) can be more effective than either alone. For example, we have studied how opportunities for “hands-on explorations” of phenomena can be used to prepare students to learn from a well-organized lecture because they create “times for telling.” We have compared this kind of learning experience to other frequently-used instructional approaches like having students summarize a relevant text to prepare to learn from a lecture on the topic or spending twice as much time in hands-on exploration and missing the lecture. Across several different studies with different content, we found that students in “time for telling” conditions have shown evidence of learning and transfer that was markedly superior (Bransford & Schwartz, 1999; Schwartz, 1993; Schwartz and Bransford 1998).

Several pilot studies provide additional indications of the value of focusing on PFL transfer (Biswas et al., 2003; Schwartz & Martin, 2003). In each of the studies, one group completed intuitively compelling activities (e.g., teaching a computer agent, inventing solutions to statistical problems), whereas the other groups received “direct” instruction (e.g., being tutored by the computer, or hearing and practicing procedures). On SPS measures, the direct instruction groups look mildly better. However, on the PFL assessments, when students had resources like texts and worked examples to learn new relevant concepts, the “teach” and “invent” groups greatly outperformed the “direct instruction” groups. For example, given the same resources for learning, 9th-grade students learned to find and use standardized scores better than college students who had completed a semester of statistics. Had the studies only used SPS measures, the teaching and inventing activities would have merely seemed inefficient, and their value for future learning would have been overlooked.

Overall, PFL measures provide a new window for exploring the kinds of learning that best prepare students for life. Ultimately, they also have implications for rethinking the kinds of assessments used to certify people as graduates and professionals. An important focus for Strand 3 research involves experiments to test and extend the PFL approach to transfer. This research is important because it will provide a new set of measures for other work in Strand 3, for LIFE, and for the field in general.

3.3.3 Theoretical Issue 2: An Overarching Design Space Framework: A second cross-cutting issue involves the need to create an overarching “design space framework” (DSF) that helps learning scientists be much clearer about the “place” of their theories and experiments within a broader context of design possibilities. The need for such a framework has emerged as LIFE members discussed cross-strand ideas and hypotheses. The need also exists outside of LIFE. For example, within the past eight months, LIFE members have participated in workshops sponsored by a variety of different groups (e.g. the Learning Federation, Microsoft) that brought together people from the game and simulation industries, computer science, military, and learning sciences. There was great enthusiasm to communicate but also considerable difficulty. People tended to talk past one another because there was no systematic way to represent the different constellations of variables that were present (yet often invisible) in the many examples that people showed and discussed.

The DSF to be used in Strand 3 (and hopefully for LIFE in general) defines a 3D “problem space” of learning experiences. The horizontal dimension involves the richness of the available experiences. They might range from a verbal description, a video, or a simulation, to a real-life situation. Researchers who promote “learning from experience” or “hands-on” activities envision working on the far right of this dimension. Creating simulated experiences that mimic aspects of “live” interactive experiences is a goal for many technology applications built for fun and school; these reside just to the left of “actual experiences” on this dimension.



The vertical dimension involves activities that help people interpret, “capture”, represent and sometimes exaggerate their experiences. A discussion can highlight systematic principles of experience, and, further up the vertical dimension, may provide explanations. Technology can enhance the analysis of experiences by allowing people to capture and replay activities that can be analyzed and used to develop useful explanations and abstractions—including opportunities to see multiple perspectives on the same “captures” (e.g. Barron, 2003; CTGV, 1997, Schwartz, Brophy et al., 1999). Tools can also generate useful abstractions. Overall, opportunities for richer analyses and explanations can help people learn *to* experience more deeply, which, in turn, can affect what they learn *from* experience. The perceptual learning and expertise literature indicates the powerful role of new knowledge for noticing, which, in turn, affects what one learns (e.g., Bransford, Franks, et. al, 1989; Chi et. al, 1991; Garner, 1974; Gibson & Gibson, 1955; Hanson, 1970; NRC, 2000). Many educational environments (e.g. “hands-on laboratories,” “internships,” etc.) are high on the “experience” dimension but low on the vertical “interpretation” dimension—and there is evidence that this hurts transfer (e.g., NRC, 2000). The third axis of the framework considers the knowledge, attitudes, identities, and goals that people bring to a learning situation. People with relevant expertise often learn from a minimum of description (e.g. Bransford & Johnson, 1972; Sharp et. al, 1995). In contrast, novices may need high-fidelity experiences with interactive opportunities to “bump up against the world” and receive feedback (e.g., Barron et. al, 1998; Black et. al, 1998; CTGV, 2000). Also important are people’s learning goals, like engaging in an activity for its own sake versus getting ready for a “high stakes” task (e.g., teaching a class, a job interview, military combat; Barron et. al, 1998; Biswas et. al, 2001; Bransford, 2003a; Chatham & Braddock, 2001). People’s preconceptions and goals can sometimes interfere with new learning, so variables along the third axis can have both positive and negative effects on what one learns (Luchins, 1942; NRC, 2000; Singley & Anderson, 1989). Strand 3’s emphasis on transfer (especially PFL) and the 3D framework frame the research activities discussed next.

3.3.4 Research Theme 1: Validating and Extending the PFL Approach to Assessment: We noted earlier that several studies provide strong evidence for the fruitfulness of looking at PFL measures of transfer. Strand 3 research will conduct studies that focus explicitly on STEM-relevant content and will be more extensive than those conducted so far. The general design will involve: (a) pretests; (b) “high quality” versus “traditional” instruction; (c) SPS measures (which will probably not differentiate between groups); and (d) PFL measures. At least two studies will be conducted: one at the college level (in Engineering or Bioengineering) and one at the K-12 level (in science). The instruction and assessments will be vetted with content and assessment experts both within and outside of LIFE. The goal is to obtain broad agreement that the studies are fair and useful tests of the PFL hypothesis. This process is important for the LIFE Center, and the field, to develop new ways to measure the results of their work.

3.3.5 Research Theme 2: Exploring the DSF with an Emphasis on the Vertical Dimension: Strand 3 will conduct studies that explore STEM-relevant learning to help clarify and test the DSF. Our goal is not to systematically explore every possible combination of levels in the

framework—there are too many. We will choose points in the framework that allow us to explore the hypothesis that many basic assumptions about learning and instruction (e.g., “hands-on learning is preferable”) tend to be incomplete and often are high on only one or two of the dimensions in our framework. We will study whether and how learning and transfer (especially PFL transfer) can be optimized when their 3D potentials are maximized.

The first set of studies will focus on the importance of the DSF’s vertical dimension (interpretation of experiences). We will begin by extending the findings of Judd’s (1908) classic experiment on transfer (for a replication see Hendrickson & Schroeder, 1941) to STEM-relevant hands-on activities such as engineering or science laboratories. Participants in Judd’s study practiced throwing darts at a submerged target, hence their experiences on the horizontal axis were “rich.” Half the students received the “experience only” condition. The other half additionally received explanations about the visual displacement of the target. This “explanation” group falls on the “rich” part of the interpretive dimension, whereas the experience-only group falls in the “lean” part. The explanation did not help students’ initial attempts to learn to hit the target; both groups learned by trial and error. However, the explanation did affect transfer as measured by students’ abilities to learn to hit new targets at different water depths. It is noteworthy that Judd’s transfer measure is one of a few in the literature that fits a PFL model; it measured new learning under conditions of feedback rather than simply testing attempts to apply existing knowledge in an SPS (no resources nor feedback) condition.

Ongoing work by LIFE members with partnering Engineering and Bioengineering Centers, and with K-12 schools, indicates that many labs are similar to Judd’s high experience/low interpretation condition. Even when lab instructors give lectures before going to the lab, our argument is that students often are not prepared to understand the significance of the lecture (Schwartz & Bransford, 1998). We will use these laboratory experience as our “control” conditions and assess the value - added for learning and transfer when opportunities for explanation accompany or follow lab experiences. Effects on SPS and PFL transfer will be assessed.

Another variation on the vertical dimension will examine how social interactions help people learn to experience. For example, we have found that social interactions lead to more structured representations (Roschelle, 1992; Schwartz, 1995), and that group members who respond to one another’s suggestions transfer their learning as a group and individually more successfully than groups that tend to ignore one another’s correct bids (Barron, 2003). Our studies will examine how different kinds of task and technology support for social interactions (e.g., with scaffolds for articulating and “making visible” students ongoing discussions) prepare them for future learning—in part by preparing them to notice more about subsequent rich experiential environments (e.g. Michael et. al, 1993).

3.36 Exploring the DSF with a Special Emphasis on Dimension 3: These studies will examine the knowledge and belief dimension, in part by manipulating “learning sets.” For example, we have found that preparations for a public performance or a subsequent project led to superior learning (Barron et al., 1998; Biswas et al., 2001; CTGV, 1997). In these studies, we will leverage but extend our Teachable Agent project funded by NSF (a collaborative grant with Stanford, UW, & Vanderbilt). A teachable agent (TA) is a software agent that students teach using standard representational tools (e.g., concept maps, equations, truth tables, diagrams). Students test their TA and then remediate its knowledge (and their own) based on how well it performs. We will compare students who simply use a TA interface as a representational tool (we will turn off the “agent” properties) to prepare themselves for a private or public assessment, with students who prepare a TA to either take a private or public assessment at the front of the class (on a screen). The orientation to prepare a TA to take a public test should lead students to develop the most comprehensive understanding. Not only is there a high-stakes performance, but students also have to formulate their knowledge so that the agent can reason effectively without the benefit of the “situational smarts” that students might otherwise use to “wriggle through” their own public assessment.

3.37 Exploring the DSF with a Special Emphasis on Dimension 1: Studies in this section will emphasize the “richness of experience” dimension, which can be viewed as ranging from language to virtual to “actual experiences.” We plan to conduct several studies comparing real vs. simulated experiences, taking the work of the other strands on everyday uses of representational tools and media into the classroom to see if the effects hold in this “statistically noisy” context (e.g., people do not homogeneously self-select into classrooms as they do in most informal settings).

An especially important set of studies will examine the cyclical nature of learning from experience. Our previous work (e.g., Bransford, Zech et al., 1999; Schwartz, et. al, 1999; CTGV, 2000), plus studies of informal learning, suggest that there are some very important aspects of the “richness of experiences” dimension in DSF that are often overlooked. For example, project curricula often encourage students to work in a relatively linear manner until the project is completed—at this point the project (or class) ends. One can think of this as a “one-shot” project. In contrast, many environments (e.g., workplaces) have frequent “quasi-repetitive activity cycles” (e.g, see Bransford, 2003-a, b and research cited under Strand 2). The cyclical nature of events makes it meaningful and useful to find ways to improve “the next time around.” These attempts to improve include developing tools and social practices for working smarter—and this is a powerful way to enhance PFL transfer.

We will study “working smart” environments in STEM-relevant areas in both K-12 and college (bioengineering or engineering) environments. For example, in our first design, PFL transfer tests will provide an overview of a problem that students will need to solve and give them time to prepare. We will compare groups of students who will have had prior experiences with at least three activity cycles that allow them to learn to use and modify tools with students who will have spent the same amount of time using tools in the context of doing a typical one-shot project. Data will explore the degree to which—on the transfer test—students prepare by seeking to modify the tools they used earlier as well as invent new ones that will help them work smart on the transfer task. Another line of work in this area will involve attempts to integrate the literature on modeling to enhance science and mathematics learning (much of it funded by NSF with ideas about PFL transfer and the DSF. Members of Strand 3 (especially Jeremy Rochelle) have done a great deal of modeling work in this area (e.g., Roschelle & Jackiw, in press). The NSF Center for Innovative Learning Technologies (CILT.org) has also developed a set of design principles that we believe complement but will be extended by the current emphasis on PFL transfer and the DSF. Analyzing the conceptual collisions and synergies among these different perspectives appears to be a fruitful way to progress towards a more integrated science of learning and design.

3.3.8 Helping Develop LIFE’s First Signature Project: Another major project for Year 1 involves leadership in helping shape LIFE’s first Signature Project. The project will involve extensive input from all three strands, but will ultimately require a “designed environment” that Strand 2 will help build in order to allow LIFE to explicitly study important issues (see below).

4.0 Candidate Signature Projects for LIFE’s Inter-Strand Research Collaboration

We have previously noted that LIFE research ranges across several different and largely distinct intellectual traditions. This is a great strength, but it presents the typical challenge of interdisciplinary collaboration. As described earlier, LIFE designed a set of activities that promote cross-talk among our three Research Strands as well as with the field as a whole (Conceptual Collisions and Hot Topic workshops). The capstones of these efforts are the Signature Projects. Below we describe three candidates currently being discussed.

4.1 Signature Project Candidate #1: Simplicity vs. Complexity in Learning Environments

What optimizes initial learning and transfer of learning to novel domains? Both simplicity and complexity are heralded as important components. Like our contrasting proverbs above, neither tells the whole story, and each may be true under certain conditions. Each of the research traditions in LIFE provides a valuable but different perspective on how simplicity/complexity affects the nature of learning, and makes this topic a potential Year-1 Signature Project.

In formal educational settings (and in much of the cognition and technology literature), simplification is often handled by a “decomposition” strategy, in which things to be learned are arranged into smaller-sized chunks than the task itself. Bruner (1960) made the provocative argument that any concept could be taught with some degree of fidelity at any age, but his arguments are often misinterpreted. Curricula that are supposedly based on his ideas are often organized into small units that, once mastered, are designed to act as building blocks for later mastery of more complex skills and concepts. At one level, this seems so obviously necessary that it tends to be accepted without question. Students are unlikely to succeed if they are simply thrown into expert-level curriculum in a sink-or-swim manner. But the “small building blocks” model is only one of many ways to simplify.

Scientists who study informal learning environments (the socio-cultural tradition) think about “simplification” in different ways than this decomposition strategy. In many apprenticeship settings, newcomers engage in “legitimate peripheral participation” (Lave & Wenger, 1991) by helping do little pieces of work in the context of whole tasks that are being directed by experts in the context of typical knowledge use. This is very different from deferred gratification to do any “real” productive work until after graduating from school. Each view of simplification for learning has its merits.

Other examples of strategies for simplification appear in informal learning environments. In sports, adults and children benefit in learning to ski from shorter skis and specially designed environments like reduced slopes (Brown, et al., 1984). Even if asked to practice sub-skills, the novices still understand why they are practicing and how such practice fits into the well-performed whole. In contrast, students in school are asked to do sub skills without a vision for how they fit together to enable complex tasks.

Most video game designs are also excellent at helping novices enter complex environments. They typically present students with “just manageable difficulties” that let them actually start playing the game (rather than feeling they are simply preparing to play the game). Furthermore, most games allow people to proceed at their own pace and stay at their personal optimal levels of game difficulty (e.g., see *D. Berliner; Csikszentmihalyi, 1997). Work in Strand-1’s neuroscience and developmental tradition provides yet another perspective on the juxtaposition of simplicity and complexity in optimizing learning. In areas such as the acquisition of language and social skills there appear to be trade-offs between simplicity and complexity, both of which serve to assist learning (e.g., Kuhl et al., 2001). As described earlier, research suggests that the brain approaches some problems computationally, that is by (unconsciously) calculating the distributional and probabilistic characteristics of events. The studies suggest that learning and transfer are enhanced by at least moderate degrees of complexity and variability (reflecting real-world variability) in the stimuli used for initial learning; and that this can be understood within a computational framework. If things are made too simple and the stimuli too ‘stripped down,’ people (including both infants and adults) have difficulty abstracting invariances amidst change, and little transfer of learning occurs to novel stimuli and environments. Neuroscience provides an additional measure to behavioral science, allowing us to examine how degrees of variability/complexity change the location and duration of brain activation. This in turn may provide a neural measure of learning and transfer, at least for some forms of learning. The role of Strand-1 in a Signature Project on simplicity/complexity is to see whether these computational principles apply more broadly than the instances so far studied — in short, do the principles that derive from Strand-1 studies, and the neuroscience techniques, help illuminate learning in other cognitive domains?

4.2 *Signature Project Candidate #2: Games as Research Environments*

Can game technology be used to explore fundamental issues in the science of learning? A second candidate for Year-1 Signature Project is Games for Research Environments (GRE). The goal is not simply to study what students learn by playing existing games but, instead, to capitalize on the incredible powers of game technologies to create variations in environments that allow us to experimentally study processes of learning that otherwise would be difficult or impossible to study. A major goal of the prospective Signature Projects is to design flexible but standardized

environments that we and other scientists in the field can use for research. Without agreed-upon standards, people frequently talk about different phenomena without realizing it. For example, Reeves (Reeves & Geiger, 1994) notes that media researchers found that the act of standardizing stimuli for the research community was a major development that accelerated progress in that field.

We can design GRE's that allow us to compare properties and outcomes of learning in virtual environments with learning in "real" environments. For example, how do we explain and exploit differences between opportunities to physically ambulate through environments as opposed to navigating through them with joy sticks and other devices that reduce typical correlations between action and perception (Reiser, 1992[RP2]). What are important differences between opportunities to replay and study our actions as avatars in a game vs. having access to video capture technology that allows us to do things with our real world actions. Another example is using a driving simulator to create an experiment that may potentially have powerful real-world impact on adolescent behavior. The simulator can be used to create real-world driving difficulties (near accidents, swerves, adverse conditions such as rain). An especially exciting possibility is that students can be helped to use the simulator to conduct their own studies. For example, they might choose to study the effects on simulated driving of using a (real) cell phone, vs. talking with a peer sitting next to them vs. simply attending to the task. We suspect that adolescents will be interested in joining us in the design of these science projects. Their experiments can also serve as contexts for learning about other information such as human attention, the effects of alcohol on brain, reaction times and driving (the simulator can be programmed with a response-delay) and so forth. Strand-1 investigators would contribute to the GRE project by helping to design MRI-compatible game or virtual world technology that can be used while subjects are engaged in some (simplified) aspects of game play.

There are many possibilities within the GRE concept, and we believe that this direction will allow us attract industry support. LIFE researchers and advisory board members have been instrumental in a number of recent "Games and Learning" conferences including ones hosted by: (a) *The Learning Federation* in January 2003 (Henry Kelly and Ed Lazowska, LIFE board members); (b) *Microsoft Research* in September 2003 (PI Bransford and Kurt Squire, LIFE consultant, participated); and (c) The "Gaming To Learn Conference" at Stanford University September 18-19, 2003, that LIFE Co-PI Pea and Strand research leaders Reeves and Schwartz have organized, with IBM sponsorship. These meetings have convinced us of widespread excitement and potential value of games/simulations for studying learning, but it is also clear that there are many challenges involved. Overall, the idea of GRE's provides a new perspective on the field of games and simulations. We have already talked with several groups about possibilities for modifying existing games and simulations to provide instrumentation.

4.3 Signature Project Candidate #3: The 'Social Brain's' Influence on Learning

Do social stimuli activate learning mechanisms in a uniquely powerful way? Is interactivity itself (whether or not it is social) important in creating learning environments? Investigators in the three strands take different approaches and have different interpretations of data suggesting that learning is often enhanced in social/interactive settings. This makes it an excellent third candidate for a Year-1 Signature Project with potential to uncover principles of learning encompassing a variety of domains and settings.

Investigators in the neuroscience strand, using language and social understanding, suggest that learning is enhanced in live face-to-face situations as opposed to those that are technology mediated. A recent example is the demonstration that infants learn aspects of a foreign language extremely rapidly when exposed to foreign speakers in face-to-face interactions, but that no learning occurs when the same foreign speakers are presented via DVD (Kuhl et al., 2003). Another example is that ubiquitous power of imitation and cultural learning when people interact in social groups (Meltzoff, 2002; Rogoff, et al., 2003). One interpretation is that the social brain regulates attention and other mechanisms critical to learning (including hormones). Researchers in the cognitive neuroscience Research Strand approach the question by varying the degree to which a stimulus is perceived as social and measuring the effects on neural processing, cognition, and behavior. Researchers from the

informal Research Strand would also argue for the importance of social interaction to learning. However, research in this tradition does not treat all social interaction as equivalent but instead ties the power of learning to particular types of historically-evolved social relationships and interactions.

Researchers in the formal-learning research strands take an interestingly different approach. They argue that interactivity (physical or social) is the key, regardless of whether this comes from live or mediated sources, including technology-mediated interaction with non-human, virtual people. For example, they investigate the degree to which learning varies in environments involving direct hands-on activity vs. interfaces providing virtual hands-on activity vs. mentally simulated (simply imagined) ‘hands-on’ activity. There is also the capability to study on-line virtual worlds, where multiple people can interact with one another (avatars), agents, and (virtual) physical artifacts, as in Massively Multiplayer Online Role Playing Games (MMORPG) (e.g., <http://www.mogonline.com/>). Our 3-D problem space outlined in *Figure 2* provides a framework highlighting three factors influencing learning. A Signature Project focused on the role of social and physical interaction in learning would attempt to coalesce these multiple perspectives, incorporating lessons learned from biologically-based examples in Strand 1, the relational and practice-based approach of Strand 2, and the general “interactivity” hypothesis of Strand 3.

5.0 Education, Collaboration, and Outreach (ECO)

The education, collaboration, and outreach activities of the Center are a direct consequence of the Center’s focus on learning. We place greater emphasis on creating and seeding collaborations and on education as a subject of study than would a more traditional outreach designed to teach students, other researchers, and interested practitioners the content of our scientific work.

Outreach—as the concept of interacting closely with the larger research and education community—is a responsibility of all PIs. ECO is conceived as an enabling structure whose expertise will maximize productive interactions of the whole Center with the field. ECO will organize short- and long-term visitors to the research groups and the Signature Projects. ECO has set aside funding to seed work collaboratively with some visitors and colleagues, and to solicit additional funding when needed for longer-term visits or joint research. The other responsibilities of ECO are: the dissemination of concept papers developed by strand research; the dissemination of syllabi of courses and programs of study developed by the Center’s faculty as part of their teaching; the organization of annual workshops on Hot Topics related to the works of the research strands; and a yearly graduate seminar on cross-cutting issues.

ECO’s Director Nora Sabelli is a PI and a member of the Executive Committee, where the close relation between research and field activities will be developed, monitored, and maintained. The ECO Director will work in close contact with members of the ECO Program Board, and will be assisted by a staff member who will implement the administrative tasks associated with all aspects of the field-oriented work.

Although LIFE will produce specific materials to be shared (research and concept papers, monographs, tools, and course syllabi), its outreach focus is on building relationships with outside groups and enabling them to take advantage of its resources. ECO coordinates those products, methods, assessments, and other resources emerging from LIFE’s research that can be used by other researchers. ECO’s work includes identifying target audiences that will benefit from these resources, communicating the opportunities, and supporting partners and the broader community in using them. All LIFE Center PIs have experience in establishing informative, well-designed, and maintained web sites to make scientific work that we will develop through the LIFE Center visible to outsiders, including our proposal and annual reports. We will also develop presentation materials that can be used by Center staff in scientific meetings, and in reporting to the NSF and our Review Boards.

ECO will actively pursue, in close collaboration with affiliated researchers or institutions, additional funding for specific activities that can ensure a larger and sustained impact on the field at large. ECO will perform specific functions in the following areas:

Concept papers, reports, and state-of-the-art monographs. ECO will solicit, edit, and publish internally-developed reports and monographs. The multi-strand approach to research that LIFE has chosen suggests that we will be in a position to produce a series of monographs that enhance our own thinking, while making public transformative research topics. We contemplate an irregular series of monographs (concept papers and state-of-the-art reviews) for wide distribution. Concept papers are an extremely important part of our process. They serve as a guide to inform the field of the current state of our thinking, and are intended to spark discussion and possible collaborations. Information shared in a short concept paper is understood as preliminary and requiring further development, yet it is useful for clarifying and organizing ideas and as a basis for later exploration. From a concept paper, researchers can develop a number of different research projects around a single leading-edge idea and increase the cumulateness and replication of their work. Both concept papers and non-exhaustive “state-of-the-art reviews” can offer new perspectives on an issue or point out an area in need of research. In addition, reviews could consider contrasts among various ways of looking at a certain topic, including those where a conceptual collision exists, and synthesize other reviews to provide theoretical insights into a given topic based on the perspectives of two or more strand approaches, disciplines, or levels of analysis.

Hot Topic Workshops. ECO will organize workshops on Hot Topics of research interest to the field, under the guidance of the LIFE Program and Budget Committee. Hot Topic Workshops and Fora are used to analyze, discuss, and debate specific technical concepts, problems, methods, and criteria around a particular topic of timely interest. Small groups of experts will be invited to a workshop for in-depth examination of important issues with the goal of resolving uncertainties and developing consensus views when possible; or they may issue white papers or reports representing the discussions if controversies persist. We plan to hold at least one such workshop every year from LIFE funds, and to consider others in collaboration with partners. Topics for these meetings will be proposed by LIFE’s researchers in consultation with the Scientific Review Board (SRB). Each week-long meeting will follow the organization of the very successful Gordon Research Conferences. Criteria for the selection of applicants, and final names of invitees and presenters, will be determined by consultation with the SRB.

Advanced Tools and Methods for Studying Learning. Technology and its use underlie the research and design work of the LIFE Center. ECO has funds to support existing relevant tools, and will document and publish the shareable tools developed as part of the Center’s focus on enabling technologies. In the last two decades, traditional fieldwork practices have been augmented significantly by analysis techniques that rely on the capture and analysis of detailed audio-video recordings of human activity. LIFE researchers are devoted to significantly advancing the field’s capacities to work smarter in how we capture, transcribe, annotate, code and index, and provide access to learning data. Distributed communities of researchers could thus share access to remote instruments and datasets and work together to advance the state of knowledge for their disciplines, building a cumulative knowledge base and creating “digital video collaboratories” (Pea & MacWhinney, 2003; Pea et al., 2004).

Scientific visitors. ECO will coordinate and help identify opportunities for visiting scientists and arrange visits to the laboratories where the research takes place. These activities are aimed at enhancing scientific and educational contacts with the national and international research and education communities. Scientific visitors will generally be scientists who can benefit from short visits and discussions with Center researchers, and who can, in turn, benefit the Center’s research. We are particularly interested in hosting research visits by post-doctoral and graduate students who will become the future research pool of the field.

Education and education visitors. ECO will arrange for research internships by graduate students and faculty (e.g., from minority-serving institutions), and organize for dissemination new courses developed by LIFE’s faculty and researchers at its participating institutions. The Center’s education activities fall into three broad categories: course development and education visitors; graduate workshops; and general outreach of the Center’s activities. Many Center researchers have

ongoing teaching responsibility for undergraduate and graduate courses. ECO will work with these faculty to organize syllabi, reading lists, programs of study, and similar materials for publishing on LIFE's website. ECO will also correspond with external faculty to arrange faculty visits for team-teaching, plan special workshops (e.g., on methodology), and discuss the course materials for adoption at their institutions.

The training of graduates is an important mechanism for contributing to building capacity in the field. We hope to host graduate students from research laboratories that are synergistic with our work, but also to conduct yearly graduate workshops on topics such as conducting multi-disciplinary research, working within the informal and formal education environments to maximize adaptive learning and transfer, and designing technological environments that can accomplish such transfer.

Testbeds and partners. ECO will coordinate with groups, both formal and informal, for participation in the implementation and study of Signature Projects. Developing criteria for inviting and selecting testbed partners will be one of the first tasks of the ECO Program Board, whose members represent the communities we expect to attract to LIFE's work. Given the Center's focus on *research* and not on *implementation*, a productive interaction between both is critical to iterating design studies in order to ensure that the products of research, whatever they may be, are validated and of use to colleagues. Therefore, we will work closely with the ECO Program Board to create testbed collaborations focused on implementation. During the definition and piloting of a Signature Project, we will be able to identify external groups with an interest in becoming testbeds for the pilot and developing proposals to expand and continue the work. These groups can be schools, colleges, universities, and not-for-profit organizations—individually or as a coalition. Criteria for selecting testbed partners will be formulated with the ECO Program Board, but we can say that the testbeds will have access to formal and informal environments, and incorporate a strong component of research on the *process* of implementing the collaborations.

We have established contact with several possible partners (see attached letters) that include private foundations (Gates Foundation), education reformers, NSF-funded centers for R&D in education technologies (TELS)—besides those represented in our ECO Program Board. In addition, we hope to integrate some of LIFE's insights into the interrelation of informal and formal education into the UW College of Education teacher preparation programs.

6.0 Advisory Boards

We are conscious of the ambitious nature of our proposal and the implications it raises for making our strategies and advances open to others as the work progresses. We have developed a tiered approach to soliciting and incorporating advice on our overall progress, and for involving researchers in the field in our own internal review processes:

- An overarching external programmatic *Advisory Committee (AC)*;
- Three external Review Boards (*Scientific Review Board*; *Technology Review Board*; and Education, Collaboration, and Outreach, or *ECO Program Board*); and
- An *Evaluation Task*, including a research component that evaluates the footprint of the LIFE Center's activity in the field.

The members of the **Advisory Committee (AC)** represent the highest levels of scientific and educational leadership, and can provide the LIFE Center with a vision of the future, and strong advice on priorities. The Board chairs and the evaluation leader will report directly to LIFE's Advisory Committee, whose members will then be in a position to evaluate both our strategies and our progress as seen by others. We have been delighted to receive enthusiastic acceptance to our invitation to join the AC. **AC Chair:** *John Bruer* (President, McDonnell Foundation), *Alice Agogino* (UC-Berkeley), *William Greenough* (UIUC), Henry Kelly (President, Federation of American Scientists), *Ellen Condliffe Lagemann* (Dean, Harvard Graduate School of Education), *Marshall Smith* (Hewlett Foundation), *Lauren Resnick* (U. Pittsburgh, Director, Learning Research and Development Center), *John Seeley Brown* (Director Emeritus and Vice President, Xerox PARC), *Thorsten Wiesel* (President Emeritus, Rockefeller University).

The external **Scientific Review Board (SRB)** consists of researchers in the strand areas, known both for their expertise and for their broad view of learning and research. The board will work closely with LIFE researchers to: define the most promising and challenging new opportunities from the work proposed by the strands, refine the research design of Signature Projects, and expand the reach of the ECO activities. **SRB Chair:** *Michael Posner* (U. Oregon), *Shirley Brice Heath* (Brown University), *James Greeno* (U. Pittsburgh), *Steven Grossberg* (Boston University), *Ken Koedinger* (CMU), and *Barbara Rogoff* (UC-Santa Cruz).

Membership of the **Technology Review Board (TRB)** includes expert researchers who will review technical and implementation aspects of the design of environments and the Signature Projects. **TRB Chair:** *Louis Gomez* (Northwestern University), *Gerhard Fischer* (U. Colorado-Boulder), *Geneva Haertel* (SRI), *Lawrence Howard* (Vanderbilt), *Marcia Linn* (UC-Berkeley), *Brian MacWhinney* (CMU) and *Elliot Soloway* (U. Michigan).

The Education, Collaboration & Outreach, or **ECO Program Board** will be composed of representatives of research and education partners able to help orient ECO's activities, and define the collaborations and partnerships that will help the Center achieve its ambitious objectives for impact in the fields of research and education. **ECO Chair:** *Shirley Malcolm* (AAAS Director, Education and Human Resources), *Dennis Bartels* (President, TERC, R&D group working in science, mathematics and technology), *S. Raj Chaudhury* (Norfolk State University, an HBCU/Historically Black College/University), *Thomas Harris* (Vanderbilt, Director of VaNTH Bioengineering Education Research Center), *William Nelson* (President, Little Planet Interactive Media), *David Santucci* (Texas Instruments, Education), *Robert Semper* (Executive Associate Director, The Exploratorium), and *Steven Weimar* (Director, Math Forum, Drexel University).

Longer term, we foresee an increase in the membership of this board, as work and collaboration progress, course offerings are developed, and technology systems are integrated. The ECO Program Board will be instrumental in facilitating the joint development of research, testing, and education activities that will lead to the impact in the field at large that we hope to achieve.

The AC and Review boards will each meet annually. The Review Boards will be expected to interact with LIFE staff electronically during the year. Research within the strands will evolve naturally, and the Review Boards will help the Center prioritize its work and keep it at the forefront of advancing the learning sciences. Evaluation of the LIFE Center's work, which itself includes a research component (see *Evaluation*, Section 7.0), will be under the leadership of **Barbara Means**, reporting directly to the Advisory Committee.

The LIFE Center will create an *Industry Board* reporting to the Executive Committee, comprised of corporate affiliates who have strong interests in learning sciences, technology development, education, and the outreach activities of the Center. An Industry Board planning committee—comprised of Center PIs Bransford (UW) and Pea (Stanford) and Co-Chairs UW Prof. Ed Lazowska and Stanford Prof. Byron Reeves—will develop this function for the Center during its first year of operation. These faculty have extensive experience with industry affiliations, including current programs that manage relationships with over 50 companies that contribute substantial funding and expertise to research and teaching at the UW and Stanford.

The Center will adapt the Stanford Media X model to accelerate implementation of the Industry Board. Media X is a Stanford campus-wide network to coordinate interdisciplinary research and technology design in the contexts of education, commerce, and entertainment. Media X projects address challenges at the intersection of social and computing sciences and the arts, and address critical technology issues including ease of use, natural forms of input and output, collaboration tools, machine learning, natural language processing, social and emotional responses to technology, enhancement of learning, and interaction strategies in business. (Projects are summarized at <http://mediax.stanford.edu>.)

Media X has established membership agreements, intellectual property (IP) policies, conference formats, visiting research positions, and governance procedures that enable Stanford to collaborate

effectively with 20 corporate partners who contribute \$1.5M+ annually to the campus. Strand Leader Reeves is the Media X co-founder. He and PI Pea are currently the faculty leaders of the Media X Executive Committee. Relevant Stanford University administrators and faculty associated with Media X have been briefed about the LIFE Center and endorse the connection. Media X membership fees go into a common pool allocated by faculty to innovative research biased toward interdisciplinary collaboration. The LIFE Center will adapt the general guidelines used by the Media X program regarding IP.

7.0 Evaluation

Past evaluation studies of NSF-funded research centers have focused on outcomes that are closely tied to incentives already built into university systems: research publications, new researchers trained, and successful grants. While useful, these outcomes do not provide a complete picture of the success of a center. Social Capital approaches (Bozeman, Dietz, & Gaughan, 1999; Dietz, 2000) to the study of centers' effectiveness investigate how centers have constructed mechanisms for broadening the network of researchers in fields and expanding the influence of their research publications. The chief advantage of these new approaches is their emphasis on the *value of knowledge* created by research centers—the extent to which such centers yield increases in the range and intensity of uses to which new knowledge is put.

We draw on past studies and a Social Capital approach for evaluation and in formulating overarching questions. This approach to evaluation requires methodologies to uncover the social processes by which new knowledge is produced and valued by the wider communities of scholars working within and across LIFE's strands, and draws on elements of citation analysis, analysis of curriculum vitae, social network analysis, and case study analysis. SRI's evaluation researchers have experience using these methods. Given the established norms for such evaluation methodologies, we will forego their explanation here.

In all likelihood, it will take more than five years to see some of the changes seeded by the work of centers such as LIFE. We will focus our data-gathering efforts on documenting both benchmark outcomes and the processes of achieving success (or failure) so that they can be made part of a later longitudinal. Our overarching starting questions will focus on:

Adding value to research knowledge: Does LIFE influence researchers' conceptualizations of transfer and the bridge between formal and informal learning? Is knowledge generated by LIFE incorporated into practices beyond specific Center activities?

Preparing new researchers: How is LIFE working to prepare the next generation of researchers to make new bridges between formal and informal learning? Are the career trajectories of graduate and/or undergraduate students who work with LIFE evolving in expected ways? What are the more promising "boundary crossings" among the disciplines represented by the strands?

Building capacity for conducting new forms of research: Has the focus of Center researcher grants changed in ways attributable to LIFE? How is LIFE supporting new networks of researchers to gain access to relevant interdisciplinary research and education? Is the process of evolution of Signature Projects into testbeds successful and documented?

Educational impact: How are students integrated into the operation of the Center? Are there mechanisms being established to test and study the LIFE Center with outside partners?

Policy and management: What are the management, cultural, technical, and other challenges associated with these types of activities? How do strategies for mitigating these challenges and documenting processes evolve from year to year?

Partnerships: How does industry contribute to the Center's research priorities and methods? Does industry participation increase the application of knowledge generated by the Center?

7.1 *Methods and Plan of Work for the Evaluation*

A representative sample of 25-30 LIFE researchers and each of their closest 2-3 colleagues outside the project will be the primary focus of the majority of evaluation activities. We will sample LIFE researchers from different institutions who play diverse roles within the project (PIs, senior researchers, junior researchers, and post-doctoral students) and have varying levels of involvement (more central and more peripheral) in Center-related activities. We will use publications from their closest colleagues outside the project (obtained from the social network analysis and biographical sketches) to perform citation analyses. These analyses will focus on whether LIFE effects changes in patterns of researchers' citations of people outside their disciplines.

For the analysis of curriculum vitae/biographical sketches, we will also obtain sketches of a sample of 25-30 researchers from participating institutions, to analyze their publication patterns and career trajectories for evidence of interdisciplinary (cross-strand) work. The social network analysis will focus on the core sample of 25-30 researchers and analyze the degree to which LIFE results in a broadening of participating researchers' connections to people working in LIFE disciplines distinct from their own.

Annual surveys and interviews will be administered to a wider array of participants in LIFE activities: researchers in Signature Projects; attendees of Hot Topics seminars; and project staff and researchers who spend more than 160 hours per year on Center-related activities. Two foci of these data-collection activities will be on the perceived *coherence* of strand research activities and on the perceived level of *cumulative* knowledge created by Center-related research.

7.2 *Evaluation Management and Staffing*

Too often evaluations are performed solely because funders require them, doing little to enhance the project's functioning or build a knowledge base. PIs in this proposal are strongly committed to continuous reflection and improvement. The evaluation activities will be both integrated within, and distinct from, the operation of the Center. The Evaluation Director will report directly to the Advisory Committee in order to highlight the importance of evaluation activities and avoid a conflict of interest. We believe this arrangement is optimal for ensuring that the evaluation is relevant to the problems and conflicts that arise during the Center's life, and that its findings will be incorporated into ongoing Center operations. We understand that, because it is continuous and more intensive, this arrangement places a heavier burden on the Center than would a more traditional evaluation. But we believe having Center processes and intermediate outcomes scrutinized by individuals with both "insider" and "outsider" independence will provide meaningful information that will be useful to both LIFE leadership and NSF.

Barbara Means, Co-Director of the Center for Technology in Learning at SRI International, will oversee the overall evaluation. Dr. Means is well known for her work on evaluating the use of rapidly- changing technologies in educational contexts (Haertel & Means, 2003), and is Co-PI on an NSF grant to explore the use of social network analysis for evaluating the diffusion of educational innovations. **Marianne Bakia**, SRI Research Social Scientist, will manage day-to-day activities, conduct periodic interviews with PIs and senior staff, design and administer surveys, and produce annual reports for the PIs on center progress. **Dr. Judith Fusco**, SRI Research Scientist will perform the social network analysis using data from surveys and curriculum vitae. **Yukie Toyama** will conduct the citation and curriculum vitae analysis. **Dr. William Penuel**, SRI Senior Researcher will advise the evaluation team on refinements to the design, implementation, and analysis plan that are necessary as the project evolves.

8.0 *Management*

The Center will be managed by the Director, PI Bransford, working with PI Sabelli. The Center has formed an internal Executive Committee (EC) constituted by the five PIs, and a Programs and Budget Committee (PBC), chaired by the Director. The membership of the PBC consists of the PIs plus Strand Leaders (Senior Researchers who will assist the PIs at each institution with management

and program decisions, and who are expected to play a strong role in the development and conduct of Signature Projects). The PIs will be assisted by financial staff that will help with overview of the budget, finance, subcontracts, purchasing, report preparation, and similar cross-institution activities.

The Center management closely follows the structure of the Center presented in Figure 1. The specific tasks assigned to PIs and Strand Leaders are:

Implicit Learning and the Brain (I-LAB) will reside at the UW's Center for Mind, Brain, and Learning, with co-PIs Kuhl and Meltzoff joined by Strand Leader Reeves at Stanford. *Informal Learning* will reside at Stanford with PI Pea, joined by Strand Leaders Stevens and Bell at the UW. PI Bransford will lead *Designs for Formal Learning and Beyond* at the UW, with Strand leaders Schwartz at Stanford and Roschelle at SRI. **ECO** activities will be directed by PI Sabelli at SRI's Center for Technology and Learning, *Signature Projects* are the joint responsibility of the PIs and strand leaders.

The Center will continue the series of weekly Center phone or video-conferences conducted in the last few months, whose task is to create synergy among the research strands, the Signature Projects, and ECO. The conferences will allow the Center management to keep abreast of the work. Each strand and ECO will conduct a similar series of more specific meetings, and one Center meeting each month will be dedicated to Signature Projects/Hot Topics. Funds for these meetings and for travel between the sites are in the SRI budget, in order to simplify oversight and monitoring, and to ensure the integration role of ECO. We have attempted—but not succeeded—in reducing further the burden on each individual PI. Their commitment is reflected in a 10% time support for each PI under management, and 10% of each Strand Leaders for Signature Projects.

9.0 Summary of What LIFE Will Accomplish

We stated in the Introduction that our ten-year vision is “to have played a catalytic role in establishing a transformed sciences of learning that combines bio-, psycho-, and socio-cultural theories and methodologies with studies of media and technology to provide a solid foundation for advancing processes of learning and development in ways responsive to the changing demands of work and life in a technology-enhanced global society.” We believe that we have used the flexibility that a Center provides to lay out a plan that will, in five years, created a path to achieve that vision. To recapitulate:

1. There will be *new insights* about processes of learning as revealed and measured in informal or formal settings, on the role of implicit learning in both, and on high-performance learning environments that combine the best of both approaches.
2. There will be an integrative understanding forged in *interdisciplinary science* that brings to bear neurobiological, psychological, cultural, and technological theories, methods, and levels of analysis.
3. There will be a *new scientific basis for measuring learning and transfer* which privileges neither a formal (e.g., written tests) nor informal (judging performances) metric for learning, but rather proposes rigorous measures of the degree to which particular learning experiences point to “preparation for future learning.”
4. There will be a principled basis for organizing and studying the potential of *new technological modes of interaction, and representation*.
5. *Signature Projects*, new technologies and theoretical frameworks will be integrated into the fabric of learning research and education, and of education research and practice.

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