

CONNECTING YOUNG LEARNERS WITH
THE WORLD OF EMERGING SCIENCE:
A DESIGN-ORIENTED CASE STUDY

by

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with

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Introduction

The U.S. National Science Foundation provides some \$5.7 billion annually to support highly innovative research in science and technology (NSF, 2010a), with the bulk of this funding going to research scholars and laboratories at major U.S. universities. Supported projects have helped to position U.S. researchers at the leading edge of discovery and innovation in areas as diverse as genomic biology, computing, nanotechnology, oceanography, and space exploration. This brings up a tantalizing question for educators: How might this massive national investment in leading-edge research be harnessed at the same time to improve the teaching of science for new generations of young learners in K-12 schools?

One possible answer would be “not at all” – that the worlds of research science and school science are too far apart for one to reasonably be expected to contribute to the other. Research science takes place using specialized equipment and facilities, in highly specialized and still-emerging topic areas, and in cycles of research that can stretch over years, whereas school science is aimed at conveying broadly general ideas of science in topical chunks lasting from forty-five minutes to a few weeks. Moreover, a key goal of school science is to provide educational scientific experiences to all students, whereas the object of leading-edge research science is to generate rigorous, high-quality scientific research in tightly controlled settings (Houseal, 2010). The gulf between science as a topic of school study and scientific research at the leading edge is immense, and so skepticism about how discovery-oriented research science might contribute to general educational goals may well be warranted.

Even so, it is widely recommended that young students be provided with opportunities to interact with and learn from research scientists as a part of their education. The *National Science Education Standards* (National Research Council, 1996), for instance, states, “Students must be given access to scientists and other professionals in higher education and the medical establishment to gain access to their expertise and

the laboratory settings in which they work” (pp. 220-221). Moreover, it has been argued that integrating emerging areas of biological science, such as genomics, into education at an early stage “would serve not only biology students but scientists and their research projects, as well.... Teaching a new or emerging field is an ideal way to deeply engage students in exploring fundamental questions that are at the heart of scientific pursuit and to encourage them to ask their own questions. Addressing these questions in turn inspires young minds and active researchers alike, and science benefits” (Jurkowski, Reid, & Labov, 2007, p. 263).

This paper describes an effort by a leading-edge scientific research project in the area of insect behavioral genomics to make its ongoing research activities a source of educational opportunities for young learners. The project, BeeSpace, was funded by the Biology Directorate of the National Science Foundation from 2004-2009 to investigate how behaviors of worker honey bees are related to expression of particular genes, and to develop computational resources to assist the genomic researchers in their work. One product of the project’s educational outreach, an eight-hour, video-based online curriculum dubbed “Electronic BeeSpace” (Figure 1), was written about in the February, 2011, issue of the National Science Teachers’ Association journal *The Science Teacher* (Stone, Buell, & Naeger, 2011). This paper investigates three questions with respect to the educational outreach instance that gave rise to the online curriculum. First, how did that instance come to be? Second, what were its features? Third, how did students learn from it? The circumstances of BeeSpace and its education component are unique, but the lessons to be drawn from them may be of more general interest. In this paper, we make use of a hybrid methodology we call “design-oriented case study,” a mix of qualitative case study (Stake, 1995; Yin, 2009) and educational design research (Kelly, Baek, Lesh, & Bannan-Ritland, 2008), to describe how BeeSpace educational outreach took shape over multiple design episodes, and to present evidence for how a small group of high school students learned from their involvement in one such episode.

Background

Where are young students situated with regard to the content of the curricula they are expected to master? More than a century ago, educational philosopher John Dewey (1902/1956) offered an analysis of young learners' relationship to the topics of their studies that remains as provocative today. "The child and the curriculum are simply two limits which define a single process," he wrote. "Just as two points define a straight line, so the present standpoint of the child and the facts and truths of studies define instruction (p. 11). For Dewey, the process of learning was fundamentally about relating to one another "the logical and the psychological aspect of experience – the former standing for the subject matter itself, the latter for it in relation to the child" (p. 19). Rather than seeing subject matter as something "fixed and ready-made in itself, outside the child's experience" (p. 11), learners must be brought to the understanding that the school curriculum functions as a map of what previous scholars have discovered: "Without the more or less accidental and devious paths traced by the explorer there would be no facts which could be utilized in the making of the complete and related chart.... The map orders individual experiences, connecting them with one another irrespective of the local and temporal circumstances and accidents of their original discovery" (pp. 19-20). Therefore, for Dewey a chief goal of instruction is to bring child and curriculum into alignment through the internalization of external experience. Doing so amounts to leading the learner to construct personal meaning out of curricular matter, what Dewey called "psychologizing": "Hence the need of reinstating into experience the subject-matter of the studies, or branch of learning. It must be restored to the experience from which it has been abstracted. It needs to be *psychologized*, turned over, translated into the immediate and individual experiencing within which it has its origin and significance" (p. 22, emphasis in original). From a Deweyan perspective, then, leading-edge projects like BeeSpace have potential for offering educative experiences to young learners in part because their research traverses new scientific territory where "mapping" is still actively being done.

Before proceeding further into the BeeSpace example, it is useful to take stock of what might be called “research science meets school science” (RSMSS) educational initiatives more generally. From the time of the National Science Foundation’s establishment sixty years ago, education has been a key aspect of the NSF mission (England, 1983; Lomask, 1976). NSF has funded the development of numerous curricular materials and has supported a great many graduate students in the sciences. In its current administrative form, NSF is composed of ten directorates and offices, each of which operates in semi-independent fashion to oversee programs that solicit proposals for projects seeking limited-term funding. One of these, the Education and Human Resources (EHR) Directorate (2010 budget of \$873 million), oversees most education-oriented programs supported through NSF funds. The NSF’s nine other directorates and offices are referred to collectively in the Foundation’s budget documents as being concerned with “Research and Related Activities,” rather than with “Education” as EHR is; R&RA funding amounted to \$5.73 billion in 2010 (National Science Foundation, 2010a). Were it not for a fairly recent change to NSF funding guidelines, it is doubtful whether many NSF-supported projects aside from those administered under EHR would engage in educational outreach as a project-funded activity. However, a change to NSF funding guidelines in 1997 led to increasing emphasis on educational outreach as a secondary goal; in that year, the Foundation announced that all projects seeking funding would be considered with regard to both “scientific merit,” the traditional criterion, and “broader impacts.” While the so-called “broader impacts criterion” (BIC) was initially presented as a way to encourage funded research projects to disseminate *results* of their research to a wider public (Mervis, 1997), in more recent years it has increasingly been redefined to encourage direct involvement by research projects and their staffs in educational outreach efforts (Avila, 2003).

Educational audiences are likely to be most familiar with the educational activities that NSF supports via programs it administers through EHR. RSMSS initiatives like those supported through EHR in recent years can be considered to encompass a half-dozen or so different varieties, each making use of research scientists’ expertise in

somewhat different ways to support school learning of science. Table 1 offers a capsule summary of these types, together with descriptions and exemplary studies. Different as they are from one another, the various types of RSMSS initiatives we identify have two commonalities that merit consideration here. First is that each of them has more often than not involved bringing well-established scientific understandings into the school setting, rather than exploring science at interdisciplinary margins and frontiers of discovery in research settings. Second is that each of the six types is typically centered on a pedagogy of hands-on, problem-solving inquiry (hereafter abbreviated “HOPSI”). Whether the RSMSS type involves single scientists in the classroom, use of new technologies, field visits, citizen science, summer activities, or scientist-teacher collaborations, activities are generally set up so that the learners are in charge with regard to both posing of questions and carrying out of investigations. As the studies referenced in Table 1 attest, each of these six types of HOPSI-oriented RSMSS has been implemented successfully in numerous instances, often with demonstrable effects on student learning. Developers of RSMSS curricula often point to HOPSI pedagogy as especially suitable for encouraging young learners to discover connections between their own interests and abilities and the world of scientific discovery, in a manner that Dewey would recognize and encourage. However, examination of these studies makes clear that resource requirements for setting up these sorts of educational interventions can be high, and that particular aspects of them might be problematic to adopt in science-research-centric situations like those faced by leading-edge scientific research projects. Two such aspects are the expectation that significant funding and expertise be devoted to creating artificial curricular activities intended to simulate scientific research, and the expectation that dedicated and active research laboratories and facilities be turned over to hands-on use by novices.

Iterative development of educational outreach in BeeSpace

BeeSpace (NSF Award No. 0425852) was conceived and funded as a research enterprise focusing on the emerging areas of behavioral genomic biology and

bioinformatics. As one of eighteen projects that were awarded five-year funding through NSF's "Frontiers in Integrative Biology" program, its research was intended to link disparate disciplines in order to spur scientific advances. An overall goal of the BeeSpace Project was to develop computational tools that would assist bee genetic researchers in understanding better the relationships between honey bee genetics and social behaviors. The mapping of the honey bee genome was being completed as the project began, and bee researchers were in need of ways to integrate this new knowledge about the bee's genetic make-up with existing knowledge about the genomes of other organisms, previously published gene-by-gene studies of bee behavior, and available studies of genome-behavior linkages in other species. To this end, BeeSpace was conceptualized as a bioinformatics project, with the aim of developing a computer software environment for navigating across these literature collections and gene maps. At the same time, BeeSpace supported genetic microarray studies to investigate relationships between individual genes in the honey bee genome and individual bees' engagement in nursing, foraging, colony defense, and other social behaviors. All this meant that from the outset, BeeSpace was focused primarily on promoting research in the biological and computational sciences, not in education. However, the BeeSpace Project proposal did promise to engage in educational outreach as a broader impact, and engaged staff that could help it carry forward this goal. This is a not-unusual situation for NSF programs administered through directorates other than EHR; typically they promise and offer some sort of K-12 educational outreach as a means of satisfying the broader impacts criterion, but only rarely do they undertake research into their educational offerings (Avila, 2003).

In the case of BeeSpace, an educational research agenda took shape only gradually, as it became clear to project insiders that the project's educational outreach was developing along lines that did not appear to be well-described in science education literature and appeared to merit some analytic attention. The principal author's (Buell) role as the project's coordinator had some bearing on the turning of attention to educational research – previously a full-time graduate student in educational

psychology, he had found himself somewhat off the degree track for a time following an adviser's departure, and had been hired by BeeSpace as a full-time academic professional. Project investigators, scientists, and other affiliated educators, including this paper's co-authors, all played vitally important roles in the shaping of the outreach itself and in supporting the emerging research agenda.

The longer work from which this report is adapted (Buell, forthcoming) considers three research questions with respect to an instance of education outreach that was conducted by the BeeSpace Project in summer, 2008. First, how did that instance come to be? Second, what were its features? Third, how did students learn from it? BeeSpace educational outreach took shape over a series of iterations, influenced both by the project's major research directions and by the project principals' sense of their goals for the education component. In conducting research into this outreach, Buell found it useful to recognize BeeSpace as a unique and bounded case open to qualitative case study analysis (Stake, 1995; Yin, 2009), and to consider the way the project went about developing its educational outreach over multiple iterations as a variety of educational design research (Kelly, Baek, Lesh, & Bannan-Ritland, 2008).

How did the 2008 BeeSpace Education Week (BSEW08) come to be?

The educational outreach instance that is of central interest for this research took place over the course of one week in July, 2008, in the home research quarters of BeeSpace: a university-based genomics research institute and a nearby honey bee field research center. Fourteen high-school age students from a university-affiliated public high school, together with their school's biology teacher, participated in a weeklong series of activities that was led by BeeSpace Project scientists. In analyzing how this outreach came about (the first of the three research questions motivating this study), Buell utilized a technique of "design narrative" (Barab, Baek, Schatz, Scheckler, & Moore, 2008) to trace the development of ideas over the course of six design episodes that occurred over a four-year span. As Barab and colleagues comment, "A challenging

part of doing educational research on design-based interventions is to characterize the fragility, messiness, and eventual solidity so that others may benefit.... This involves not simply sharing the designed artifact, but providing rich description of the context, guiding and emerging theory, design features of the intervention, and the impact of these features on participation and learning” (Barab et al., 2008, pp. 322-323). The six episodes analyzed in this manner (Figure 2) were: 1) middle and high school outreach as initially described in the project proposal; 2) and 3) instances of one-day and two-day outreach carried out with middle school students in the 2005-2006 school year; 4) a proposed arthropod camp for middle school students given consideration in 2006; 5) a pilot iteration of a week-long workshop offered to seven middle school students in summer, 2007; and 6) BSEW08, the week-long workshop offered to fourteen high school students in summer, 2008, whose lesson content was simultaneously video-recorded as the basis for the online “Electronic BeeSpace” resource. Space limitations preclude full discussion of all six episodes in this paper, and so only BSEW08 will be treated in detail. However, it is worth mentioning here that the analysis of the first five episodes revealed ongoing tensions between educational and research aims for the project, which Buell attributed in part to differences in “activity systems” (Engestrom, 2001) of school and scientific research. An early proposal that would have offered BeeSpace-themed curricula to a group of disadvantaged middle school students in an existing mathematics-oriented summer camp encountered problems when sponsors discontinued the host camp. Once that came about, project principals found themselves faced with the decision of whether to create such a camp themselves, or instead to focus outreach more directly on the actual science of the project, treating development of advanced curricular content in enduring form as a desired outcome in itself, and in the process involving a better prepared group of learners as collaborators. Charting the latter course led by degrees to the shape taken by BSEW08; the working-out of tensions and contradictions between scientific research aims and educational aims over the various iterations yielded a form of curriculum somewhat different from any of the RSMSS curricula described above.

One way of thinking about BSEW08 as an outcome of such tensions and contradictions is through the lens of what organizational theorist Yrjo Engestrom (2001) has termed “third generation activity theory,” a research perspective that draws from Lev Vygotsky’s (in Cole, John-Steiner, Scribner, & Souberman, 1978) and A.N. Leont’ev’s (1979) earlier ideas concerning the historically and culturally situated nature of all human activity. In his work, Engestrom utilizes an expanded triangular graphic framework that describes instances of human collective activity in terms of how they encapsulate relations among subject, object, instrument (mediating artifact or tool), community, social rules, and divisions of labor. For Engestrom, “The emerging third generation of activity theory takes two interacting activity systems as its minimal unit of analysis, inviting us to focus research efforts on the challenges and possibilities of inter-organizational learning” (2001, p. 133). This perspective led Buell to consider the research laboratory-based curriculum of BSEW08 as the shared object of a realm of school science, on the one hand, and research science, on the other (Figure 3). If K-12 science outreach and university research science comprise conceptually separate activity systems, then BeeSpace and similarly situated projects may be thought of as having a potentially shared object of project-related educational outreach. Efforts by BeeSpace developers to draw directly from models of educational outreach like the six RSMSS prototypes described above can be construed as having brought to the surface various tensions and contradictions, among them resource availability and lack of fit between typical science education pedagogies and the affordances and constraints of a leading-edge scientific research project. Hands-on problem-solving by novice students was not an achievable pedagogical approach in an active scientific laboratory where research was ongoing, for reasons of participants’ safety and non-interference with the research. By this understanding, the various design episodes could be regarded as workings-through of these tensions, with more and less successful outcomes. To the extent that BSEW08 emerged as a departure from any of the typical models of RSMSS, its curriculum merits attention as a potential instance of expansive learning along the lines considered in Engestrom’s model.

What were the features of the BSEW08 curriculum?

"Experiencing BeeSpace" was the theme for a week-long workshop offered from July 7 to 11, 2008. Geared to high school-age students who had completed at least one year of biology, the BeeSpace Summer Educational Workshop (BSEW08) offered an in-depth look at honey bee biology, behavioral genomics, and Colony Collapse Disorder. Fourteen students had the opportunity to learn from project scientists about their work, tour their laboratories, and engage in hands-on activities intended to promote deeper knowledge and foster interest in science careers. All of the students attended the university-affiliated public high school at which one of the co-authors (Stone) taught during the school year. Each had volunteered to take part in the workshop after receiving an email that Stone had sent to all of the school's rising (incoming) sophomore, junior, and senior year students; all who volunteered were accepted. All costs for their participation were borne by the project.

The students came to the project office each morning for three hours of activities related to learning about honey bee anatomy and physiology, social behaviors, and genomic research. Following a lunch provided by the workshop, most of the same learners continued together as a group in afternoon sessions that were conducted by the biology teacher at the high school, for the purpose of practicing skills for science competitions; the afternoon sessions were not a subject of this research.

The core team planning the BSEW08 curriculum consisted of the high school biology teacher (Stone); a graduate student in honey bee genomics who had been selected to serve as lead instructor (Naeger), and the project coordinator (Buell). As a team, they were directly responsible to the project's principal investigator (Schatz), and received advice and assistance from other project investigators. As the video-based curriculum that emerged from BSEW08 illustrates, roughly half of the fifteen contact hours involved hands-on activities and tours, with the remaining time devoted to presentations by Naeger and other researchers involved with the project.

The week's curriculum consisted of the following activities. Except as otherwise mentioned, all sessions took place in the project offices and meeting rooms, located at the on-campus genomic biology institute that served as the project's research home.

The curriculum included the following:

- *Monday*: Introductions, Overview of Week, Overview of Honey Bee Biology, Handling of Day-Old Bees, Electron Microscopy with BugScope.
- *Tuesday*: Introduction to Removable-Frame Beehives; Visit to Honey Bee Research Laboratory, Including Outdoor Hive Observation and Introduction to Field Research Facilities; Introduction to BeeSpace Research.
- *Wednesday*: Talk on Molecular Analysis of Bee Genetics; Talk on Conceptual Basis for BeeSpace Project; Honey Tasting.
- *Thursday*: Tour of Genetic Analysis Laboratory Facilities; Hands-On Simulation of Microarray Analysis; Talk on Symptoms and Possible Causes of Colony Collapse Disorder.
- *Friday*: Talk on BeeSpace Bee Behavioral Research Initiatives; Outdoor Pollinator Observation; Talk on Computational Aspects of BeeSpace.

The order of these activities was intentionally structured by the education team so that on Day One the learners could first learn basic information about bee biology from an expert (who, like each of the presenters, organized her talk around an illustrated set of slides) and then be introduced first to bees in hands-on fashion through direct handling of baby bees, anatomical observation using visual microscopes, and web-based access to the BugScope electron scanning microscope. Only after an extended visit to the bee laboratory on Day Two, led by Naeger, did the focus of learning shift from bees and bee research in general, to the behavioral genomics investigations being conducted by the BeeSpace Project itself. Days Three, Four, and Five featured increasingly complex slide-illustrated lectures by Naeger and project researchers, interspersed with hands-on activities such as tours and simulations that were intended to complement directly each major talk.

As lead researcher, Buell made use of observational and interview data to develop an account of design features that informed the BSEW08 curriculum. BSEW08 was a one-time event, tied closely to the sponsoring project and involving activities that were created expressly for the workshop. The development aim was not to create a curriculum that could be fine-tuned in further workshop iterations, as the project timeline did not allow for those; instead, the goals were, first, to identify features of design which could inform similarly situated projects in the future, and, second, to capture workshop content via video, in order to create enduring standalone lessons for dissemination via the project's website. Accordingly, Buell's research was not meant to be a full-scale design-based curriculum study (cf., e.g., Clements, 2007; Lamberg & Middleton, 2009). Instead, his aim was to inquire into the nature of the BSEW08 curriculum, giving consideration to the situation of the workshop with regard to its participants, their goals, and the circumstances mediating their activity during the week.

Data analyzed for investigation into the second research question consisted of full transcriptions of interviews Buell conducted with workshop organizers and students both prior to and following the workshop, video recordings for fifteen hours of workshop activities and related transcriptions, written responses prepared by students during the week, and planning documents and field notes that Buell had prepared in his capacity as a workshop organizer. In written form, this data amounted to more than three hundred pages of single-spaced text. To draw meaning from this qualitative data relevant to the research question, he utilized the approach of constructivist grounded theory (Charmaz, 2000). This variant of grounded theory methodology (Glaser & Strauss, 1967; Strauss & Corbin, 1994) recognizes that researchers' interpretations will necessarily play a role in the identification of concepts from the data, but shares with other varieties of grounded theory the use of descriptive and category codes as methods for data reduction, together with a process of constant comparison among groups, concepts, and observations to arrived at understandings supported by evidence.

If RSMSS outreach as we described it in the typology of Table 1 entails efforts to bring the understandings of research science into the domain of school science, through

processes of adoption and adaptation and through use of HOPSI (hands-on, problem-solving inquiry) pedagogy, then our research into characteristics of the BSEW08 curriculum leads us to suggest that in this instance, BeeSpace was involved in something rather different from RSMSS outreach as typically enacted. Instead, the week took shape as what might be considered an intensive instance of “lab tourism,” wherein students were brought into contact with project science through high-touch activities like anatomical dissection of bees and visits to beehives and research facilities, and were then involved as seminar learners for multimedia-supported lectures designed to tap into the background knowledge and interest developed through the preliminary activities. In the remainder of this paper, we adopt the term “Inreach” to emphasize the difference in approach. The essential difference from RSMSS outreach is that Inreach does not aim to repurpose the actors, tools, and facilities of research science to fit school science purposes, but instead aims bring young learners into the world of research science itself, even if primarily as visitors rather than as partners.

At this stage in our explorations, we consider seven aspects as being of central importance to the notion of Inreach (Figure 4). Together, these comprise a tentative and partial model for Inreach that may operate in somewhat nested fashion, as depicted in Figure 2. Our assertion is that the structuring of BSEW08 supported students’ regarding the workshop week as a *coherent experience* in which *scientific authenticity* was maintained by mechanisms including *necessary simplifications* and *characteristics of the research setting* itself, and from which learners were led toward *connecting worlds* of scientific research and academic study, in ways relating in part to *characteristics of the students* themselves and their consideration of how the BSEW08 fit in with their own *learning trajectories*. Inreach is offered here as a broad-brush sort of model, descriptive of what was done and what learners came away with, rather than of any fully substantiated theory. Aspects we identify as being part of the approach taken with BSEW08 are these:

- *Coherence of Experience.* Learning can be enhanced through educational encounters that present new material in ways that are structured in logically connected fashion, rather than piecemeal.
- *Scientific Authenticity.* To the extent feasible, artificiality is to be avoided in favor of subject matter and approaches that are authentic to the scientific content that is the topic of study.
- *Connecting of Worlds.* Learners construct meaning from newly encountered material through a process of discovering and appreciating connections and relationships between that material and knowledge they already have.
- *Characteristics of Setting.* As a means of building coherence of experience, elements of the setting can be arranged in such fashion that opportunities for learning can be enhanced. Situational elements that can be manipulated to enhance learning opportunities may include settings, facilities, technologies, opportunities for interaction with experts, and narrative guidance.
- *Necessary Simplifications.* Despite the desirability of incorporating scientifically authentic content and approaches, real-world considerations and circumstances will frequently limit the degree of authenticity that may be attained. Among such considerations are safety, security, expense, and availability of resources.
- *Characteristics of Learners.* Learners will differ with regard to readiness and willingness to engage in the work of relating newly encountered material into their existing understandings. Pedagogical approaches to facilitate the work of learning are thus unlikely to be reducible to a narrow set of recipes; different pedagogies are likely to be most effective with different combinations of learners and curricular content.
- *Learning Trajectories.* Individuals and groups of learners bring their histories and expectations with them into new educational encounters. The work of connecting personal understandings and curricular content is thus socially and historically situated.

As is typical with grounded theory accounts, the Inreach model has been developed through close qualitative analysis of empirical data collected through case study; in this instance, the data available to us from BSEW08 included field notes, pre- and post-workshop interviews of students and developers that were audiotaped and transcribed, and lesson content that was videotaped and transcribed. The methodological approach of design-oriented case study uses these grounded theoretical understandings as an evidence base for drawing out design principles with potential applicability to other learning situations.

In the next section, we make use of the Inreach model in taking up the question of how students learned from the BSEW08 experience.

How did students learn from BSEW08?

Our design focus and the inclusion of leading-edge scientific content imposed limitations on the kinds of evidence that could be collected for student learning: the curricular content of BSEW08 emerged from the presentations delivered by the expert speakers themselves within the workshop week, and so was not available beforehand so that researchers could construct pre-test questions to assess learners' prior knowledge directly. Moreover, although it would have been possible to construct content-specific post-test items from the videotaped and transcribed curricular materials, this step was not taken in the research, for several reasons. First, without pre-test measures available, it was felt that such post-testing would yield inconclusive and uninterpretable results. Second, it was felt that an unvalidated test of content-specific knowledge given to a small group of learners would tell us little, even if differing degrees of prior knowledge could somehow be factored out. Third, for the project as a whole, BSEW08 was an exercise in small-scale outreach and educational materials development, rather than a research enterprise in its own right; as mentioned above, educational research is rarely if ever an integral part of leading-edge scientific research projects, and BeeSpace was no exception in this regard. Finally, researcher interest had more to do with how students

perceived the relevance of the workshop experience in their learning, than with the salience of particular items of information they might have gleaned from the workshop week. For all these reasons, we approached the question of learning through semi-structured interviews with students rather than through content testing. Eleven of the fourteen students who took part in BSEW08 participated in the interview research as well. These included seven girls (four incoming sophomores, two incoming juniors, one incoming senior) and four boys (two incoming sophomores, one incoming junior, one incoming senior). Students' names have been replaced by pseudonyms in this report.

Interviewing took place at three points. First, one week prior to the workshop, each student was interviewed by telephone about their interest in being part of BSEW08, about their prior experiences with science learning in and out of school, and about their background knowledge in the areas of insect biology and genomics. Each pre-BSEW08 interview lasted ten to fifteen minutes and was audio-recorded and transcribed. Second, focus group interview sessions were conducted of the students at the end of the workshop week, with half the group participating in each session; topics included their impressions of successful and less successful activities and the workshop overall, and their suggestions for improvement if the workshop were to be offered again. Each focus group session lasted about thirty minutes and was videotaped and later transcribed. Finally, roughly four months after the BSEW08, in mid-November 2008, each student was again interviewed individually by telephone, about their recollections of workshop week activities, their impressions of the workshop as a whole, and their ideas concerning how what they had learned at BSEW08 related to other aspects of their learning, both prior to and subsequent to the workshop week. These interviews lasted ten to fifteen minutes apiece and were audio-recorded and later transcribed.

For reasons of space, only information collected during the interviews four months subsequent to the workshop is discussed in this paper. Analysis of students' interview statements from this time showed them to be quite similar overall to statements they had made in the end-of-week focus group sessions, and to statements

they had made relating to interests in their pre-interview sessions (Buell, forthcoming). Below, we present students' comments about the workshop in relation to aspects of the Inreach model introduced above.

Coherence of Experience and Connecting Worlds. As evidenced by comments made by developers in the course of planning the BSEW08 curriculum, a primary objective was to build coherence of experience through enactment of a curriculum that would support connecting the worlds of students' everyday experience and the project's scientific exploration. Comments made by interviewed students four months later indicate in general terms the sense they made of the workshop week, and the detail with which they remembered its content. We consider comments like the following to support a claim that students considered BSEW08 a coherent learning experience:

“[I learned about] behavior in general and how it changes from bee to bee, like the differences between the queen and the workers, how they have sort of like a caste system, and they [workers] can move up as they go older.” (Audrey, incoming sophomore)

“I learned a lot, for instance about how the bees navigated, how they used the sun to get their bearings. I thought that was very surprising. It was also very cool to learn about the bees' life cycle and what they bee researchers were doing.” (Jeff, incoming sophomore)

“I would say that I learned a lot about their behavior, and that it's very interesting how there's specific behavioral patterns that can be discerned for different types of bees, which I thought was fascinating. And it's just interesting how they can all communicate as a community. I really saw a lot during the week, especially when we talked about and got to witness the waggle dance.” (Ruth, incoming sophomore)

Closely related to *coherence of experience* is the ability for learners to *connect worlds* of workshop content and everyday experience. Learners' ability to make such use of the BSEW08 experience is evidenced through responses like the following:

“I never realized how important bees were. I always found them to be pesky because they stung me. Now I’m definitely more aware when I see bees’ nests or wasp nests, so it does come back in my memory.”
(Eileen, incoming sophomore)

“I didn’t know anything about bees before. And not only are they interesting – I mean, they waggle dance and things like that – but they’re actually kind of fascinating. I kept reading the book you handed out right at the end [Gould & Gould’s *The Honey Bee*, 1995]. I mean, they’re programmed so that they waggle dance less accurately the closer the flower patch is. And all the bees will go out and spread out over a wide area. But if it’s really far away they’re very accurate, they all land in the same flower patch of the same size, even though it’s farther away. It’s fascinating. I didn’t know any of this stuff, and it’s just really cool.”
(Jonathan, incoming senior)

“What I got from BeeSpace is a new perspective on genetic research. I think BeeSpace really seeks to introduce students to a type of research they don’t necessarily get a chance to learn about in school, because in school biology courses we only get the very basic information. To have the same information applied to something more specific, like research on bees, is actually a very good way to cement our understanding.” (Vivian, incoming senior)

In the main, the students’ comments indicated solid general recall of the content and structuring of the workshop week, four months after the event. We interpret the nature and specificity of their recall, together with their comments regarding the structuring of the workshop week, as support for a notion that the students experienced BSEW08 as a coherent whole, and as a vehicle for helping them to connect the worlds of academic study and scientific research.

Scientific Authenticity Characteristics of Setting, and Necessary Simplifications.

From the outreach initially envisioned in the project proposal through the planning of

BSEW08, BeeSpace principals spoke and wrote about the project in ways that emphasized developing educational opportunities that were authentic to the science of the project, rather than contrived. In BSEW08, this resulted in a curriculum that centered on scientists' showing and explaining their work in ways they believed would be accessible to young learners.

Some students recalled particular laboratory procedures that they had learned about:

“The qRT-PCR was very cool, and the microarrays. I kind of like it when we did that [microarray simulation activity] to figure out which genes were present.” (Steven, incoming sophomore)

“I learned a lot of the different techniques like ... qRT-PCR, and how they used [micro]arrays to get a lot of data from just one solution set, so you could have a great amount of data points and analyze them all relatively easily, rather than just looking at each individual one, which is time-consuming.” (Arthur, incoming junior)

Other comments pointed to students' recollection of details of the authentic research setting in which the workshop took place:

“I think the laboratory environment was the most important, in my perspective, because it kind of showed students what it's really like to be researching things, discovering new things, in a real environment, a real situation, with real tools and facilities to use. So that really seemed to stick with me afterwards.” (Ruth, incoming sophomore)

“It was really cool to go out and look at hives, but I learned a lot about all kinds of different diseases affecting honey bees, and how gene expression is worked out. I have to say that the tour of the bee lab with the giant mirrored room where they get to control the length of the day cycle just to see what happens, that was really interesting. Now no one dares to bring honey bees up around me because they know I'll talk for half an hour.” (Jonathan, incoming senior)

“I thought it was really cool to go out where you kept the bees, getting to see all that and going on a tour of the labs that they have there.” (Vivian, incoming senior)

For developers of BSEW08, the desire to offer an authentic and immersive learning experience to the young learners conflicted on occasion with the painstaking, expensive, time-consuming, and occasionally hazardous facts of laboratory and field research. Naeger, the entomologist who was the workshop’s main presenter, remarked on one occasion, “In so much of the lab work you just, when you’re doing it, you just transfer a drop of some liquid into a tube with some other liquid in it, and you never really see what’s going on, and so you can’t really show them what’s happening that way.... I do feel perhaps that I didn’t emphasize enough some of the ugliness of lab work, how finicky it can be, and the large number of non-results, and what a long and time-consuming and expensive process it is.” In interviews, however, two students picked up on just that aspect of scientific research:

“I was surprised at how committed these professors and students and researches are to solving this problem, using this as a model. There were so many setbacks, and someone could easily have given up at that point and started something new, but they were very dedicated.... Even though they had some setbacks, they’d move past them and create new things.” (Arthur, incoming junior)

“I learned that it’s pretty tedious, but very rewarding. It seems to have a lot of potential, because I know the genome has been almost entirely decoded, and it seems to be giving a lot of interesting information to researchers at this point.” (Ruth, incoming sophomore)

The tension between authenticity and necessity for simplification was particularly acute with regard to introducing the students to microarray analysis, a laboratory technique that was critically important to BeeSpace behavioral genomic research. Microarray studies can be carried out only after bee brains are harvested from a field study that can take weeks or months, and laboratory analysis involves a complex

process that can itself take weeks, uses chemicals that are harmful unless handled with caution, and costs tens of thousands of dollars. Even so, Naeger recognized that simply talking about the process in a slide-illustrated presentation would not suffice to engage the students in understanding what the microarray analysis entailed. “That’s one reason I liked the little microarray demo kit,” he recalled of the simulation activity. “I thought that was ideal. In the simulation that we ran, basically we dotted the slide, we added a chemical to the dots, and we looked at the color. The actual array is about a one-hundred-and-twenty-step process including steps where one step would take five hours -- other steps can take just a minute. But it’s very time-consuming and it’s very expensive -- hundreds of dollars per slide -- and so the fact that there is this cheap and easy simulation, I think, is very beneficial.” In a separate conversation, the biology teacher (Stone) also spoke about the value of the activity, commenting, “I thought that was particularly useful after the introduction to BeeSpace, because that also included an introduction to microarrays. But a simulation isn’t nearly as meaningful as a real activity, and a simulation by itself doesn’t mean a whole lot unless you have the context already.”

Six of the eleven students made a point of mentioning the simulation activity in the November post-workshop interviews. Although one characterized it as a “little mini fake lab-type thing where we did some RNA processing and gene isolation” and said she “wanted to learn more about microarrays” than could be conveyed in the workshop, five others who also mentioned the activity in the post-workshop interviews said they found it useful and would have liked the opportunity to do more activities of the sort.

Characteristics of Learners and Learning Trajectories. It must be acknowledged that the learners who took part in BSEW08 were a highly select group. This was due in part to the subsidiary place of educational outreach within the project as a whole, in part to an expressed desire to make educational opportunities available to young learners most ready to benefit from them, and in part to the perception by project principals that making use of a high-stakes research laboratory as a classroom for young learners depended upon developing relationships of trust. While prior episodes of

educational outreach by the project were considered for and offered to learners of middle school age, a decision was made in the planning of BSEW08 to offer places to students who had completed freshman year high school biology. Moreover, the involvement of a high school biology teacher (Stone) from the outset of the project offered unparalleled opportunities to engage students from that school, a university-affiliated institution that is generally ranked as one of the top-performing public high schools in the nation, as part of the outreach. In addition, the fact that each of the participating students was a volunteer, willing and able to devote a week of summer to BSEW08, ensured that only individuals with strong interest in the workshop and its activities would be part of it. This was a group whose members would have to be considered as having no difficulty with “border crossing” into science, to borrow Glen Aikenhead’s (2001) phrasing. Even so, only about half of the participating students expressed interest prior to the workshop in continuing study of biology beyond high school; several claimed greater academic interest in subjects ranging from computer science to English literature, and others expressed indecision about what they might study in college.

Overall, the students suggested in the November interviews that their experience with BSEW08 had left them more interested in studying biology in general, and bee behavior and genomics in particular. Students who had not previously considered biology to be their career path made comments like these in the November interviews:

“I’ve found that a lot of my interests do relate to animal psychology and animal behavior, to understand various species, and to understand humans through various species, or making obscure connections between various types of animals and animal societies. So I guess understanding honey bee behavior is pretty central to my college major. I might even end up going into that if -- well, a lot can change in two years, but maybe. And I guess that whether or not I end up going into that, it’ll affect me anyway, because in the end science ends up

affecting almost anybody who's part of the world." (Marge, incoming sophomore)

"I got a better feel of what this field would be like if I actually went into it. It's definitely higher on my list of careers than before. Right now I'm thinking about English as at the top of my list, but I know you can do that and combine it with something else. I'm still working on the 'something else' part." (Audrey, incoming junior)

Several students who had expressed general interest in biology prior to the workshop week indicated that their experience in BSEW08 gave them an improved sense about where such an interest might lead:

"If I ever do anything with genomes of any sort, that [workshop week] would be terrifically useful. I was really considering entomology as a major, so that would be useful, too.... I enjoyed it a whole lot, and more than I ever expected. [I'm surprised by] the amount of information I was able to absorb, or to be bombarded with and then absorb. I mean, we learned a ton of stuff that one week.... The presenters did an absolutely great job of making the information stick, at least for me. I'm still amazed at how much I remember." (Steven, incoming sophomore)

"I actually really enjoyed what we learned during the week, and I thought that it would be a great career path to follow.... It's always going to be a viable career path, because there's always more species to study. And problems will keep on arising, and we'll always want to see if those problems are traced back to the DNA or some evolution of the DNA. And so it's actually influenced what I want to study in quite a bit, and made me think that this is something I would really enjoy doing." (Arthur, incoming junior)

"I thought giving students the experience to observe and understand scientific research is something that's very valuable, something that not a whole lot of students can actually get to

experience.... It definitely leaves a different impression of going into science, as opposed to what you learn in schools.” (Karen, incoming sophomore)

Overall, the comments made by the students in the semi-structured interviews conducted in November, four months after the BSEW08 workshop week, showed them to be a group that both retained general knowledge of the BSEW08 content and considered carefully how what they had learned during the week might relate to their enduring interests. BSEW08 appears to have stood out for them as a highly memorable experience in its own right, and to have afforded substantial opportunity for integrating the week’s content with their ongoing trajectories as learners.

Memorability of BSEW08

Although the November interviews were fairly brief – about fifteen minutes apiece – they turned up evidence that the students were recalling aspects of the workshop week quite well at a distance of four months. One question asked during that interview was this: “From the vantage point of these several months, what stands out most about the workshop week?” We find Endel Tulving’s discussion of *episodic memory* to be a useful starting point for interpreting the learners’ responses to this question. Tulving (1972) describes episodic memory as “a more or less faithful record of a person’s experiences” such that “every ‘item’ in episodic memory represents information stored about the experienced occurrence of an episode or event.... To ask a person about some item in episodic memory means to ask him when did event *E* happen, or what events happened at time *T*” (Tulving, 1972, pp. 387-388). Tulving (1985) distinguishes episodic memory both from *procedural* memory (which “enables organisms to retain learned connections between stimuli and responses”) and from *semantic* memory (which is “characterized by the additional capability of internally representing states of the world that are not perceptually present”); only episodic memory “affords the additional capacity of acquisition and retention about personally

experienced events and their temporal relations in subjective time and the ability to mentally ‘travel back’ in time” (Tulving, 1985, p. 387).

Students’ responses to the interview question, “What stood out for you about the workshop week?”, serve to illustrate both the variety of topics that were covered and the variety of interests that different students brought to the experience. Each of the following comments strikes us as being primarily episodic in nature:

I would have to say it was the activities, like visiting the bee lab, being able to wear the beekeeping suits and having the talks, and building our tree trunk for the bees to live in. (Debra, incoming sophomore)

I would say just the ability of the speakers to connect with a bunch of high schoolers at some level. I would have expected – they're so smart, that they might not be able to express it in the best way for us to understand it. But they talked at a very informal level and I got a lot from their talks. I think a lot of the other kids did too. (Audrey, incoming junior)

The things I remember most were talking about the Colony Collapse Disorder, and actually going out to visit the bees. And I remember some of going to visit the bee laboratory, talking about how they can change the environment to actually observe bee behaviors. And I remember some about the microarray studies. But I don't remember a whole lot about the actual genomics. (Jeff, incoming sophomore)

I really liked all the hands-on stuff that we got to do. Having an opportunity every day to go out and do something really worked well with the lectures and everything.... I thought it was great to go out where you kept the bees, and getting to see all of that and going for a tour of the labs that they have there. (Vivian, incoming senior)

Other questions asked in the November interview invited the students to state what they had learned in semantic or procedural terms. Two such questions were these: “What would you say you learned about bees and behavior during the week?” “What

would you say you learned about genomic research during the week?”. Consideration of students’ responses to these questions moves us beyond episodic memory in its own right, some way toward what some researchers have termed a “remembering to knowing shift,” in which factual material that is initially recollected in connection with the circumstances in which it was learned (such as in a college classroom), may in time become incorporated into learners’ conceptual knowledge, as the learners gradually forget how they acquired it (Conway et al., 1997; Herbert & Burt, 2004). In introducing the concept, Conway et al. (1997, p. 395) wrote:

We suggest that when a new knowledge domain is to be acquired, memory is represented initially in a way that supports or even compels recollection of the learning episode. As learning proceeds, the underlying representations may change such that they no longer primarily lead to recollective experiences and instead become so highly familiar that they are simply known. Thus, we postulate a shift in the basis of learning that is episodic and literal to learning that is semantic and conceptual.

Responses related to the students’ learning about bees and behavior suggest to us that, although the students recollected well where they had learned the facts they spoke about, they were at the same time able to discuss them in general-knowledge terms. These include the following:

Well um, bee behavior I think has to a lot with trying to protect the brood, and making sure that the young have enough food to grow into productive members of the hive, so that they can make more young. And they also have to make sure they collect enough food for winter. And I think a lot of it goes into preparing the hive so that the next generation can come. And once there begins to be too much, then they have to go and make a new hive. (Arthur, incoming junior)

We learned that the scans of brain activity were different for the different social – like the workers and the queens. But there are different stages in life. First they were nurses, and then workers, and then like

there were progressions in their work activities. (Debra, incoming sophomore)

Most interesting was that it had parallels to human nature. So I could see more things about that than I could with some of the others, which seemed more hypothetical to me or seemed to apply more to just bees or insects. (Eileen, incoming sophomore)

I learned a lot about, for instance, how the bees navigated, how they used the sun to get their bearings. I thought that was very surprising. It was also very cool to learn about the bees' life cycle and what the bee researchers were doing – that was also very interesting. (Jeff, incoming sophomore)

Well, especially mostly about worker bees and their behavior. And just the way throughout their life they might be nurses or foragers, and certain genes are activated when they are nurses or foragers for collecting food and stuff, but that changes depending on what the hive needs. And so it shows environmental influences and genes. (Karen, incoming sophomore)

The thing I remember most is about colony collapse disorder, and how all of a sudden bees are disappearing and they have no idea where they went. (Vivian, incoming senior)

From the standpoint of assessing merits of the BSEW08 curriculum, the post-interview responses amount to a rich array of episodic memories, held in detail by participants four months after the summer workshop. This richness of detail should not come altogether as a surprise, in light of prior studies that show how vivid episodic memories can be retained over many months or years (e.g., Falk & Dierking, 1997, Anderson & Shimizu, 2004; Medved & Oatley, 2000). Even so, locating it here provides some support for a finding that the participants experienced BSEW08 as sufficiently out of the ordinary to have retained its episodic coherence at a distance of four months to a greater extent than, for instance, a series of lectures on its own (cf., Conway et al., 1997;

Herbert & Burt, 2004). At the same time, the participants' ability to speak in some detail about particular knowledge they had gained from the workshop, regarding topics such as bee behavior and genomic biology, provides support for a finding that, as with the studies carried out by Conway et al. and Herbert and Burt, the participants' memories of BSEW08 were at least in part available to them as semantic knowledge as well. Taken together, these findings suggest that, at least for the group of academically advanced volunteer learners who took part, the curricular format of BSEW08 functioned in ways akin both to information-rich academic lectures with carefully sequenced content, and to high-interest, out-of-the ordinary experiences ranging from field trips to residential camps to expositions.

Moreover, value can be seen in the finding that different post-interview questions tended to elicit participants' recollections either primarily as episodic memories, or as such memories in linkage to semantic knowledge. This brief account of students' interview responses at a single point in time cannot provide definitive answers, but in all, the interview data point to BSEW08 as a rich curriculum that shows evidence of memorability and holds out promise for planting seeds of enduring meaning in the participants' lives.

Potential for Inreach to connect learners with leading-edge science

Educational scholars at least as far back as John Dewey have sought the means to bring young learners into meaningful connection with the cultural wealth that is embodied (some say entombed) in school curricula. In this section of the paper, we consider briefly how an Inreach curriculum itself might accord with Dewey's ideas. Our intent in doing so is to see if a place for an Inreach pedagogy might be carved out, particularly in settings that potentially have much to offer to the education of young learners, but where a pedagogy of hands-on, problem-solving inquiry might not readily fit, such as science laboratories where high-stakes, leading-edge research is being carried out. To be clear, we do not mean to put the pedagogies into competition with

one another, but rather to suggest some areas where each might be the better fit, and some ways in which they might usefully be brought into fuller connection.

For Dewey, the content of a curriculum holds potential for meaningfulness through the facts, or *symbols*, it brings into relationship: “The genuine form, the real symbol, serve as methods in the holding and discovery of truth. They are tools by which the individual pushes out most surely and widely into unexplored areas” (1902/1954, p. 24). However, the potential for meaningfulness remains unfulfilled unless those symbols can be connected with the learner’s experience: “A symbol which is induced from without, which has not been led up to by preliminary activities, is, as we say, a *base* or *mere* symbol; it is dead and barren. Now any fact, whether of arithmetic, or geography, or grammar, which is not led up to and into out of something which has previously occupied a significant position in the child’s life for its own sake, is forced into this position. It is not a reality, but just the sign of a reality which *might* be experienced if certain conditions were fulfilled” (p. 24, emphasis in original). By this reasoning, an important measure for the meaningfulness of a curriculum to learners must rest in its capacity to encourage the taking up of the material as authentic symbols, thereafter accessible to the learners as objects for further learning.

In Dewey’s estimation, symbols of knowledge take their meaning from the relations to which they belong. Thus, elsewhere (*Democracy and Education*, 1916/1985), he argued that everyday objects fulfill this symbolic function best only if transformed into objects of scientific reasoning. He used water as an example:

The everyday conception of water is more available for ordinary uses of drinking, washing, irrigation, etc., than the chemist's notion of it. The latter's description of it as H₂O is superior from the standpoint of place and use in inquiry. It states the nature of water in a way which connects it with knowledge of other things, indicating to one who understands it how the knowledge is arrived at and its bearings upon other portions of knowledge of the structure of things. Strictly speaking, it does not indicate the objective relations of water any more than does a statement

that water is transparent, fluid, without taste or odor, satisfying to thirst, etc. It is just as true that water has these relations as that it is constituted by two molecules of hydrogen in combination with one of oxygen. But for the particular purpose of conducting discovery with a view to ascertainment of fact, the latter relations are fundamental. The more one emphasizes organization as a mark of science, then, the more he is committed to a recognition of the primacy of method in the definition of science. For method defines the kind of organization in virtue of which science is science. (p. 224)

Dewey returned to this example in *The Quest for Certainty* (1929), commenting:

Water as an object of science, as H₂O with all the other scientific propositions which can be made about it, is not a rival for position in real being with the water we see and use. It is, because of experimental operations, an added instrumentality of multiplied controls and uses of the real things of everyday experience.

By Dewey's reasoning, an important measure of the ability for a curriculum to lead to scientific understanding inheres in its capacity for transforming objects of everyday experience into objects of inquiry. In the case of BSEW08, interviews of learners and observational accounts suggest that the BeeSpace workshop curriculum moved learners from everyday knowledge of honey bees, as organisms in nature and as agriculturally important insects, to a scientific knowledge of the species *Apis mellifera* as a model organism for scientific examination of the genetic basis for insect social behavior. In essence, the BSEW08 curriculum centers on the sentiment famously expressed by Theodosius Dobzhansky in 1973: "Nothing in biology makes sense except in the light of evolution." Developers of the curriculum intended for the project's leading-edge science research to serve as an accessible example to non-specialist learners of ways that genetics and experience interact to produce social behaviors that aid a species' survival, whether that species be *Apis mellifera*, *Mus musculus*, or *Homo sapiens*.

Throughout his works, Dewey argued against presenting learners with predigested material for memorization. In *The Child and the Curriculum*, he termed it an “evil” that “even the most scientific matter, arranged in most logical fashion, loses this quality [of functioning as an authentic symbol for inquiry] when presented in external, ready-made fashion, by the time it gets to the child. ... What happens? Those things which are most significant to the scientific man, and most valuable in the logic of actual inquiry and classification, drop out. The real thought-provoking character is obscured, and the organizing function disappears” (1902/1956, p. 26). Dewey has sometimes been interpreted by more recent educational reformers as advocating for learners’ engagement in problem-solving inquiry as the only legitimate pedagogical approach and rejecting any role for “telling” by more accomplished instructors -- the very viewpoint he explicitly rejects in *The Child and the Curriculum*. In his estimation, “No such thing as imposition of truth from without, is possible. All depends upon the activity which the mind itself undergoes in responding to what is presented from without” (1902/1956, p. 31).

Dewey’s ideas as glossed here carry several implications for the seven design features we introduced in presenting BSEW08 as an instance of Inreach. With regard to *coherence of experience*, it is Dewey’s contention that there is no qualitative separation between the learner and the curriculum to be studied; rather, learners’ goals in understanding their world are at one with those of scientists engaged in methodologically rigorous attempts to do the same. Thus, a challenge of making the curriculum meaningful is to make the encounter experiences coherent, bringing learners to a level of understanding that connects personal and social realms of knowledge. This is the essence of “psychologizing,” bringing into personal understanding the symbols that scientific understanding brings into relationship with one another. With regard to *characteristics of setting* and the *connecting of worlds*, it is worth noting Dewey’s metaphoric likening of scientific discovery to exploration of new territories, and his insistence that for learning to be experienced as meaningful, learners must come to recognize that the curricular “maps” summarizing the outcomes of discovery are drawn

using authentic symbols that trace relationships and connections between and among phenomena of a living world. Thus, personally meaningful *learning trajectories* develop from an attitude of inquiry that endeavors to understand curricular material as a unified whole and connect it with the learner's lived experience.

Conclusions and caveats

In line with Dewey's own injunction to "abandon the notion of subject-matter as something fixed and ready-made" and to see learners' experience as "something fluent, embryonic and vital," educators have in recent years endeavored to make use of the resources of research science to contribute to the education of young learners. One line of "research science meets school science" approaches takes a pedagogy of hands-on, problem-solving inquiry as the central mechanism for bringing young learners into meaningful contact with the world of scientific discovery. We distinguish a half-dozen such approaches in this paper, namely individual scientists in the classroom, technology-centric initiatives, field trips, citizen science projects, summer science camps, and laboratory-to-teacher initiatives. Successful instances of each type are frequently held up as models for leading-edge research science initiatives that are seeking to make meaningful contributions to the education of young learners. In this paper, we have looked into the case of a leading-edge research project in biological sciences, utilizing a methodological approach we term design-oriented case study to investigate first, how the project's educational involvements took shape over a series of development cycles, and second, how students reported learning from one of the project's educational offerings, BSEW08. With regard to the development of BSEW08, we suggested that Engestrom's notion of interacting activity systems offers an operational model for considering the influence of tensions and contradictions between "worlds" of research science and school science operating over the micro-history of the project life cycle. In seeking to explain the nature of BSEW08 itself, we coined the term "Inreach" to describe what we regard as key features of the curricular design, and utilized features of

the Inreach model to introduce students' comments about what they had learned from their participation in BSEW08. In addition, we looked at BSEW08 from the standpoint of memorability, making use of Tulving's (1972) construct of episodic memory and the notion of a "research to knowledge shift" (Conway et al., 1997). This led us to suggest that design features of BSEW08 might have contributed both to how learners remembered the experience at a distance of four months, and to how they integrated some of the ideas they encountered in the workshop into their knowledge and academic interests. Finally, we suggested that the design features we identified in BSEW08 are relevant to design principles for meaningful learning that have been described by Dewey (1902/1956).

The foregoing discussion is not meant to promote BSEW08 or the Inreach approach as a panacea. We recognize that any conclusions drawn from any single case will be tentative at best, and suggest that any generalizing be done at the reader's peril. Moreover, we acknowledge that there are aspects of the case discussed in this paper, and of the researchers' relation to it and methods for analyzing it, that might justify regarding this work as an exercise in interpretivism as much as of empirical scholarship. The approach of design-oriented case study taken here was, we acknowledge, more emergent than it was intentionally designed, and there is need to take the notions developed from this instance and follow up on them in a more controlled manner, as befits the later stages of curricular design research as described, for instance, by Lamberg and Middleton (2009) and by Clements (2007).

We believe we have made the case here that a curricular approach like that taken for BSEW08, design features of which we abstract into our Inreach model, represents one way that a leading-edge scientific research project can succeed in contributing materially to the education of young learners. At the same time, we believe that the case narrative highlights some potential problems with implementing Inreach in ways that are broadly democratic. We point in particular to the involvement only of high-performing students in BSEW08.

The research described in this dissertation was carried out in what Kelly (2008, p. 5) calls “design research commissive space,” within which researchers intentionally “foreground the fluid, empathetic, dynamic, environment-responsive, future-oriented and solution-focused nature of design.” This was neither a controlled experimental situation conducive to comparative assessment of groups of learners on a criterion variable such as a test or common curriculum, nor was it a setting in which the researchers were solely or primarily visitors, as with much qualitative ethnographic and case study-oriented research. As Kelly writes,

Design researchers often recruit the creativity of students, teachers or policy-makers not only in prototyping solutions, but also in enacting and implementing the innovation, and in documenting the constraints, complexities, and trade-offs that mold the behavior of innovative solutions in contexts for learning. By observing and participating in the struggles of design, and the implementation or diffusion of an innovation, design researchers may learn not only how to improve an innovation, but also how to conduct just-in-time theory generation and testing within the context of design processes and in the service of the learning and teaching of content. (Kelly, 2008, p. 5).

As was the case with this study, design research occurs over multiple iterations, and at least through the middle stages it is well-accepted practice to work in carefully structured circumstances with carefully selected sets of learners in order to set up best-case situations for study of issues that merit research attention. In the words of education design researcher Jan van den Akker, “The aim is not to elaborate and implement complete interventions, but to come to (successive) prototypes that increasingly meet the innovative aspirations and requirements.... An iterative process of ‘successive approximation’ or ‘evolutionary prototyping’ of the ‘ideal’ intervention is desirable” (van den Akker, 2009, pp. 45-46). Mathematics curriculum researcher Douglas Clements has noted that it is often not possible or desirable in a single study to employ all phases of a complete design research framework; instead, investigation

“should proceed in the context of a coherent, dynamic research program that uses all the phases that are applicable and tractable” (Clements, 2007, pp. 61-62).

Circumstances obtaining in the real-world environment of the BeeSpace Project enabled this research to proceed roughly through what Lamberg and Middleton (2009) have conceptualized as the fourth phase of their seven-phase “Compleat Model of Design Research,” the phase of “prototyping and trialling.” The research did involve accomplishments relating to their first three phases (grounded models, development of an artifact curriculum, and feasibility study), but circumstances of the BeeSpace Project did not permit extending to Lamberg and Middleton’s latter phases of field study, a definitive test, and research into dissemination and impact.

In terms of the five questions posed by the National Science Foundation as aspects of its “Broader Impacts Criterion,” the BeeSpace Project’s education initiatives can lay claim through identification and trialing of the Inreach model to advancing “discovery and understanding while promoting teaching, training, and learning” (broader impacts question 1 in NSF, 2010b, p. III-1). Despite not having had opportunity to proceed to definitive tests beyond the favorable circumstances of the summer 2008 workshop, the Inreach model has reached the stage of an “existence proof” in Lamberg and Middleton’s (2009) terms, and with further development shows promise for enhancing “the infrastructure for research and education” (broader impacts question 3) of NSF projects falling under the heading of “Research and Related Activities” (R&RA), as BeeSpace did. Moreover, the conduct of research into BSEW08 contributes to NSF’s desire that outcomes “be disseminated broadly” to enhance understanding (broader impacts question 4). However, the activities reported in this research cannot lay claim to having progressed far in the important area of broadening “the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)” (broader impacts question 2). Largely as a result, NSF’s fifth “broader impacts” question, seeking information about the benefits of the approach “to society,” remains difficult to answer.

As Jennifer Greene and colleagues (Greene, DiStefano, Burgon, & Hall, 2006, p. 54) have observed, “There is a powerful need to promote STEM education that includes

high-quality scientific content, effective pedagogy, and sensitivity to equity and diversity concerns.... In our experience, it is quite common to observe STEM programming that considers two domains yet overlooks or struggles to address the third.” The Inreach approach that we describe in this paper depends crucially upon affordances and constraints of leading-edge scientific research projects like those funded through NSF’s R&RA-oriented programs, as distinct from the Foundation’s Education and Human Resources Directorate’s programs. Features of R&RA projects position them differently from EHR projects with regard to capability for developing and delivering educational opportunities that amount to coherent experiences, rich in scientific authenticity and with potential for connecting the worlds of learner and scientific researcher. Only now that the broad outlines of this approach have become clear does it appear feasible or defensible to propose the approach for use in learning settings that are intended to meet the needs of a broad range of learners, with abilities and interests positioning them at all points of the “border crossing” continuum described by Aikenhead (2001), from “potential scientists” to “outsiders.” Now that the results described in this research have been found with the admittedly elite group of learners we involved in our prototype efforts, it becomes more justifiable to investigate implementing the approach more generally.

An additional challenge relates closely to the one discussed above, but merits separate attention. From the standpoint of the scientific researchers and laboratories involved in this research, an important consideration at all phases of educational involvement was the matter of *trust*. Stone, the high school biology teacher who developed educational materials for the project and who recruited the students for the 2008 summer workshop, had worked with the project from its inception in 2004. He was known to one of the project investigators both as a former graduate student and as a collaborator on previous educational projects, and to several other investigators as a teacher of their own children when they attended the high school where he taught. The level of trust that existed among the project researchers, staff, schoolteachers, and students extended beyond the boundaries of the project in ways that were highly

facilitative for the kinds of educational interactions that could be attained. However, it is no small question to ask whether these sets of relationships might have some bearing not only on the level of resources that project investigators permitted to be put to educational use, but also on the potential and limitations of the Inreach model itself as a means for promoting the sorts of broader impacts that the National Science Foundation seeks to attain. John Dewey's (1899/1956, p. 7) comments in this regard are well worth recalling: "What the best and wisest parent wants for his own child, that must the community want for all of its children. Any other ideal for our schools is narrow and unlovely; acted upon, it destroys our democracy."

For these reasons, it is imperative that further investigations into the Inreach model directly take up the issue of trust. In the BeeSpace instance, trust was accomplished through both formal and informal means, and through the growth of connections that originated outside the scope of the project and are likely to extend beyond it. To the extent that a high level of trust is important to the success of school-laboratory collaborations along the lines of the model described here, this question must be posed: Do formal aspects of the Inreach design lend themselves to development of that level of trust, in ways that can open up this set of opportunities to schools and students that are not fortunate enough to share the level of informal connections that enabled the design to emerge as it did from the circumstances afforded by this particular project? Important testing grounds for the Inreach model would be substantial NSF Education and Human Resources directorate-supported programs where pre-university education is held to be of research interest in its own right, with program goals and funding levels in place to support broadening of the investigation begun here.

It is not our intent to position Inreach as a competitor to forms of RSMSS outreach that are grounded in HOPSI pedagogy. Each approach, we believe, has an important role to play in bringing new generations of young learners into contact and communication with the realm of scientific research. For that matter, activities such as BSEW08 and Electronic BeeSpace need not be considered ends unto themselves, but

could potentially be components of Inreach/outreach cycles that move between bringing learners and teachers into connection with scientists and their work via Inreach, and bringing those who have participated in Inreach experiences back into the classroom to share their experiences and enthusiasm with classmates and colleagues in the school setting.

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Tables and Figures

RSMSS Type	Description	Exemplary Studies
Individual scientists in the classroom	One-on-one collaborations between laboratory scientists and classroom teachers that are intended to improve classroom science learning.	Andrews, Weaver, Hanley, Shamatha, & Melton, 2005; Bybee, 1998; Bybee & Morrow, 1998; Druger & Allen, 1998; González-Espada, 2007; Laursen, Liston, Thiry, & Graf, 2007; Waksman, 2003; Avery, Trautmann, & Krasny, 2003; Bers & Portsmore, 2005; Buell, Harnisch, Bruce, Comstock, & Braatz, 2004; Doore et al., 2008; Dyehouse, et al., 2009; Lundmark, 2004; McIntosh & Richter, 2007; Moldwin et al., 2008; Stewart et al., 2009; Wolf & Laferriere, 2009.
Technology-centric initiatives	Initiatives that center on introducing students to innovative technologies whose use is ordinarily reserved for scientists engaged in advanced research.	Bruce, Jakobsson, Thakkar, Williamson, & Lock, 2003; Bruce et al., 1997; Thakkar, Bruce, Hogan, & Williamson, 2001; Potter, Carragher, Carroll, et al., 2001; Young, 2009.
Field trips for science learning	Out-of-school visits undertaken for educational purposes in which learners observe and study the material of instruction directly in functional settings.	Krepel and Dural, 1981; Orion, Hofstein, Tamir, & Giddings, 1997; Drayton & Falk, 2001.
Citizen science projects	Projects or programs in which volunteers, many without specific scientific training, assist in research-related tasks such as observation, measurement or computation.	Bhattacharjee, 2005; Bonney, Cooper, Dickinson, et al., 2009; Brossard, Lewenstein, & Bonney, 2005; Potenza, 2007; Trumbull, Bonney, & Grudens-Schuck, 2005.
Summer science camps	Intensive face-to-face interactions between scientists and students in lab settings outside of school time.	Hay & Barab, 2001; Fields, 2009; Waksman, 2003.
Laboratory-to-teacher initiatives	Collaborations between teachers and scientists that do not involve students directly, although they are typically intended to change teachers' practices.	Anderson, 1993; Drayton & Falk, 2006; Howe & Stubbs, 2003; Loucks-Horsley, 1999; Willingale-Theune, Manaia, Gebhardt, De Lorenzi, & Haury, 2009.

Table 1: Six varieties of Research-Science-Meets-School-Science educational initiative.