

FROM OUTREACH TO INREACH:
CONNECTING YOUNG LEARNERS WITH
THE WORLD OF EMERGING SCIENCE

BY

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DISSERTATION

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Abstract

Agencies that fund scientific research have called increasingly in recent years for the projects they support to contribute to broader social and educational impacts. However, the means by which these projects might best utilize their own resources to support educational outcomes for young learners have received relatively little attention. This dissertation explores how a scientific research project developed a summer 2008 science education workshop for high school students, situates the case within a larger context of leading-edge scientific research projects having public education aims, and considers ways in which carefully structured learner-scientist interactions may contribute to young students' meaningful learning of science. The research questions are:

1. How did scientists and educators in a university research project come to design an intensive educational activity on the topic of their research, for an audience of high school students?
2. What were the distinguishing features of this educational activity?
3. How did the students learn and remember from this experience?

The research takes shape as a design-oriented case study, tracing the development of the education initiative from its beginnings through its impact on learners. The first research question is explored through the technique of “design narrative” (Barab et al., 2008), to trace the development of ideas that culminated in the workshop curriculum through a series of six design episodes that occurred over a four-year span. The second question is investigated through qualitative analysis of workshop documents and post-workshop interviews with organizers and learners, and through comparison of the workshop curriculum with various sorts of “research-science-meets-school-science” (RSMSS) outreach that have been reported in recent science education literature. The third question is explored through analysis of the workshop's memorability, as evidenced by comments made by learners in interviews four months after the workshop. Findings relating to the first question indicate that tensions and contradictions between the project's primary research role and its secondary educational aims were important factors in shaping the curriculum of the 2008 summer education workshop. Investigation of the second question revealed ways in which the 2008 curriculum differed from the various forms of RSMSS outreach previously reported, and led to a conclusion that the form of

curriculum exhibited by the workshop merits consideration as “Inreach” rather than outreach. Investigation of the third question revealed that at a distance of four months, learners continued to recall episodic aspects and substantive knowledge from the workshop in detail. Analysis of this set of findings suggests ways in which features of the workshop curriculum enhanced its memorability by students. A separate chapter considers how design features of the 2008 curriculum relate to principles for learning that are drawn from the literature of science education. In the concluding chapter, the study’s findings are considered with regard to how they might strengthen efforts by scientific research projects to develop and deliver forms of educational involvement that are both meaningful for students and supportable within the means of the projects themselves. In addition, consideration is given to ways in which the findings from this research might spur further investigation in subsequent design-based research that overcomes limitations inherent in a single-case study.

Acknowledgments

“The truly educated never graduate,” proclaims a bumper sticker I spotted last week in a university parking lot. Completing this dissertation some fourteen years after beginning PhD studies in the University of Illinois College of Education, I must admit I have come perilously close to being truly educated. An extended involvement in doctoral studies that that started from an interest in educational technologies for language learning (developed over a decade of teaching English to international learners) has somehow led me to dissertation work in the area of project-related science education. And as another slogan has it, the joy has been in the journey. In these acknowledgments, I would like to express my thanks to the people and groups that have led to my extended stay in one of the world’s pre-eminent university communities, and whose influences and support have made possible both this dissertation and the sometimes-meandering path of scholarship that has led to it.

My mentor, guide, and inspiration throughout my too-long journey as a doctoral student has been Chip (Bertram C.) Bruce, a polymath and all-around nice guy whose watchwords have been inquiry, collaboration, community, and meaningful engagement across cultural and institutional divides in order to accomplish social change. I would like to think that in some small way at least a few of these qualities come through in this dissertation, which he has done so much to help me bring to completion. Chip and I first met during my first semester as a graduate student, through a seminar course he taught on the topic of evaluation of instructional technologies. He became my de facto adviser following Jim Levin’s departure from Illinois in 2003. It was far from being a job responsibility – Chip’s primary faculty affiliation was with the University’s school of library science, and he was not affiliated at all with the department of educational psychology in which I was enrolled. Nonetheless, he went out of his way to steer me toward research assistantship positions that were highly educative for me – first as an evaluation assistant with the National Science Foundation-funded GK-12 program on campus, and subsequently with the NSF-funded project that is the subject of this dissertation. Words cannot express the depth of my gratitude to Chip for his support throughout my time as a graduate student and academic professional at the University of

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It is thanks to my early advisor and mentor, Jim Levin, that I began this journey. Working with Jim at the outset of his and Chip's designing the CTER online master's degree program led me to understand that educational technologies are valuable only to the extent that they can serve as catalysts to meaningful learning at individual and social levels. Jim introduced me to a community of scholars in the College and around the University, both professors and graduate students, who were as practical-minded as they were scholarly with regard to developing and implementing new technologies in educationally meaningful ways. Jim also served as my introduction to the METER Partnership, a limited-term initiative funded by the state of Illinois to assist high school teachers of mathematics and English in exploring innovative use of technologies in their classrooms. Renee Clift, together with the other principal investigators in METER, taught me the importance of coupling the meaningful integration of technologies into classrooms with rigorous standards of educational research. These practical lessons served as invaluable complements to seminar courses in qualitative and mixed-methods educational evaluation, conducted by outstanding professors like Jennifer Greene and Robert Stake. I am far from the first graduate student involved in educational project work who has been struck by the gulf between practical understandings developed in small-scale collaborations, and the neat and abstracted forms of knowledge that

characterize many of the studies of educational practice that find their way into journals. Each of these educators has provided me with invaluable guidance in bridging the research-practice gulf in authentic ways.

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Chapter One

Introduction

July 8, 2008 - The buzzing of tens of thousands of honey bees fills the air as fourteen high school students and their teacher observe a graduate student researcher removing the cover from an outdoor research hive. Clad in protective gear from head to toe, the students watch and listen closely as they are led through the colony's innermost workings, witnessing foragers as they return laden with nectar, worker bees transferring that nectar into newly made comb cells for storage, other workers feeding larvae and newly emerged mature bees and, finally, the hive's sole queen, mother to the entire colony, as she goes about her daily work of laying thousands of eggs, attended by still other workers who feed and care for her. A video camera records the students in close engagement, as they and their guide relate what they are seeing and hearing about, back to opportunities they had the previous day to hold individual live, day-old worker bees and to examine bee anatomy under visual and electron microscopes.

July 11, 2008 - It is three days later, and the same individuals are in a seminar room at the campus genomics institute where the graduate researcher works. He is presenting an hour-long, slide-illustrated talk about his and his colleagues' work, at a level of detail that would seldom be found outside graduate-level university seminars and research laboratories. The students -- who have now spent this summer week learning in depth about honey bees, their agricultural importance and place in the environment, and above all their utilization as model organisms for behavioral genomics research -- are paying close attention to the lesson, offering frequent questions and comments that will add to the enduring usefulness of this lecture presentation as an online video resource.

These are field notes from a weeklong curricular encounter between the fourteen students, their biology teacher, and a group of scientists who were among the world's foremost professionals in the field of honey bee genomic research. This dissertation takes shape as a design-oriented case study that explores how the 2008 summer workshop and various predecessor activities came about, situates the case within a larger context of leading-edge scientific research projects having public education aims, and considers

ways in which carefully structured learner-scientist interactions may contribute to young students' meaningful learning of science. The research questions are:

1. How did scientists and educators in a university research project come to design an intensive educational activity in the area of their research, for an audience of high school students?
2. What were the distinguishing features of this educational activity?
3. How did the students learn and remember from this experience?

Agencies that fund scientific research have called increasingly in recent years for the projects they support to contribute to broader social and educational impacts (e.g., Mervis, 1997; National Science Foundation, 2006). However, the means by which these projects might best utilize their own resources to support educational outcomes for young learners have received relatively little attention. This research explores how a five-year-long, federally funded research project investigating behavioral genomics of honey bees endeavored to bring middle and high school students into meaningful contact with areas of emerging scientific discovery, in ways that were both educationally sound and manageable for the project. The study takes the form of a design-oriented case study, in which instances of educational outreach conducted by a particular scientific research project are explored to yield insights into how such projects might develop and deliver worthwhile educational outreach for young learners.

Among the key reforms recommended in recent national science education standards is a call to bring learners into closer contact with professional scientists. As the authors of the 1996 *National Science Education Standards* have written, opportunities must be provided “for students to investigate the world outside the classroom ... and 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” (National Research Council, 1996, pp. 220-221). At the same time, some individual scientists and scientific research organizations have taken upon themselves a responsibility to reach out to schools, sharing their knowledge and stirring the interests of the next generation of scientists and users of science research. Initiatives bringing high school learners into contact with research scientists have taken many forms. Such efforts have ranged from bringing individual scientists into the classroom, to

developing technology-centric initiatives for teacher and student education, to engaging in large-scale curricular reform efforts involving entire school districts, and have taken place in both in-classroom and out-of-school settings.

Calls to align the teaching of science with the actual practices of scientists are not new, but they take on added urgency in an era when the scientific knowledge necessary for informed and active citizenship is increasing at an unprecedented rate. Over the past two decades, scientists' professional associations and educational standards-setting bodies have proffered a comprehensive set of recommendations for building scientific literacy for all, from the elementary years through high school (Aldridge, 1992; Augustine et al., 2005; National Research Council, 1996; Rutherford & Ahlgren, 1989; Committee on High School Science Laboratories, 2005). These guidelines have in turn heavily influenced educational researchers, textbook publishers, and curriculum developers, but up to now the consensus view is that the recommended practices can be found only rarely in actual high school classrooms (Yager, 2005). At the same time, scientists have been called upon to position their work in ways that benefit society broadly (Stokes, 1997). Much remains to be done to bring into schools the vision of a scientific literacy that is characterized by authentic engagement with scientific understandings, methods, content, and modes of inquiry. One part of the resolution to this ongoing dilemma may come from the domain of leading-edge scientific research. For this to come about, ways must be found to mesh educational interests with the work of the scientific research itself.

The Advent of Big Biology

The twenty-first century is being heralded as "the century of biology" (Venter & Cohen, 2004). The sequencing of DNA shows us the commonalities among all species on earth, and global climate change reminds us that all forms of life are interdependent. Human health and environmental health are linked inextricably. Fifty years ago, the Cold War and related space race between the United States and the Soviet Union brought about the first "Big Science" collaborations in the fields of physics and astronomy (Galison & Hevly, 1992). Today, genomic research, along with systems biology and nano-scale biotechnology, is increasingly being carried out through large-scale, cross-disciplinary research collaborations in the life sciences that exhibit "Big Science" characteristics: big

budgets, big staffs, big machines, and big laboratories. Sociologist Elaine Welsh and colleagues (Welsh et al., 2006) contend that this new "Big Biology," facilitated by the breakdown of traditional barriers between academic disciplines and the application of technologies across these disciplines, presents major challenges for the provision of infrastructure and training, the organization of research groups, and the development of suitable research funding mechanisms and reward systems.

Together with such challenges come educational opportunities. In a call to bring the new science of metagenomics into the classroom "while it's still new," for instance, staff members with the National Research Council (Jurkowski, Reid, & Labov, 2007, p. 263), offer the following insight:

The benefits of integrating metagenomics and other new sciences into biology 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. Indeed, in the case of the emerging field of metagenomics, the most basic questions may be the most profound. Addressing these questions in turn inspires young minds and active researchers alike, and science benefits.

It is for this reason that I focus in this dissertation on the case of a leading-edge scientific research project's engagement in a series of educational outreach efforts that were intended to make the emerging science at the center of the project a key source of curricular material.

Chapter Two

Background

Role of the National Science Foundation

Interrelated research and educational concerns are central to the National Science Foundation (NSF), the United States government agency whose approximately \$6.9 billion annual budget (FY2010) supports fundamental research and education in all the non-medical fields of science and engineering. The authors of NSF's strategic planning document for FY2006-2011, *Investing in America's Future* (National Science Foundation, 2006), suggest that networked cyber-infrastructure and newly developed tools such as genetic sequencing

have not only made it possible to reach the frontier faster; they have also increased by levels of magnitude the levels of complexity open to exploration and experimentation. ... The convergence of disciplines and the cross-fertilization that characterizes contemporary science and engineering have made collaboration a centerpiece of the science and engineering enterprise (p. 2).

Education has been a core mission of the NSF since the agency's founding in 1950. The National Science Foundation Act of 1950 (Public Law 81-507) directed NSF to support, as one of its five aims, "science and engineering education programs at all levels and in all the various fields of science and engineering" ("The NSF Mission," no date). Over the ensuing six decades NSF has underwritten education-oriented programs in areas as diverse as doctoral and postdoctoral education, summer institutes for K-12 teachers, and development of textbooks and related curricula for biology, mathematics, and social sciences (Lomask, 1976). Under its current organizational structure, most education-oriented programs are funded and managed through NSF's Education and Human Resources (EHR) directorate, with a 2010 budget of \$873 million. The degree of separation between education-centric and research-centric programs can be discerned from NSF budgetary documents, such as the 2010 funding proposal (NSF, 2010), which treat EHR as separate from all the other NSF nine directorates and offices that are referred to collectively under the heading of "Research and Related Activities" (R&RA),

with a combined 2010 budget of \$5.73 billion. However, one major exception exists to the general separation of education and research aims under NSF. In 1997, NSF introduced a major change to the merit review criteria under which all proposals to NSF are evaluated for funding. Since that time, reviewers have been instructed to judge proposals according to both a criterion of "intellectual merit" and a criterion of "broader impacts." Initially, the Broader Impacts Criterion (BIC) was instituted primarily to encourage scientific research projects to explain how they intended to share the results of their work with the general public (Mervis, 1997). More recently, however, the focus of BIC has shifted to place emphasis on encouraging research scientists to engage in educational outreach (Avila, 2003). The case at the center of my research is typical of NSF-funded research projects in its concern with providing educational outcomes as a means of fulfilling the BIC mandate. For this reason, this research can be expected to hold interest for the entire class of NSF-funded R&RA projects.

Understanding NSF's two merit review criteria. *The National Science Foundation Grant Proposal Guide* (NSF, 2010, p. III-1) directs that proposals for funding must address five questions related to the project's intellectual merit, and five questions related to the project's broader impacts. The first set of questions is typically referred to as NSF's Intellectual Merit Criterion, or IMC. Under the general question, "What is the intellectual merit of the proposed activity?", these questions are posed:

1. How important is the proposed activity to advancing knowledge and understanding within its own field or across different fields?
2. How well qualified is the proposer (individual or team) to conduct the project? (If appropriate, the reviewer will comment on the quality of prior work.)
3. To what extent does the proposed activity suggest and explore creative, original, or potentially transformative concepts?
4. How well conceived and organized is the proposed activity?
5. Is there sufficient access to resources?

The second set of questions is generally referred to as NSF's Broader Impacts Criterion, or BIC. Under the general question, "What are the broader impacts of the proposed activity?" these questions are posed:

1. How well does the activity advance discovery and understanding while promoting teaching, training, and learning?
2. How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)?
3. To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks, and partnerships?
4. Will the results be disseminated broadly to enhance scientific and technological understanding?
5. What may be the benefits of the proposed activity to society?

NSF's governing organization, the National Science Board, initially adopted this set of guidelines in 1997, following a public comments period of several months.

According to a *Science* article of the time, the new guidelines amounted to

the first major change since 1981 in the criteria NSF uses to distribute most of its \$3.3 billion budget. ... The biggest revision to the initial [1996] draft was a sharpening of the distinction between the two criteria. Many of the researchers who commented urged NSF to make clear the paramount importance of scientific excellence.... The science board took that decision to heart, deciding that reviewers should be told that the two criteria "need not be weighted equally" and giving program officers and reviewers leeway to decide their relative importance. (Mervis, 1997, p. 26)

Within the article, the then-chair of the NSB task force that drafted the guidelines, atmospheric chemist Warren Washington, is quoted as emphasizing that the principal purpose of the broader impacts criterion was to promote public awareness of research findings. "For traditional research proposals, I think quality is probably more important," Washington conceded. "But as someone who does research on global change, I recognize that there are lots of areas where it's very important that the results get out to the public. And we didn't want to ignore that aspect."

On the basis of that history, the subsequent development of the Broader Impacts Criterion in use can be regarded as somewhat surprising. More often than not, satisfying

NSF's "broader impacts" criterion has come to involve some form of educational outreach to public audiences. As National Academies staff member Bridget Avila (2003) has written,

To satisfy Criterion 2, most research grant proposals now choose to describe planned education or outreach activities and how they are related to the proposed research. These activities may involve formal education in schools, colleges, and universities; outreach via public seminars and journalism; or activities in museums and aquariums.

This shift in emphasis has led some observers to describe the positioning of the broader impacts criterion as problematic. Science and technology researcher J. Britt Holbrook (2009, p. 177) has commented, "Since its inception in 1997, BIC has been attended with controversy. Initially ignored by many proposal writers and reviewers, BIC has been the focus of complaints from scientists and engineers, of queries from Congress, and attempts by NSF to improve its understanding and utilization." A widely cited *American Physics Society News* article from 2007 quotes scientists complaining that "many physicists feel they don't have the expertise to do outreach activities," that BIC is "encouraging scientists to do things that would actually slow down the research," and describing aspects of BIC as "punitive," particularly for younger researchers (APS News, 2007). Science educator Carol Lynn Alpert suggests that "this is not simply an argument about values and moral prerogatives.... The pressure to produce scientific results, publish, mint new PhDs and gain additional collaborators in the competition for new grants creates a bottom-line incentive to keep efforts focused on the research" (Alpert, 2009, pp. 268-269).

Compounding the difficulty is the fact that although NSF has become increasingly clear over the years about what it expects authors of proposals for funding to promise regarding broader impacts, no mechanism is in place to track the actual outcomes relating to the criterion. In the words of Melanie Roberts, a former NSF staff member who examined hundreds of project proposals for references to both scientific (IMC) and social (BIC) impacts, "Since NSF does not track broader impacts outcomes, it is not known what broader impacts researchers actually carry out" (Roberts, 2009, p. 213).

Furthermore, research biologist and university administrator Warren Burggren writes that

he has attempted without success to learn from NSF and from his own colleagues about the level of expenditures nationally and at his own university that could reasonably be construed as relating to meeting the Broader Impacts Criterion. Following up at his own university, Burggren reports that he also asked colleagues about their own projects' spending on funded activities that they themselves identified as relating primarily to intellectual merit or broader impacts criteria. He writes:

Interestingly, the nature of the responses suggested considerable confusion about BIC *even among scientists successful at acquiring NSF funding* [emphasis in original]. For example, some PIs [project principal investigators] indicated that expenditures on student and postdoctoral stipends (and associated fringe benefits) comprised the vast majority of their grant expenditures, and so reported their BIC expenditures in the 40-80% range. ... Other faculty, however, who clearly supported numerous graduate students and postdoctorate students on their grants, nonetheless reported numbers in the range of 3-10% or even 0%! ... The high statistical variation in the responses along with anecdotal comments supplied to the author suggests confusion among PIs as to the nature of BIC, even though at some level they must have successfully promoted this criterion for them to be funded! (Burggren, 2009, p. 225)

The absence of clear understanding of the Broader Impacts Criterion on the part of applicants for funding has been met with a mandate from the National Science Foundation that the applicants must address the criterion directly or have their proposals returned without review (Holbrook & Frodeman, 2007).

NSF program staff administering R&RA activities often point to clearly articulated models of public outreach and engagement that developed out of programs administered by NSF's Education and Human Resources Directorate as exemplary activities worthy of emulation in R&RA contexts. This for instance is the thrust of recommendations from a 2003 National Academies report authored by Bridget Avila, which deals with a workshop conducted with NSF support in 2002 on the topic of "integrating education in biocomplexity research." As Avila recounts (pp. vii-viii):

Reviews of grant proposals and progress reports showed that many of the early education and outreach projects had not been as carefully planned as the research proposed. Many were too ambitious given the time and expertise available, others were limited in scope and would impact only a few students. NSF concluded that the proposals might improve if grant applicants became more familiar with existing high-quality projects in education and outreach. Outreach is no easy task, but successful models can make the goal of designing new programs much easier and those who are aware of the models are more likely to avoid the common pitfalls.

NSF is certainly on solid ground in recommending that designers of educational outreach to satisfy the BIC should begin by gaining familiarity with existing outreach projects. Even so, treating educational outreach solely as the public service component of a project, rather than as a research initiative in its own right, may amount to an opportunity missed. Speaking at the 2002 workshop described in the Avila report, Herb Levitan of the NSF Division of Undergraduate Education is reported as having “proposed, in line with what the attendees had identified as essential principles of research, that there are four principles that guide research, and that these principles should also be applied to integrate education and research”:

- Be original and break new ground. The best research is that which builds on the efforts of others, explores unknown territory, and risks failures.
- Provide opportunities for professional development. Research provides opportunities for personal growth for all who are actively involved. More-experienced researchers may act as mentors or trainers of those with less experience -- the “learners.” Learners gain confidence and stature among peers as they gain proficiency in a field.
- Provide opportunities for collaboration and cooperation. Because the most interesting and important problems and questions are usually complex and multidisciplinary, researchers with diverse and complementary perspectives and experiences often collaborate.
- Provide opportunities for work that results in a product. The expectation of all research is that the outcomes will be communicated and available to an

audience beyond those immediately involved in the research activity. That can occur via peer-reviewed publication or via patents or commercial products. The value of the research will then be measured by the impact of its product -- how widely cited or otherwise used it is. (Avila, 2003, pp. 7-8)

The research I describe in this dissertation proceeds in part from these recommendations to create new models, provide opportunities for collaborative professional development, and develop educational products that serve audiences beyond the project. Description of model scientific outreach initiatives, together with consideration of the principles that inspired these initiatives and of the situations in which they were developed, affords a starting point for investigating the various forms of one funded project's educational outreach. At the same time, Levitan's remarks point to ways in which leading edge projects' treatment of educational outreach as a research enterprise in its own right can potentially result in broader impacts that reach beyond the individual learners who participated in the outreach.

Six Varieties of RSMSS Outreach

Education-centric outreach projects such as those supported through the NSF Education and Human Resources' \$873 million annual budget (FY2010) offer a half-dozen promising models for the design and implementation of outreach projects bringing the resources of research science into the world of school science. In this section, I present an overview of several varieties of what I call "research science meets school science" (RSMSS) outreach that has been described in recent science literature and offer a rough typology of these efforts (*Table 1*). The six types of RSMSS educational outreach described here are: *Individual Scientists in the Classroom*, *Technology-Centric Initiatives*, *Field Trips for Science Learning*, *Citizen Science Projects*, *Summer Science Camps*, and *Laboratory-to-Teacher Initiatives*. In this discussion, I attend to theoretical rationales provided in the literature for the various kinds of outreach, claims tendered for their educational effectiveness, and available information concerning their costs and other support requirements. These factors all hold importance for scientific research projects as they seek to develop and deliver educational outreach that is both theoretically sound and

practical to implement in the context of the projects overall. In discussion of findings from my second research question (Chapter Five), I compare these types of science education outreach with the curricular model that emerged from educational activities of the BeeWorld Project.

RSMSS type 1: Individual scientists in the classroom. Numerous authors have called on individual scientists to share their expertise with science learners by visiting classrooms and collaborating with teachers on a one-to-one basis, and have described their own efforts to foster such collaborations (Andrews, Weaver, Hanley, Shamatha, & Melton, 2005; Bybee, 1998; Bybee & Morrow, 1998; Druger & Allen, 1998; González-Espada, 2007; Laursen, Liston, Thiry, & Graf, 2007; Waksman, 2003).

A survey by Elizabeth Andrews and colleagues at one university (Andrews et al., 2005) found that of 73 graduate students, research scientists and science faculty members who returned responses, 88 percent reported having engaged in such activities, and 65 percent reported they were doing such outreach at the time they were surveyed. In the surveys and in subsequent interviews with nine of the respondents, the most frequently cited activities were giving presentations, tutoring, and organizing or judging science fairs. “The vast majority ... said they would be more willing to participate in outreach if research showed that it was effective in increasing student knowledge and improving student attitudes toward science” (p. 283). Employing a similar approach, Marvin Druger and George Allen used a six-item survey to query 500 recipients of grants from the National Institutes of Health about their involvement in, and attitudes toward, K-12 education. Of the 169 valid responses they received, 91 (54 percent) of the respondents answered yes to the question, “Have you done anything to assist K-12 science education in the last 12 months?” with more than half of those reporting having spent at least 20 hours. The four most frequently reported types of activities were presenting lectures or demonstrations to elementary and secondary school classes (31 percent); sponsoring secondary students in lab or research apprenticeships (22 percent); teacher enhancement, including research apprenticeships for teachers (16 percent), and participation in science contests (12 percent).

Rodger Bybee, a principal author of the National Science Education Standards (1996), recognizes that scientists have traditionally engaged in efforts similar to those

reported by these researchers, but goes on to urge much greater involvement in K-12 education as advocates, resources and partners. He recommends that research scientists involve themselves in collaborations with K-12 students, in-service K-12 teachers, university schools of education, governmental policymakers, educational materials developers, and informal education centers (Bybee, 1998; Bybee & Morrow, 1998).

In an article written for research scientists, Wilson J. González-Espada (2007) discusses benefits of scientists' involvement for students and suggests specific ways scientists can assist science teachers. By becoming involved with K-12 education, scientists can help overcome stereotypical images of scientific researchers, assist teachers with standards alignment, develop teacher-scientist partnerships, and, advocate to “defend science against those pseudoscientific, religious, metaphysical, and commercial forces that aim at undermining reason and scientific thinking.” He cautions that to present effectively, scientists in classrooms need to be aware of students' misconceptions, use analogies and examples frequently, know their audience, keep their discussions simple, strive to present organization and context clearly, and use visuals effectively.

A sustained and well-researched set of initiatives involving placement of individual scientists in school classrooms -- in this case pre-professional scientists engaged in study for advanced degrees -- has taken the form of a National Science Foundation-funded initiative known as GK-12, for “Graduate STEM Fellows in K-12 Education.” NSF initiated the GK-12 program in 1999, and its most recent Program Solicitation, covering years 2009 and 2010, offers a total \$15 million in annual funding for 20 to 25 new campus-based projects nationwide that would continue for up to five years apiece. From its inception, the GK-12 program has been envisioned by NSF as a means for promoting one-to-one classroom-based partnerships between teachers in the sciences and graduate students studying in related subject areas. Beyond that, the program has been notable for the degree of discretion it has left to individual partnerships. As Terry Woodin, then-program director for the GK-12 program nationally, commented in 2004,

There are 118 sites in 41 states, and there are no typicals, in that each site responds to local resources and local needs. What works for one of the sites might not work for another. Mostly they share one important

characteristic -- the schools and the university and the teachers and the fellows seem to form very effective working partnerships. (Lundmark, 2004).

Numerous recent scholarly articles describing various GK-12 implementations have also highlighted the centrality of an inquiry-oriented pedagogical focus to these sorts of projects (see, e.g., 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).

At least one instance of a scientist-in-the-classroom initiative has made use of undergraduate students majoring in sciences to create and teach activities-based science lessons for pupils in elementary grades. In Project SEARCH, the undergraduates collaborated with schoolteachers to develop and implement curricula, to serve as teachers themselves, and to act as scientist role models. Project investigators Bertram Bruce and colleagues (Bruce, Bruce, Conrad, & Huang, 1997) found that the undergraduates, schoolteachers, and pupils all reported learning from and enjoying this experience, although they did encounter some logistic constraints in arranging activities that spanned school and university settings and calendars. Despite such difficulties, the investigators suggested that the model developed in Project SEARCH ought to be considered for more widespread adoption.

RSMSS type 2: Technology-centric initiatives. A second type of Research-Science-Meets-School-Science initiative that has been described in science education literature centers around introducing students to innovative technologies whose use is ordinarily reserved for scientists engaged in advanced research. Educators' presumption is that exposure to these technologies and to the sorts of new science they support will prove exciting for young learners and will encourage them to learn further about related science topics and career paths. Typically, the technology being introduced is some sort of computer program or computer interface to a visualization technology. In such instances, students are taught by an expert to work with the software directly, often to create an animated model, flow chart, or other depiction of the modeled relationship. Software might consist either of standalone tools or of interfaces to server-based

resources such as complex databases. In one such project, Biology Student Workbench, an alternate learners' interface and tutorial materials were developed to accompany an online resource already being used worldwide by molecular biologists; as the authors of a report on classroom use of this tool have commented, "Since tools such as Biology Workbench are changing how biologists do their work, providing students with access to that tool enables them to experience how biologists conduct their research, form inquiry questions, connect with the work of other biologists, and build knowledge in the field" (Bruce, Jakobsson, Thakkar, Williamson, & Lock, 2003, p. 3). A similar rationale has guided separate projects dubbed *ChickScope*, which enabled K-12 students and teachers to use Magnetic Resonance Imaging (MRI) devices via a web interface for the purpose of observing development of chick embryos (Bruce et al., 1997; Thakkar, Bruce, Hogan, & Williamson, 2001), and *Bugscope*, which provides K-12 students and teachers with web-based access to a modern scanning electron microscope to obtain close-up views of killed insects that the students themselves mail to the project for inclusion to its database (Thakkar, Carragher, Carroll, Conway, Grosser, Kisseberth, Potter, Robinson, Sinn-Hanlon, Stone, & Weber, 2000). A recent instance of this sort of technology-centric RSMSS outreach can be found in the example of iLabCentral (www.ilabcentral.org), a project created by Northwestern University and the Massachusetts Institute of Technology and supported by a \$1 million grant from the National Science Foundation (Young, 2009) that provides high school and college science labs with online access to high-end laboratory equipment used by research scientists in the areas of biology, chemistry, math, and physics.

RSMSS type 3: Field trips for science learning. Field trips are a time-honored way for teachers to lead their students on adventures beyond the classroom walls. As defined by Krepel and Durall (1981, p. 7), a field trip is "a trip arranged by school and undertaken for educational purposes in which students go to a place where the material of instruction may be observed and studied directly in their functional setting" (quoted in Orion, Hofstein, Tamir, & Giddings, 1997, p. 162). In science, as in other subject areas, school-year field trips offer opportunities to explore topics in depth, in contact with experts and in richly equipped settings where real work is being done. However, "field

trips are too rare” in science classrooms, educational researchers Brian Drayton and Joni Falk have commented (2001, p. 32).Partly as a result, they say,

Teachers are isolated from other teachers and from the scientists and people who create and use the knowledge that students are studying. Students are often isolated, discussing science with (or explaining it to) people their own age. The only adults that they discuss science with are their teachers, who are often seen as mere conduits from the science world ‘out there.’ This reinforces the image of science as what is written in the textbook or happens in the confines of the classroom.

RSMSS type 4: Citizen science projects. “Citizen science” describes scientific projects or programs in which volunteers, many without specific scientific training, assist in research-related tasks such as observation, measurement or computation. Citizen science projects aim to promote public engagement with research and with science in general, with some programs providing materials specially adapted for use by primary or secondary school students. One well-known instance of citizen science comes from the Ornithology Lab at Cornell University, where since the early 1990s researchers have hosted a series of funded initiatives with names such as Project Tanager, Classroom FeederWatch, eBird, NestWatch, Celebrate Urban Birds, The Birdhouse Network, and BirdSleuth (Bhattacharjee, 2005; Bonney, Cooper, Dickinson, et al., 2009; Brossard, Lewenstein, & Bonney, 2005; Potenza, 2007; Trumbull, Bonney, & Grudens-Schuck, 2005).

The BirdSleuth website (www.birdsleuth.org) is testament to the power of the approach for education, when the necessary resources can be brought into play. BirdSleuth offers several educational modules (some free, others requiring purchase) whose aim is to align classroom activities with various citizen science projects offered by the laboratory. Each of the modules features several instructional activities, or “investigations.” An initial module, titled “Investigating Evidence,” for instance, includes a “What is Science” investigation with several “meet the scientists” videos, a “Testing Hypotheses” investigation describing how to design science experiments, a “Show Me the Data” investigation describing how to share conclusions through graphs, a “Plan and Conduct Investigations” unit with tips for getting started, and a “Presenting Inquiry

Projects” investigation that includes peer-review forms. Additional modules being offered feature learning activities linked to the citizen science projects eBird, Crows Count, Project FeederWatch, and NestWatch.

RSMSS type 5: Summer science camps. Besides connecting with educational audiences via web-based offerings, as with the technology-centric and citizen science efforts described above, a few scientific laboratories have pioneered substantial and resource-intensive outreach activities that involve intensive face-to-face interactions with students in lab settings outside of school time (e.g., Hay & Barab, 2001; Fields, 2009; Waksman, 2003). Byron Waksman (2003), a research pathologist with the New York University School of Medicine, has written in detail of his own institution’s outreach efforts welcoming “high school students who seek a research experience in the summer months,” (p. 51). A *High School Fellows* program is offered to 25 students for seven weeks each summer that couples one-to-one mentorship opportunities each morning with “a highly structured didactic program” in the afternoons; the program is administered by a full-time staff coordinator and is supported with funding from the Associated Medical Schools of New York and outside organizations. The Fellows program is offered to “well-motivated but poorly prepared minority participants whose ability to go on to college is in doubt.... Over the 15 years of its existence, close to 90% of the participants have gone on to college, almost half entering premedical programs or programs related to science and engineering” (Waksman, 2003, p. 52).

Two instances of summer science outreach described by Waksman in his 2003 article are offered by other institutions. One is a three-week *Summer Science Academy Program* sponsored by the University of Rochester’s Environmental Health Sciences Center in microbiology and molecular biology; this three-week program, supported by a combination of tuition and grant funding, is geared for “exceptional high school students, offering both guided and independent laboratory projects, bioethics discussion workshops, computer laboratories, science seminars, and field trips” (Waksman, 2003, p. 54). Waksman’s other example is a *DNA Science Workshop* that is offered each summer by the Dolan DNA Learning Center at Cold Spring Harbor (N.Y.) Laboratory.

Science education researchers Kenneth Hay and Sasha Barab (Hay & Barab, 2001) have analyzed the curricula of two different summer science camps according to

what they identify as the camps' underlying presumptions about the nature of science learning. They distinguish in their work “between models predicated on *constructivist* (e.g., constructionism), and situated *cognitivist* (e.g., apprenticeship learning and legitimate peripheral participation) frameworks” (p. 282):

Our research is grounded in two different camps taking place in the summer of 1997. The first camp, Future Camp 97 (FC97), was a constructionist-based camp whose stated goal, in the camper brochure, was to develop educational activities that were “using technology for exploration, discovery, and invention.” Learners in this camp used state-of-the-art virtual reality (VR) technology to construct a virtual world in one of three projects: Virtual Solar System, Virtual Statehouse, and Virtual Theater project. The second camp, Scientist’s Apprentice Camp (SAC), was an apprenticeship-based camp that matched learners with nationally recognized scientists. Students worked alongside scientists to conduct authentic research projects in state-of-the-art laboratories. There were research projects in the science disciplines of chemistry, computer science, geology, physics, and psychology. The final project of SAC97 was a presentation of their research to a community of their peers, mentor scientists, friends, family, and interested members of the public. (Hay & Barab, 2001, p. 282)

For each of the two camps, Hay, Barab and their research colleagues sought answers to four questions: 1) What were the types of communities or activity groups formed? 2) What were the roles of the various participants? 3) In what practices did participants engage? 4) What did students learn? They found that participants in the FC97 and SAC97 groups differed with regard to all four research questions:

Community-centered environments (e.g., SAC97) focus on imparting fixed community practices, and learners are engaged in activities with well-defined goals and subgoals. The definition of success, for the learner, is becoming a community member, and the mentors are invested both in learner development and the quality of the outcome. Learner-centered environments (e.g., FC97), focused on learners’ developing emergent

skills, where goals are ill defined, where the success is the development of a high-quality product, and where mentors are facilitators, but do not have added investment in the quality of their product. (Hay & Barab, 2001, p. 318)

One researcher who has followed Hay and Barab's (2001) work makes the argument that a single science education camp can foster both constructivist and cognitive apprenticeship goals. Deborah Fields (2009) describes an astronomy camp that has been offered for more than two decades at the University of Arizona (www.astronomycamp.org). Fields, who identifies herself as the daughter of the camp's director (2009, p. 157), conducted her research while working as a staff member during the camp in summer 2002. She used semi-structured interviews of students and staff to elicit information about benefits that students perceived from their camp experiences and compare those with the stated goals and strategies of camp staff. As described by Fields, a typical day at the week-long camp began with brunch at noon, after the students awoke from a full night of research observation using the laboratory's telescopes. The day's learning began with viewing of a television program relevant to astronomy, such as an episode of *The Simpsons* or Carl Sagan's *Cosmos* series. Students then briefly discussed an open-ended question centering on a general science research topic such as estimation, after which they listened to a lecture by a project staff member. After working for the remainder of the afternoon on group projects, students watched the sunset together, and then headed to the telescopes to conduct their research. Participation at the camp involved the learners in self-directed research projects. Staff assisted with preliminary background research, procurement of time on the telescopes, and assistance with their use. The week ended with final presentations in which the research groups reported on their research and responded to campers' and staffers' questions. In her interviewing, Fields reported that campers found four things valuable about the camp: high-quality peer relationships; personal autonomy in choice of research projects and use of professional technology; approachability of professional staff; and new understanding concerning both research processes and challenges. For their part, staff focused in interviews on their perceptions of the camp's value for instilling the full process of science; developing campers' confidence; and enabling them to contribute their own specialized research knowledge to

young learners. Fields concludes her discussion with an acknowledgement that the astronomy camp experience was “unique” and “not fully duplicable,” but offers “design implications” drawn from the experience. Notably, she asserts,

The Camp offers a ‘proof of concept’ that constructionist and cognitive apprenticeship learning models can be integrated into a single informal science programme. Unlike camps documented in previous studies, all of which either focused on start-to-finish youth-generated research projects or on integrating youth into a community of professional scientists (Hay and Barab, 2001), the Advanced Astronomy Camp united the two and added a further element of drawing youth based on a common interest in astronomy (Fields, 2009, p. 169).

RSMSS type 6: Laboratory-to-teacher initiatives. An additional type of Research Science Meets School Science outreach does not connect students with scientists directly, but instead creates connections between science laboratories and schoolteachers (e.g., Anderson, 1993; Drayton & Falk, 2006; Howe & Stubbs, 2003; Loucks-Horsley, 1999; Willingale-Theune, Manaia, Gebhardt, De Lorenzi, & Haury, 2009). The expectation is that these connections will inspire the teachers to change their classroom practices to incorporate new scientific knowledge and will provide them with the means to do so. A cross-national instance of this variety of outreach is a set of initiatives supported by the European Learning Laboratory for the Life Sciences (ELLS). ELLS is the educational outreach arm of the European Molecular Biology Laboratory (EMBL), a cross-national research organization funded by the governments of 20 nations across Europe. As summarized by Willingale-Theune and colleagues (2009), ELLS provides continuing professional development “for European high-school teachers, based on state-of-the-art molecular biology research at EMBL, in an approach that combines formal teaching and exercises with informal discussions.” Since it began in 2003, more than 700 teachers from 22 nations have taken part in ELLS continuing development programs. As well as offering laboratory seminars for teachers, ELLS provides curricular materials for student use such as a “virtual microarray” game utilizing a floor mat and flashlights, role play exercises on topics such as genetic testing, and a webcast lecture

series presented by high-profile women scientists and targeted to students, teachers, and the general public.

Discussion

At their best, instances of each of the six RSMSS types function as important supplements to the sorts of science education that are recommended in professional society publications such as the *National Science Education Standards* (National Research Council, 1996) and the American Association for the Advancement of Science's *Benchmarks for Scientific Literacy* (AAAS, 1993). The *Standards* and *Benchmarks* each promote a vision for promotion of scientific understanding that is grounded on instilling in students an appreciation for and understanding of science as a form of inquiry. As defined in the *Standards*,

Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (National Research Council, 1996, p. 23)

Likewise, in the words of the AAAS *Benchmarks*:

Scientific inquiry is more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of "making a great many careful observations and then organizing them." It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as "the scientific method." It is much more than just "doing experiments," and it is not confined to laboratories. More imagination and inventiveness are involved in scientific inquiry than many people realize, yet sooner or later strict logic and empirical evidence must have their day.... If students themselves participate in scientific investigations that progressively approximate good science, then the picture they come away with will likely be reasonably accurate. But that will require recasting typical school laboratory work.... Another, more

ambitious step is to introduce some student investigations that more closely approximate sound science. Such investigations should become more ambitious and more sophisticated. Before graduating from high school, students working individually or in teams should design and carry out at least one major investigation. They should frame the question, design the approach, estimate the time and costs involved, calibrate the instruments, conduct trial runs, write a report, and finally, respond to criticism. (AAAS, 1993)

Accordingly, within the *National Science Education Standards* for grades 9-12, attention is given to both “abilities necessary to do scientific inquiry” and “understandings about scientific inquiry” (National Research Council, 1996). The abilities discussed amount to a toolkit for a problem-solving approach to inquiry: identify questions and concepts that guide scientific investigations; design and conduct scientific investigations; use technology and mathematics to improve investigations and communications; formulate and revise scientific explanations and models using logic and evidence; recognize and analyze alternative explanations and models, and communicate and defend a scientific argument. In a companion publication, *Inquiry and the National Science Education Standards* (Olson & Loucks-Horsley, 2000, p. 29), the following are identified as “essential features” of classroom inquiry:

- The learner engages in scientifically oriented questions.
- The learner prioritizes evidence in responding to questions.
- The learner formulates explanations from evidence.
- The learner connects explanations to scientific knowledge.
- The learner communicates and justifies explanations.

For many science educators, the term “inquiry-based” is synonymous with a hands-on, problem-solving approach. Alan Colburn (2000), for instance, comments, “My own definition of inquiry-based instruction is ‘the creation of a classroom where students are engaged in essentially open-ended, student-centered, hands-on activities.’” Similarly, Marcia Linn suggests that:

Instruction is both effective and durable when teachers use students’ ideas as a starting point and guide learners as they articulate their repertoire of

ideas, add new ideas including visualizations, sort out these ideas in a variety of contexts, make connections among ideas at multiple levels of analysis, develop ever more nuanced criteria for evaluating ideas, and regularly reformulate increasingly interconnected views about the phenomena. (Linn, Lee, Tinker, Husic, & Chiu, 2006, p. 1049)

Even so, Olson and Loucks-Horsley emphasize that all five features they identified as essential features of inquiry can take place among continua from greater amounts of learner self-direction to greater amounts of direction from the teacher or material. They go on to decry as “myths” statements such as “all science subject matter should be taught through inquiry,” “true inquiry occurs only when students generate and pursue their own questions,” “inquiry teaching occurs easily through use of hands-on or kit-based instructional materials,” “student engagement in hands-on activities guarantees that inquiry teaching and learning are occurring,” and “inquiry can be taught without attention to subject matter” (Olson & Loucks-Horsley, 2000, p. 36).

The six RSMSS types described above are well-designed and successful sorts of educational outreach grounded in pedagogies that center on hands-on, problem-solving inquiry. Scientific research projects that aim to make educational impacts as a secondary goal would be well advised to consider how each of the types of RSMSS initiatives could be utilized in opening the unique content and learning of their projects to educational audiences. At the same time, however, it must be recognized that these sorts of education-centric initiatives often depend on special materials, facilities, and social arrangements that are resource-intensive and have been allocated and arrayed with primarily educational needs in mind. It has been suggested that the worlds of university research science and K-12 science education differ in ways that can pose challenges to communication and collaboration. Science educator Ana Houseal, for instance, points to “major cultural differences,” including:

- University science is typically oriented to projects, whereas K-12 education is typically process-oriented.
- The knowledge base for university research science is specific to one area that may have been studied for years, whereas the K-12 education knowledge base is broad and multi-disciplinary.

- University research science projects can be extensive, with cycles measured in years and not tied to a traditional September-to-May schedule, whereas K-12 projects typically range in lengths from 45 minutes to weeks.
- The goal of university research science is to produce rigorous, high-quality scientific research and thereby to increase the knowledge base within a particular field, whereas the goal in K-12 science education is to produce educational scientific research experiences for students.
- University science pedagogy is typically teacher-centered and lecture-based, whereas K-12 science education outreach is typically student-centered and cooperative. (Houseal, 2010, p. 20)

The RSMSS types discussed in this chapter can be recognized as following an orientation similar to that ascribed by Houseal to K-12 educational outreach, and so it would not be altogether unexpected to find some lack of fit between any of them and the practices of research-centric funded projects that are expected to offer some form of educational outreach as a secondary goal. For the aforementioned sorts of RSMSS initiatives, whether the goal is to put scientists in schools, or put tools of scientists into student hands, or construct settings and situations that assist students in thinking and acting like scientists, in each instance it is the educational goals that are primary and are designed and resourced for; resources of research science are being repurposed, adapted, and borrowed for educational ends. This has resulted in exemplary outreach programs, but at high cost and typically in areas that are already well understood scientifically, rather than in leading-edge areas where scientific understandings are still emerging. In scientific research contexts where educational outreach is added on to promote broader impacts, by contrast, RSMSS models might require substantial modification to allow for the primary work of research to proceed without impediment, while making best use of the unique learning opportunities that are presented by this class of projects. In such contexts, it is likely necessary to work on a case-by-case basis to pull the best from these models into a suitable framework. Moreover, some elements of design common to and valued in all of these models, such as emphasis on making students' hands-on, problem-solving inquiry a central part of the experience, might be particularly challenging to implement in settings where high-stakes research is ongoing. To the extent that proves to

be so, it remains to be seen whether initiatives that aim to draw the best content from leading-edge scientific research projects can succeed in developing meaningful educational offerings.

Chapter Three

Methodology

The three related research questions that motivate this study are investigated here through overlapping but distinct sets of methods. The first question -- “How did scientists and educators in a university research project come to design an intensive educational activity on the topic of their research, for an audience of high school students?” -- is taken up in Chapter Four and is explored by considering in depth an instance of design activity. The second question -- “What were the distinguishing features of this educational activity?” -- is taken up in Chapter Five and is closely related to the first and is explored through comparison of curricular documents with organizers’ expressions of intent, and through comparison of the curriculum with the various types of research-science-meets-school-science outreach described in Chapter Two. The third question -- “How did the students learn and remember from this experience?” -- is taken up in Chapter Six and is explored by considering the educational activity from the standpoint of student learning, with the aim of utilizing findings to further inform the ongoing design process.

This research is structured as a single-case study (Yin, 2009) involving BeeWorld*, a scientific discovery project that was awarded \$5 million by the U.S. National Science Foundation (NSF) over a five-year period (2004-2009) to explore the genomic basis of insect social behaviors, using the honey bee as a model organism, and to develop new computational tools to support behavioral genomics research. BeeWorld was supported through NSF’s Biology directorate, and so its major funded purpose was to make new scientific discoveries, not to design novel K-12 science curriculum. However, the project proposed to engage in educational outreach as a secondary aspect of its work, as a means of fulfilling NSF’s Broader Impacts Criterion. The circumstances of the BeeWorld Project, together with the variety of research question that guides this study, makes case study as described by Yin (2009) an appropriate methodological choice:

* a pseudonym

1. A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries and context are not clearly evident.
2. The case study inquiry copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in triangulating fashion, and as another result benefits from the prior development of theoretical propositions to guide data collection and analysis. (Yin, 2009, p. 19)

The notion of *project* is centrally important to consideration of BeeWorld as a case. A project can usefully be regarded as “a temporary endeavor undertaken to create a unique product, service or result” (Project Management Institute, 2008, p. 5). NSF-supported projects are funded through a competitive review process. The process begins with the Foundation’s issuance of a Program Solicitation, which describes in general terms the sort of project proposals being sought for a particular program, the amount of funding offered, and the project timeline. Scholars seeking this funding prepare and submit formal proposals describing the research and related work they intend to perform. Expert scholars in the areas covered by the Program Solicitation review these proposals without knowledge of the individual applicants or their institutions and rank them according to merit. Unless unanticipated budget shortfalls arise at the federal level, the highest-ranked proposals are awarded funding in the amounts they request. Although scientists and other individuals working within the BeeWorld Project had other research and professional affiliations that preceded, coincided in time with, and succeeded the five-year lifespan of the BeeWorld Project, their participation in the project itself amounted to a contract to engage in specific sorts of investigations and activities in return for being provided with funding and additional resources that were specific to the project. However, projects of any sort, and perhaps research projects in particular, need to be responsive to changes that arise from within and without the project boundaries over the course of their life spans -- technologies change, research snags emerge, individuals leave, unforeseen opportunities arise. For reasons like these, planning and management of projects “is iterative and goes through progressive elaboration throughout the project’s

life cycle” (Project Management Institute, 2008, p. 7). Accordingly, understanding the BeeWorld Project, and thus understanding the potentials and limitations of such projects to contribute to educational outcomes, depends in part upon employing a research methodology that allows for recognizing the project as an evolving entity, having its own internal relations and engaging in complex interactions with the ever-changing world beyond.

Utilizing a Design-Oriented Approach

This study examines six instances of educational outreach for middle school and high school students that were designed as part of the BeeWorld Project’s broader-impacts efforts. The research methodology employed here can be considered “design-oriented case study” and bears close relationship to the emerging tradition of design-based research. Design-based research, as described in multiple recent publications (e.g., Collins, Joseph, & Bielaczyc, 2003; Design-Based Research Collective, 2003; Kelly, 2009) takes an iterative approach by employing multiple cycles of design, development, delivery, and deliberation, with each cycle informing the next in some fashion. The aim of design-based research is to test theoretical claims in the crucible of actual practice, and to continually reshape and refine those claims in light of the results obtained. Design-based research has been explained as a family of related approaches wherein researchers

foreground the fluid, empathetic, dynamic, environment-responsive, future-oriented and solution-focused nature of design.... 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, Baek, Lesh, & Bannon-Ritland, 2008, p. 5)

In characterizing the present research as an instance of design-oriented case study, I wish to focus attention on both the designed and emergent aspects of the case under investigation. As with any case study, the research took place in a naturalistically bounded setting rather than in a controlled experimental setting; however, the case itself

consisted of iterative cycles of development, enactment, and assessment of lessons learned along the way.

Role of the researcher. It must be acknowledged that design-based research places the researcher in the dual role of developer and assessor. My own roles with the scientific project whose work I describe both inform and complicate my stance as a researcher. As a member of the project's administrative team from the beginning of the project, with the title of full-time coordinator from October 2005 through September 2008, I was in a position to become familiar with the day-to-day workings of the project and to assist with establishing and carrying out its related educational and outreach missions, under direction by the project's principal investigators. Additional responsibilities included developing and maintaining the project website, planning meetings and special events, and assisting project investigators with budgeting and related paperwork, all of which shaped my general understanding of the project and its goals. As coordinator, I found myself in a position both to influence and to research the course of educational outreach traveled by the project. At the same time, as an educator rather than a biologist or computer scientist by training, I was in the position of novice and learner myself with regard to the research domains of the project.

The research described in this dissertation should be understood to have occurred in what Kelly (2008) calls “design research commissive space.” 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 I as a researcher was solely or primarily a visitor, as with much qualitative ethnographic and case study-oriented research. As educational researcher Anthony E. 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, 2009, p. 5)

Yin (2009) regards participant observation as a legitimate role for case study researchers, but he treats the notion with caution out of concern for bias. Among the “distinctive opportunities” afforded by this researcher stance, he mentions an “ability to gain access to events or groups that are otherwise inaccessible to study,” “the ability to perceive reality from the viewpoint of someone ‘inside’ the case study, and “the ability to manipulate minor events -- such as convening a meeting of a group of persons in the case” (p. 112). However, in Yin’s estimation, these opportunities are offset by “major problems” due to “the potential biases produced,” among them “less ability to work as an external observer,” a tendency to become “a supporter of the group or organization being studied,” and engagement in “a participatory role [that] may simply require too much attention relative to the observer role” (pp. 112-113). Educational design researchers recognize the challenges of this dual positioning, but they endeavor to meet those challenges head-on. Plomp (2009, pp. 29-30), for example, suggests that several measures can be taken to guard against the potential conflict of interest that arises when the researcher is also the designer, evaluator, and implementer. These include:

- Make research open to professional scrutiny and critique by people outside the project.
- As a rule of thumb, shift from a dominance of “creative designer” perspective in early stages, towards the “critical researcher” perspective in later stages.
- Utilize a research design that builds upon a strong chain of reasoning; triangulation of data sources, data collection methods, and investigators; empirical testing of the intervention; and systematic documentation, analysis, and reflection upon design, development, evaluation, and implementation processes and their results.

This research has been carried out with awareness of the potential for bias, but it should be noted that not all recommended measures could be employed. With regard to

the opening of research to professional scrutiny, I have endeavored in the data chapters (Four, Five, and Six) to err on the side of inclusiveness in presenting source data. My own position with regard to the research shifted from that of paid project administrator and designer up to the phase of data collection, to that of unaffiliated researcher during the analysis and writing up of this research, affording the taking of a somewhat independent critical stance. Multiple data sources, data collection methods, and analytic approaches were employed, as is described in the following sections, but the framing of the research as a dissertation study precluded use of multiple investigators. Moreover, as will be described, some of the data was collected retrospectively, and cannot be considered altogether free of unintentional selection bias on the researcher's part. Such testing of the intervention as was conducted was limited to qualitative data drawn from multiple participants, and so the research emphasis was on identification and exploration of emerging issues of interest rather than on confirmation. With these caveats in mind, the focus of this research has been to document, analyze, and reflect upon design, development, evaluation, and implementation processes and results drawn from a single case, in ways consonant with the tenets of design-based research suggested by Plomp (2009).

I would also like to note that my dual positioning as a project staff member and researcher, together with the uniqueness of the project itself, has posed challenges to research participant confidentiality that are not unusual in design-oriented studies. Although I have utilized pseudonyms and removed other personally identifying information in reporting this research, it is important to acknowledge here that efforts at maintaining participant confidentiality cannot be altogether successful in research of this nature. The scientific research project that I call "BeeWorld" in this report was unique, and anyone interested in its activities would have little difficulty learning about it through publicly accessible sources. It has therefore been an important part of my research process to check back with key participants at various stages of writing, to obtain their assurance that they are comfortable with the characterizations that I have made of them and their work.

Design Narrative: Investigating the First Research Question

The first research question posed in this study is, “How did scientists and educators in a university research project come to design an intensive educational activity on the topic of their research, for an audience of high school students?” The approach I take to investigating this question is to develop and discuss a *design narrative*. Barab and colleagues propose design narratives as a means “for sharing design trajectories and accompanying theoretical assertions in ways that will be credible, trustworthy, and useful to others.” The authors write:

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.... In helping others to determine the generalizability of the derived theoretical assertions, the goal is to lay open and problematize the completed design in a way that provides insight into the “making of” the design.... 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)

Accordingly, Chapter Four takes shape as an account of six educational “design episodes” engaged in by the BeeWorld Project from the time of its inception through the fourth year of its five-year funding cycle. The central focus of research is the sixth episode, that of the 2008 BeeWorld Summer Education Workshop (BSEW08); descriptions of the other five episodes are provided in order to describe the trajectory by which key design features of the sixth episode took shape. For the first five of these episodes, my research data consists of publicly available documentation and personally archived meeting notes, memoranda, and communication records that were analyzed retrospectively. For the sixth episode, these varieties of data were augmented through conduct of interviews with organizers prior to and following the design intervention, and through deliberate, contemporaneous collection of design documentation. All data has been rendered anonymous for reporting through use of pseudonyms and removal of other personally identifiable information. As suggested by Barab et al. (2008), each of these

episodes is presented as having consisted of four components: “(1) a definable and bounded set of preconditions, (2) a change in our thinking, (3) design intervention, and (4) impact.” While this manner of compartmentalizing an ongoing series of events is necessarily somewhat artificial and arbitrary, the design narrative offers at least a first approximation of a thick description that can help readers to decide for themselves whether and to what extent the particularities of the BeeWorld experience might hold relevance for their own situations. No claim is made for the generalizability of the experiences reported in this research; however, it is to be hoped that insights generated from this set of experiences might point to ways in which the novel educational designs that emerged from the BeeWorld situation could merit further study under more controlled circumstances, as befits the multi-phase nature of many design research studies (e.g., Clements, 2007; Lamberg & Middleton, 2009).

Identifying Distinctive Aspects of an Educational Activity: Investigating the Second Research Question

The second research question posed in this study is, “What were the distinguishing features of this educational activity?” Chapter Five includes description of these features and contrasts them with elements of the various “research-science-meets-school-science” outreach types described in Chapter Two. Eisner (1965) identifies four “levels of curriculum,” from the outermost *school curriculum* (including academics, athletics, band, and other extracurricular activities), to an entire school’s *academic curriculum*, to various *subject-matter* curricula, to individual *course* curricula. BSEW08, like both its predecessor activities and the various RSMSS educational activities previously described, took shape as a course curriculum. From the perspective of its sponsoring project, it was meant to be an educational rich activity that could be undertaken within the constraints and affordances offered by BeeWorld; it amounted to a sort of “commodification” (Russell, 1997), of the *process* of laboratory research, turned to an audience of high school learners, much as both the publishing of research findings in professional journals and their eventual inclusion in textbooks amounts to a commodification of the *results* of laboratory research. From the perspective of the high school biology teacher whose students would be involved, BSEW08 would have value to

the extent that its curriculum could be made to contribute to the subject-matter curricula of the school year. Moreover, as with the previous activities considered here as design episodes, the BSEW08 curriculum needs to be understood both as “curriculum as designed” and as “curriculum in action” (Barnett & Coate, 2005). That is,

The first and most obvious sense of curriculum design lies in the process prior to its enactment, prior that is to the associated teaching and learning. Here the task is that of producing a specification of the curriculum that sits in course proposals. This is an important stage of curriculum design, but it can only be a proto-curriculum, a sketch of the curriculum. The curriculum has *subsequently* to take shape, complete with its open spaces, *in situ*.... Learning is in part a function of both the curriculum-as-designed and the pedagogy, and all three can be said to constitute the *curriculum-design-in-action*.... *Curriculum-design-in-action is inescapably a relational matter.* (Barnett & Coate, 2005, p. 131, emphasis in original)

For this reason, my exploration of the second research question involved analysis of data from both the planning and conduct of the BSEW08 curriculum, drawing from student and organizer perspectives and including planning documents, notes of meetings, audio-recorded interviews with planners and learners, and videotaped records of the various BSEW08 curricular events themselves. The corpus analyzed for this question included some fifteen hours of videotapes and twenty-five hours of audio recordings, which when transcribed amounted to more than three hundred pages of single-spaced text. Employing data-coding procedures utilized in grounded-theory methodology (Glaser & Strauss, 1967; Strauss & Corbin, 1994; Charmaz, 2000), I proceeded from high-level coding of data to selective conceptual coding (Charmaz, 2000, p. 516), in order to develop a data-driven account of design features that characterized the BSEW08 curriculum. In the process of reducing this data, first, to some 876 coded segments each ranging from a phrase to several paragraphs in length, and, ultimately, to seven analytic categories encompassing 138 coded segments, a good deal of interpretation and simplification have inevitably been introduced. My discussion of this set of findings indicates ways in which these design features distinguish the BSEW08 curriculum both from its predecessor activities and from the various forms of RSMSS outreach.

Several kinds of research data were collected from the eleven BSEW08 learners who participated in the workshop-related study. First, about one week prior to the workshop, I interviewed all but one of the students who had granted research permission individually by telephone for approximately 10 to 20 minutes. The interview questions asked about the students' interests in science learning, experience with the workshop topics (honey bees and genomic research), and expectations for the workshop week. I audio-recorded each of these interviews and subsequently transcribed them in their entirety. (The pre-interview protocol may be found in Appendix C.) Second, I videotaped each of the learning activities during the workshop week, for purposes of both research and curriculum development, and reviewed these video recordings in detail for information about student participation. These videotapes, amounting to about ten hours of material, were also transcribed in their entirety; the videotaped lessons have been published in slightly edited form on the project's website, as an "Electronic BeeWorld" online curriculum. Third, the students were asked to complete brief "writeback" reports on days 1, 2, 3, and 4 of the five-day workshop; these consisted of their writing a sentence or two in response to each of the prompts: "What interested you most about today's activities?" "What did you find surprising about what you learned today?" "What would you like to learn more about, related to today's learning?" and "What aspects of today's lesson could have gone better?" Fourth, as a wrap-up activity at the end of Day 5, the students participated in one of two focus group sessions that I conducted, each of which lasted for about 20 minutes. During these focus group sessions, which I videotaped and subsequently transcribed, I asked the students to talk about what they felt they had learned over the course of the week, what aspects of the workshop they felt had worked well and why, and what activities might be improved in any future iterations of similar learning workshops. (The protocol of focus group questions appears as Appendix D.) Fifth, at a date approximately four months after the workshop week (the occasion was the Veterans Day school holiday in early November, 2008), I arranged to interview each of the workshop participants individually by telephone in order to learn about their recollections of the workshop and about any subsequent learning that they regarded as relating to the workshop in some manner; I also audio-recorded and subsequently transcribed this set of interviews. (The post-interview protocol appears as Appendix E.)

Aspects of Student Learning: Investigating the Third Research Question

The third research question posed in this study is, “How did students learn from this experience?” In Chapter Six, I investigate this question by analyzing qualitative data from students who participated in the 2008 BeeWorld Summer Education Workshop (BSEW08). This data includes transcriptions of interviews I conducted with each student prior to the workshop week, and again four months after the week, as well as transcriptions of focus group interviews conducted with most of the students at the end of the workshop week; additional data came from videotaping conducted during the workshop itself, and from short written responses collected from the students during the workshop week. The analysis delves into how students’ post-interview responses shed light on memorability of various aspects of the workshop at a distance of several months.

Summary

The component studies reported in Chapters Four, Five, and Six explore the three research questions of this dissertation through an approach of design-oriented case study. The overarching logic of design research and the employment of the techniques of design narrative and participant interviewing were selected as having value as analytic tools for exploring case-based data generated in the context of a scientific research project that had provision of educational outreach as a secondary funded purpose. In Chapter Four, a design narrative is constructed and analyzed to yield principles that influenced the directions taken in various episodes of educational outreach undertaken by the project. Data for construction of this narrative comes from a combination of sources including project documents created by the author and publicly available records and transcribed interviews of developers. In Chapter Five, data from the 2008 BeeWorld Summer Education Workshop is analyzed to identify design features that distinguish this episode. Chapter Six presents and analyzes data drawn primarily from student interviews that were conducted four months subsequent to BSEW08, in order to discover what students reported having learned and remembered from the workshop.

Chapter Four

BeeWorld Education Outreach Prototypes

Research Question 1: How did scientists and educators in a university research project come to design an intensive educational activity on the topic of their research, for an audience of high school students?

From 2003 through 2006, the National Science Foundation's Biological Sciences (BIO) directorate granted initial funding for a total of 18 research projects at U.S. universities, as part of its Frontiers in Integrative Biological Research (FIBR) program. Each of the 18 accepted projects (six each in 2003 and 2004, and three each in 2005 and 2006) was granted approximately \$5 million in funding to be spent over a five-year period. The intent of FIBR was to address grand challenges that cut across disciplinary boundaries. As described in the program's Request for Proposals for 2004 (NSF 03-581), FIBR

supports integrative research that addresses major questions in the biological sciences. FIBR encourages investigators to identify major under-studied or unanswered questions in biology and to use innovative approaches to address them by integrating the scientific concepts and research tools from across disciplines including biology, math and the physical sciences, engineering, social sciences and the information sciences. Proposers are encouraged to focus on the biological significance of the question, to describe the integrative approaches, and to develop a research plan that is not limited by conceptual, disciplinary, or organizational boundaries. (National Science Foundation, 2003)

One of the six projects that were awarded five-year FIBR funding in 2004 was BeeWorld, based at a major Midwestern university. BeeWorld brought together content experts in the areas of honey bee genomics and computer science, to develop new knowledge about the genetic bases for insect social behaviors and to create new informatics tools to assist genomic biologists. BeeWorld aimed to explore the genetic bases for insect social behavior, using the Western honey bee, *Apis mellifera*, as a model organism. From the outset, this involved the project in leading-edge research into some of the most basic and enduring "big ideas" in the biological sciences: evolution by natural

selection, cellular organization of life, genetic inheritance through chromosomes, DNA and modern molecular biology, adaptive behaviors within an individual organism's lifetime, and interaction of organisms and environment in complex ecosystems (cf., Pruitt, Underwood & Surver, 2003; Prawat, 1993; Wong et al., 2001). Further, BeeWorld and the other FIBR projects represented clear instances of "big biology," employing big budgets, advanced facilities, advanced technologies, and cross-cutting interdisciplinarity (c.f., Venter & Cohen, 2004; Galison & Hevly, 1992; Welsh et al., 2006) to shed new light on issues of enduring importance.

Like all proposals for NSF funding since 1997, the BeeWorld proposal was subject to a competitive review, and reviewers were instructed to rank funding proposals with respect to two criteria: scientific merit and broader impacts. The FIBR Call for Participation for 2004 (National Science Foundation, 2003) required that applicants submit as part of their proposal a Project Description including two main components:

1. Describe the vision and goals for the project including an explicit statement of the major question(s) in biology to be addressed, the proposed creative approaches to attain the goals, expected outcomes, and how the proposed project will advance the frontiers of biology (Maximum 5 pages).
2. Education and Training Plan (maximum 2 pages). Describe how the proposed research will be integrated with educational activities and how these activities promote diversity as an integral component. Indicate how students trained in this research will be better able to handle emerging research problems in biological areas.

Scientific Aims of BeeWorld

Biological research at the genetic level, such as that engaged in by BeeWorld scientists, is premised on the understanding that continual interactions between the environment, including other individuals, and the individual's genetic endowment, or genome, give rise to gene expression during the individual's life. The chemical function of genes is to enable the production of proteins that are essential to all aspects of an individual's development, survival, and behavior throughout its lifetime. Not all genes

are “switched on” at all times; instead, complex environmental and social cues influence when, where, and to what degree the individual’s DNA -- a copy of which it carries in the nucleus of every cell in its body throughout its life -- will become a template for production of mRNA in particular cells at particular times, thereby producing the proteins that enable the individual to sustain its life in constant transaction with its environment.

BeeWorld presented the honey bee as an attractive model for studying social behavior. The brain of a bee is primitively simple; it is no larger than a grass seed and is made up of only a few million neurons, about 1/100,000th as many as the human brain. Yet throughout their lifetimes, bees engage in complex, socially orchestrated behaviors involving the raising of young, defense against predators, food gathering, and the construction and maintenance of habitat -- all for the benefit of the colony as a whole and often at the expense of their own individual comfort and continued survival. Honey bees typically live in colonies of 60,000 or so individuals; nearly every bee in a colony is of the worker caste, except for a single queen, who lays all the colony’s eggs, and a few hundred male drones whose only function is to mate with the queen. The queen is no different genetically from any worker, and has attained her status immediately after emerging from an egg laid in a specially constructed “queen cell”; unlike the females, drones are born from unfertilized eggs.

Nearly all bee behavioral research centers on the worker bees. Worker bees born in spring or summer typically live for a little more than a month (in contrast to queens, who live several years, and to fall-laid workers, who survive the winter to complete their work the following spring). For thousands of years, human beekeepers have recognized that the same individual worker bees will progress through a range of social behaviors over the course of their lifetimes. Typically, the progression of tasks goes from: cleaning cells near the one they emerged from and keeping nearby brood warm (days 1-2); feeding larvae in the brood cells (days 3-11); producing wax, building combs, and transporting food within the hive (days 12-17); guarding the hive entrance (days 18-21); and, finally, venturing outside to visit and pollinate flowers while collecting pollen, nectar, propolis (plant sap used for hive waterproofing), and water to bring back to the hive. Although this is the usual progression of behaviors, the needs of the colony are always paramount. By manipulating hive social conditions (e.g., removing older or younger bees from the

colony), researchers have figured out ways to encourage older bees to revert to nursing behaviors, and young bees to begin foraging outside the hive weeks sooner than they typically would.

An overall goal of the BeeWorld 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, together 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, BeeWorld 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, BeeWorld supported genetic microarray studies to investigate relationships between individual genes in the honey bee genome and individual bees' engagement in nursing, foraging, and colony defense.

Educational Aims of BeeWorld

From the outset, organizers of the BeeWorld Project meant for education and research components to go hand in hand. Throughout its lifespan, BeeWorld would include graduate students as members of its research teams, and would share project progress with colleagues from other institutions through the hosting of annual workshops. Aside from these means for broadening the project's impact to professional and pre-professional groups, BeeWorld investigators also proposed to offer educational outreach that would connect project science with audiences of middle school, high school, and undergraduate students. The project proposal promised, "The education components of the BeeWorld Project will be integrated with the research components. The goal is to target available resources to high school and college students prepared to make use of the opportunity." Curricula grounded in problem-solving inquiry were envisaged: "Our plan assumes students learn science best when they are engaged in authentic scientific inquiry, making use of the methods and ideas of current science.... It emphasizes the importance of community, whether the learning takes place in a classroom or the larger scientific

community.” BeeWorld-specific content was to form a part of the curriculum for undergraduate students at a separate university in North Carolina, where one of the project’s lead researchers was based. A biology teacher at a campus-affiliated public high school was made a part of the project, with the expectation that he would assist in development and trialing of BeeWorld-themed content appropriate for high school learners. Middle school outreach was to be accomplished by weaving BeeWorld-themed content into an existing summer camp program in mathematics that was targeted to students from traditionally underrepresented groups; camps were anticipated for mid-summer 2006 and 2008 (near the ends of years 2 and 4 of the project’s five-year life). Some cross-linking of educational curricula from the various levels was envisioned; for instance, it was anticipated both that undergraduates from the university in North Carolina could design some educational materials or travel to Illinois assist with counseling middle school age learners in the summer camps, and that project researchers and graduate students could lead some of the camp lessons. The authors of the proposal proclaimed interest in offering educational outreach that would hew closely to the science of the project itself. They wrote:

We will avoid superficial ‘meet a bee’ outreach in favor of sustained development of student competence in modern integrative biology and informatics. This focused approach will ensure that we do not duplicate ongoing efforts targeted at the general public ... but instead create educational opportunities vital to the success of BeeWorld.

From the standpoint of educational design research, the proposal’s outreach components can be understood as an initial prototype for the sorts of outreach that would be developed and tried out over the life of the BeeWorld Project. Moreover, the rationale for the initial design presented in the proposal included criteria that would continue to be important for the education planning team, as we sought to utilize project resources efficiently and effectively to design and implement high-quality educational outreach. These quality criteria included imperatives to “target available resources to high school and college students prepared to make use of the opportunity,” “engage in authentic scientific inquiry, making use of the methods and ideas of current science,” “avoid superficial ‘meet-a-bee’ outreach in favor of sustained development of student

competence in modern integrative biology and informatics,” and consequently “create educational opportunities vital to the success of BeeWorld.”

As a member of the project organizational team and a co-developer of its educational outreach, I was involved with six different episodes of outreach development targeted to middle and high school students (*Figure 1*); four were actually implemented, while the other two did not proceed beyond the planning phase. These were: 1) the originally proposed plan for contributing to the curriculum of an existing summer camp (not implemented); 2) school-year visits in December 2005 to a middle school for girls, including classroom presentations by the project’s lead investigator and myself and a subsequent field trip to the campus bee research facility; 3) a daylong set of presentations at the same middle school in May 2006, featuring hands-on activities and tutelage by a graduate student in the bee laboratory; 4) a proposed “all about arthropods” camp for middle school students that would have taken place in summer 2007 (not implemented); 5) piloting of a BeeWorld-themed camp in summer 2007, offered primarily to students at the middle school where we had conducted the 2005-2006 outreach; and 6) a second iteration of a BeeWorld-themed weeklong workshop, offered in summer 2008 to students at the university-affiliated high school. Following the practice of Barab et al. (2008), each episode description in the design narrative that follows is described with regard to preconditions, changes in thinking, the design intervention, and outcomes.

Six Outreach Episodes

Episode 1: The original plan for a middle school camp add-on. As set out in the proposal, project outreach at the middle school level was to have placed special emphasis on minority students in a low-resource community, by adding BeeWorld-themed biology content into Summer Math, an existing two-week-long summer camp that had been developed to benefit 8th-grade students who had not previously been excited about or well-prepared for science and mathematics. BeeWorld was to have covered costs for 20 students to attend the camp in years 2 and 4 of the project. Lesson content was to have supplemented and been modeled upon the existing Summer Math curriculum, which was described as emphasizing “hands-on and high-tech activities, such

as I-Movie and Working with Robots.” Undergraduates from the college in North Carolina were expected to “develop educational materials and serve as “counselors” to introduce bee biology and modern research through hands-on activities designed to stimulate inquiry.” In addition, the proposal stated,

Campers will have access to resources at the Bee Research Facility, and will visit many campus venues to increase their awareness of future educational possibilities. The goal is to capitalize on the interest in bees that is naturally present in many children, and to use it to lead them into an understanding of how preparation for a career in science begins in high school and continues into college.

Separately from this summer initiative, the proposal also pledged that at the high school level, the biology teacher who was hired for one month of summer salary per year would help develop BeeWorld-themed material and incorporate it into the curricula of existing senior-year courses he taught in field biology and human genetics. Students in the proposed “BeeWorld-based field biology course” were expected to teach younger students about the content they had learned, during a special week of student-initiated learning activities hosted each spring by the school. In addition, the biology teacher was to offer assistance with matching his students to graduate student mentors affiliated with the BeeWorld Project.

In the course of developing educational outreach along lines promised by the proposal, the model’s reliance on dependencies external to the project became evident. At the middle school level, the major difficulty to emerge was that the Summer Math camp for disadvantaged eighth graders, to which BeeWorld was to have added curricular content, ceased operation prior to the first year of the project grant. This presented the project with the choice of either creating a camp of its own to serve a similar population (either independently or with assistance from the group that had previously operated Summer Math), or developing and implementing other sorts of outreach. A second set of challenges was related to the intention to have undergraduates from the college in North Carolina design curriculum and serve as counselors for the summer camp. Due to scheduling constraints, the college course, “bioinformatics for beginners,” was not offered for the first time until Fall 2006; while its students were directed to prepare end-

of-course projects that would serve to introduce students to issues of “nature and nurture” in general ways, these projects turned out to be of widely varying quality and to deal only in very tangential ways, if at all, with content relevant to BeeWorld science. Making this material the basis for a two-week summer camp to be held only a few months later struck the education team as unrealistically ambitious. In addition, efforts to recruit undergraduates in the course to travel from North Carolina to Illinois in order to serve as camp counselors attracted no takers. The project investigator in North Carolina planned to continue these curricular development and counselor recruitment efforts the next time the course was to be offered in Fall 2007, and hoped that the model could be realized more fully the second time. For all these reasons, the education team and project investigators agreed that planning and development beyond what was initially envisioned would be required, and so elected to develop BeeWorld outreach camps in summer 2007 and 2008, rather than 2006 and 2008 as originally planned. Over the same period, external dependencies also exerted influence on the shaping of plans for the high school outreach. Over the first two years of the project, there was little BeeWorld-specific content for the teacher to incorporate into his course curricula; moreover, the teacher was generally satisfied with his existing course curricula and was able to find fairly little opportunity within them to incorporate BeeWorld content. The teacher instead developed a 32-page booklet introducing bee biology that was made available to his students as supplementary material and to the public via the project website. The booklet proved to be a worthwhile educational output in its own right, and was eventually downloaded several thousand times; among unanticipated uses that are known to the project, one beekeeping organization in South Africa sought and obtained permission from the teacher to translate the booklet into Afrikaans and use it for their own workshop series.

The emergence of these issues during the first two years of the project led to two sets of results that together helped to shape the forms of educational outreach that the project subsequently undertook to develop and try out. First, various forms of school-year outreach for a middle school-age audience were trialed during the 2005-2006 school year; these are summarized below as educational episodes 2 and 3. Second, a six-hour-long meeting devoted solely to educational outreach was conducted in June 2006, with the goal of defining a coherent and realizable set of outreach offerings that would fulfill the

project leaders' intention, stated in the proposal, to enable "sustained development of student competence in modern integrative biology and informatics ... [and] create educational opportunities vital to the success of BeeWorld." The outcome of this meeting led to consideration of different models of out-of-school outreach summarized in this chapter as Episodes 4 and 5, and 6.

Episode 2: The first school-year outreach. While in the course of encountering and dealing with the challenges described in the section above, the education team simultaneously engaged in developing and trying out small-scale outreach targeted to a small private middle school for girls. This school was unusual in offering biology as a core course for all its seventh and eighth grade students, but was also chosen for reasons of convenience. Located adjacent to the university campus, the school was taught and attended by individuals known to the project leadership; this, coupled with the fact that it was a private rather than a public institution, made involvement straightforward. The school became the scene for trialing of Episodes 2 and 3, and some of its students went on to participate in subsequent BeeWorld summer camp offerings as well.

The activities summarized here as Episode 2 took place over two days in December, 2005. On December 6, the project's lead investigator and I paid a visit to the school's grade 7/8 biology class, to talk about the project and about honey bee biology in general. These talks were meant to prepare the 15 students in the class for a visit to the campus bee research laboratory later in the week. The students had recently been introduced to topics of genetic inheritance and insect morphology, which made this an opportune time to visit. My own presentation that day introduced topics of honey bee biology, hive social organization, and a history of bees' economic importance to humans, while the lead investigator spoke about the biological and computer science aspects of the project. Our talks were of the traditional lecture variety, illustrated with slides, videos of bee behaviors, and actual beekeeping equipment. We spoke of BeeWorld biology researchers as interested in questions such as the following:

- How do worker bees know when it's time to change from one task to another?
- How does that relate to what they can know about the needs of the whole hive, and to their own biological clocks?

- How do bees find food, find their way back to the hive, and guide other bees to where the good stuff is?
- What happens to social organization if you make a hive that only has worker bees all the same age?
- What happens if you have a forager from one species trying to ‘dance’ the location of a food source to a hive of another species of bee?
- How does all this relate to the bee’s genetic structure?

In general terms, we described the goals of BeeWorld as, first, to support experiments to answer questions like these, and second, to develop compute search tools to help bee scientists learn from other species’ research. The project research, while specific to bees, might well have implications for other species as well, we said, because if a part of the genetic map relates to a behavior in one species, it may do something similar in others.

Three days later, the same students traveled by van to the campus honey bee laboratory, about two miles distant from their school. There, the project’s lead biology researcher conducted a tour of the facilities, including a hive box used by beekeepers, a glass-encased observation hive and a screen-enclosed indoor flight cage, and described how the facilities are used to observe bee behaviors under simulated natural conditions that can be subjected to experimental control and manipulation. The researcher also described how the researchers work with bees and presented information about the biology of bees’ defensive behaviors, including release and recognition of alarm pheromones and the use of stings, fatal to the individual doing the stinging, in order to defend the colony. While the format was again lecture-focused, use of questions to increase the students’ involvement and to seek their insights was frequent, as in this exchange:

Researcher: So the smoke covers up the smell of the alarm pheromone, which prevents the bees from getting all riled up. So that's one important thing that smoke does. Another important thing that smoke does, that we really don't have a good understanding about, is it makes bees eat. When the bees perceive the smoke, many of

them go in and find something to eat. We don't have a good reason why. Does anybody have a good idea why that might be? Yes.

Student: Because once the hive is on fire, they have to take all the honey because they have to travel from the hive?

Researcher: That's a very plausible idea.

Following these activities, I prepared and gave to the class teacher multiple copies of a CD-ROM that included a lightly edited, 40-minute-long video I had prepared of the tour, excerpts from a commercially available video showing bee behaviors, still photographs from the visits, the slide set from my own presentation, and the bee biology booklet prepared by the project-affiliated high school teacher.

According to my meeting notes, memoranda, and communication records for this period, the project education team and leadership deemed this instance of middle school educational outreach a successful initial effort. The middle school teacher and her students told us they found the visits enjoyable and informative, and the project leadership was pleased with the ability to organize and deliver outreach that linked the project initiatives with educational materials appropriate and useful to a middle school audience. We recognized that the outreach contained a preponderance of lecture-based material and hoped to be able to offer more hands-on activities involving study of bees in future outreach, but also realized that we would have to continue to offer educational experiences that were safe for the students and offered good fit with the ongoing research activities of the bee research facilities. Bees, after all, are little, they live in dark, crowded places, and they sting; visitors might even be highly allergic to bee stings without realizing it, and although all lab personnel were equipped with and trained in use of injectable epinephrine devices (“Epi-pens”) in the event of allergic reactions, consequences could still be serious. Moreover, the bee laboratory was primarily a place of research devoted to the conduct of tightly controlled experiments, where a tripped-over hive box or other careless move by a learner might set back research agendas for a season or more. Through this first outreach initiative, we began to appreciate that educational outreach involving these resources directly could be a powerful tool for promoting science learning, yet at the same time we recognized that there would have to be limitations on degree of learners’ access to these resources. Certain aspects of the bee

laboratory struck us as especially attractive for learning: the researchers themselves could be seen and talked with as they went about their work, and some of the experimental equipment, such as the screened-in flight cage and glass-enclosed observation hive, allowed for close yet safe access to the insects. In addition, we and the visitors also found it useful to be able to keep a record of their learning, in the form of the multimedia CD-ROM I had prepared. However, we recognized that some aspects of the educational design could easily be improved upon, as we strove to go beyond the sorts of “meet a bee” outreach disparaged in the initial proposal. Having a bee research expert involved in the classroom visit might have been beneficial, and we also wanted to explore additional ways to engage the students directly with the bees and with the project’s scientific research agenda, in order to promote meaningful learning of project-relevant science. Considerations of this sort led us to development of the second outreach encounter later in the same school year.

Episode 3: The May 2006 outreach. Educational outreach that I report on here as a third episode took place with the same private middle school for girls where we had conducted our initial outreach. In May, 2006, we arranged with the biology teacher and school principal to conduct a set of “Bee Science Day” activities in the school gymnasium, for the approximately forty students in the school’s four grade levels; this hourlong set of activities was repeated twice, first for grades 5/6 and then for grades 7/8 (most of whom had participated in the December 2005 activities). Key to the design of this outreach was the involvement of a graduate student (GA #1) who was affiliated with the honey bee laboratory and whose own doctoral research involved relationships between brain chemistry and behavior. This student was already working with the BeeWorld Project directly as an adviser to the computer scientists. Important additional assistance was volunteered by another graduate student (GA #2) who was a PhD student in entomology, although not a bee expert herself, and who as a GK-12 fellow had assisted the middle school biology teacher the previous school year.

This day’s events took shape as a sort of multi-ring circus, with simultaneous activities in different parts of the gymnasium, and groups of students moving from one activity to the next at announced intervals. Activities included:

- A slide-illustrated talk by the graduate student from the honey bee lab, covering topics of natural honey bee behaviors, the laboratory study of bee behavior, and the honey bee nervous system.
- A station with several visual microscopes, featuring prepared slides showing cross sections of honey bee brain.
- A station where students could touch and hold live day-old bees, whose stingers are still too soft to inflict stings.
- A portable glass-enclosed observation hive with a queen, workers, and drones, where students could safely observe hive behaviors.
- A station with complete honey bee brains in capped glass vials
- A station with frames from a hive box, empty of adult bees but with comb material and capped bee larvae.
- A station with several varieties of honey in different goblets, together with pretzel sticks, so that students could taste differences between honeys made from nectars of different plants (e.g., blueberry, buckwheat, clover, fireweed, linden, orange blossom, tulip tree, tupelo).
- A station with a two-foot-long, three-dimensional painted wooden model of a worker bee in cross section, with anatomically correct organs and features that could be removed for closer examination.
- A wall-mounted display featuring both commercially produced posters describing the honey bee life cycle and beekeeping activities, and posters produced by the bee graduate student that described her research work.

As with the previous outreach in December, I was directed by the project leadership to document this day's activities using a handheld camcorder and a still camera, primarily to provide project investigators with evidence of the educational outreach for reporting purposes, but secondarily for internal review. As in December, I subsequently prepared a multimedia CD-ROM of the day's activities, including photos and video from the event and supplementary materials, and provided several copies to the teacher for her own use and to distribute to interested students. In the section below, I describe three of the educational interactions that took place during the session. The following excerpted dialogues from videos taken during the lessons

illustrate ways in which the content of the day's teaching grew out of hands-on interactions involving students, instructors, scientific equipment, and bees.

Interaction 1: This took place at the visual microscope station, and provides an example of how information flowed among the instructors and to the students. I mention it here to illustrate one way in which the bee specialist's expertise complemented the more general knowledge of the other entomology graduate student (GA#2) and my own, during the give-and-take of the day's activities.

GA #1: (to student peering into the microscope) And this one is the mushroom body.

Jim: (voice from behind camera) What does the mushroom body do? I keep hearing them talk about mushroom bodies but I have to ask.

Graduate assistant #1: Me too but it was a long time ago. I should know, but ...

Jim: I'll check with [GA #2]. (Walks with camcorder to GA #2, who is at the observation hive.) A quick question from over here. What's the function of the mushroom bodies?

GA #2: They're involved in learning and memory.

Jim: Learning and memory, okay. (Walks back to the microscope station.) Learning and memory. The mushroom bodies are involved in learning and memory.

GA #1: (smiles, shakes head) I should know that! (Later, to another student viewing the slide.) That's the mushroom body, that's associated with learning.

Interaction 2: This took place at the station where the girls were able to touch and hold the newly emerged "baby" bees. The transcribed excerpt illustrates how students' questions and answers directed the flow of knowledge during this activity.

Jim: And these are the baby bees. These emerged from the brood comb about ten o'clock this morning, and for the next day or so, they're so soft-bodied that they don't have stingers, they can't fly, they just crawl around and look cute.

Girl: (cooing) Oh my god! Ooh. (several girls let the bees crawl on their arms, and one drops to the ground.)

Jim: Now we do want to keep track of them, because if they're still here tomorrow, they're not so nice. Now these are the worker bees. Now worker bees in the summer time will live about three weeks. And in that three weeks they'll go from being helpless little defenseless things like this, to start crawling around and feeding the larvae before they pupate, and then they're doing things like hive building, and they move further and further out, and after about a week or a week and a half, they're also the ones that will go out and do the pollen and nectar collection too. (student question, in audible) What's that? Yeah, it's really strange, isn't it?

Student: When do they get their stingers?

GA: (passing baby bees to two or three students) What happens with all insects is that they have this (inaudible) (to another student) Actually what happens is, their skin may be lighter and then they'll get darker stripes, and their exoskeleton will get harder, and then they'll be able to sting.

Student: How long will that be?

GA: Tomorrow. ...

Interaction 3: Students were also observed to share newly learned information with one another over the course of the sessions. The following transcribed excerpt shows one instance where this occurred, at the station where a graduate assistant (GA) was showing activity in the portable glass-encased observation hive.

GA: And she lays hundreds of eggs a day.

Jim: And she'll keep doing that for how long?

GA: Egg laying? Queens can live for up to eight years. Usually they live for two or three years.

Jim: As opposed to the workers that live ...?

GA: Only about six weeks at most.

GA: (to small group of students). And she's an experimental queen. We'll take her back and they'll do experiments with her.

Jim: I think the beekeeper said the queen alone is worth about a hundred dollars?

Student: So I think I've heard that if another baby bee is born to be the queen she has to make her own colony or something?

GA: There are many different ways of raising queens, but if it does happen that there's more than one queen in a colony, one has to leave, or there will be a fight. But that's how bees reproduce. That's how you get a multiple colony, is that the old queen will take a few workers and her to a new location, and that's how you get from one colony to more colonies.

Student: So how does a bee become a queen?

Another student: I think I know this.

GA: Do you want to answer? Okay.

Student: I think it's a special food.

GA: How did you know that?

Student: Actually, I saw it at another table here.

According to my meeting notes, memoranda, and communication records from this period, this experience with outreach gave the education team practical knowledge concerning the kinds of high-interest, hands-on activities that could reasonably be conducted with bees, and the kinds of support necessary to conduct them safely and effectively. As before, the feedback we received from teachers and students at the middle school reassured us that the activities were both highly interesting and educationally valuable. At the same time, we recognized that one-day, school-year initiatives of the types we conducted in December and May, whether offered at research facilities or in school settings, were somewhat piecemeal in nature compared to the more structured sets of activities we hoped to conduct in summer camp settings. One-week or two-week out-of-school settings would give us the opportunity for more sustained sorts of educational outreach that could transcend the "superficial meet-a-bee outreach" disparaged in the project proposal. At the same time, the process of setting up and carrying out our early

outreach experiences also served to convince us that a great deal of planning and preparation would be required to set up a successful intensive educational activity. We looked forward to sharing our insights and findings with the larger project group at a major day-long meeting the following month, in June 2006, where the project's education outreach would be the sole agenda item.

Episode 4: June 2006 meeting, and a decision point. The June 12, 2006, meeting, conducted in the project's home quarters at the recently opened genomics institute on campus, developed into a major decision point for the BeeWorld Project's educational outreach efforts. Participants included the project's lead investigators, among them the professor from the North Carolina campus; the high school biology teacher who was assisting with the project; representatives of the campus group that was to have organized the two-week-long mathematics camp for disadvantaged students for which BeeWorld had initially proposed to provide supplemental curriculum; and the biology teacher at the private middle school for girls that we had worked with on the school year outreach. Over the course of the meeting, tensions between education and research science aims that had been implicit from the project's beginning, including within sections of the initial proposal, arose at multiple points and led to the taking of decisions by project leadership that changed somewhat the focus of the educational outreach from what had initially been proposed. For this reason, this meeting amounts to a pivotal episode in the design narrative that is presented in this chapter. The account of this meeting in this section was prepared on the basis of my meeting notes, memoranda, and communication records for this period. Topics on the day's six-hour agenda included:

- a project overview summarizing accomplishments to date on the bioinformatics, biology, and education aspects of BeeWorld;
- a discussion of inquiry science learning and its applicability to project outreach aims; an overview of the past year's middle school outreach;
- an overview of curricular development and integration by the high school teacher;
- an overview of the fall 2006 undergraduate seminar in North Carolina;
- a description of the campus group's current summer efforts with information on how they had developed away from student camps to teacher education;

- discussion of how this changed situation might influence BeeWorld's own plans to involve itself in summer outreach at the middle school level, and
- brainstorming of additional directions for educational outreach in the coming school year.

In the course of planning for this meeting, the educational team had become aware that the campus group had stopped offering the mathematics-oriented summer camp a year before and was instead concentrating its summer efforts on introducing schoolteachers to student-friendly computer programming software. As an alternative to their involvement, the high school teacher and I developed a proposal for consideration by the project investigators, which would have involved organizing, planning, and seeking students for a one- to two-week science camp from a high-needs population similar to that originally targeted for summer outreach. The proposal we offered for consideration would have involved a week of activities that included not only BeeWorld-oriented science but also other high-touch, high-interest classroom and field activities introducing several other arthropod species, along with visits to insect exhibits on campus and at a nearby zoo. In developing this proposal, we placed emphasis on activities that we felt would be most readily accomplishable with the resources we had, and most accessible to the set of learners we expected to involve in such a camp.

However, the project organizers pointed out to us in the course of the meeting that a camp of this sort would represent a significant departure from the proposal's stated goal of turning the best of BeeWorld science to educational purposes. The investigators instead directed the educational team to consider ways in which a summer camp curriculum might be developed that would center on involving carefully chosen students in conducting an independent field-based experiment with bees, having graduate students prepare specimens for genetic analysis, and having the students and graduate students together analyze the results. Over the course of the day-long meeting, project organizers voiced hope for how an out-of-school workshop of this nature might take shape and how it might contribute to educators' and sponsors' knowledge of conducting especially effective outreach as part of a leading-edge science project.

By the conclusion of the meeting, participants had reached consensus that the conduct of a camp for a small number of students would itself not amount to a

meaningful project output, nor would having the project engage in forms of general science outreach that were already in common use and did not make central use of the special affordances of BeeWorld as a leading-edge scientific research project. Instead, the consensus view was that worthwhile outputs would consist of things such as publications for educators that highlighted innovative features of BeeWorld educational workshop and the rationale for those features, and sets of lesson materials that would be useful to teachers and learners beyond the workshop itself and that would be publicly accessible, via the Internet, beyond the project's end.

Over the next several months, the BeeWorld education team endeavored to develop an outreach curriculum that would respond to the goals that the project organizers voiced in the mid-2006 meeting. A premium was placed on developing a coherent set of educational activities that could make effective use of the project's leading-edge research environment without overwhelming its capacities. This proved to be quite challenging to accomplish, and the design for a weeklong workshop that became the curriculum for the summer 2007 workshop for middle school students emerged as something of a balancing act.

Episode 5: Pilot camp for middle school students in summer 2007. At a subsequent daylong education meeting held one year later in mid-June, 2007, the education team reported on a pilot educational workshop they proposed to conduct with six to eight middle school students later in the summer. According to my meeting notes, memoranda, and communication records of the period, the workshop was presented as offering an opportunity to try out educational materials that had been created by the North Carolina undergraduates as well as additional content in the form of presentations and hands-on sessions that related specifically to various aspects of the BeeWorld research. In addition, the team proposed to make use of a topic that was currently in the news, Colony Collapse Disorder, as an organizing theme for the week. The team behind the organization of the workshop consisted of the high school biology teacher assisting the project, the recently graduated PhD student who would be leading the workshop, and me, in my capacity as coordinator, all working under the general sponsorship and support of the project's principal investigators. In the weeks leading up to discussion of the proposal, the team reached consensus on the general workshop goals, while recognizing

that much of the actual content would have to take shape over the course of the workshop itself. According to transcripts and minutes of notes of organizational meetings, aspects that the team members considered as key to success of the workshop included:

- a focus on Colony Collapse Disorder as a topic of general current interest,
- ability for the students to don bee suits in order to observe closely a working bee hive,
- participation of a research beekeeper in order to bring the students into close yet safe contact with bees, and
- working with a small number of students in order to ensure safety, close interaction among instructors and learners, and non-interference with project research being conducted during the prime field season.

The team and project lead investigators regarded the 2007 summer workshop as a pilot, being conducted both to seek feedback from learners about a set of materials that were under development and to explore a model for project outreach that appeared to hold promise for making effective use of the project setting as a resource for student learning. As planning proceeded, it became evident that not all hoped-for resources would be available, in part due to the short timeline to the pilot the same summer and in part because a summer workshop would coincide with the height of field season for the bee researchers. In addition, the early-prototype nature of the workshop led the team and project investigators to favor intentionally selecting a set of learners who they felt would be especially likely to benefit from the experience. If the pilot workshop was successful in such favorable circumstances, it was reasoned, then the design could be refined and an improved version of the workshop could be offered to a more varied group of learners the following summer; on the other hand, if the conduct of the workshop revealed problems in design even with carefully selected learners, then that would also provide useful information for improving the outreach design. Most of the learners selected to participate were personally known to the recent PhD graduate in entomology who served as the week's lead instructor, through her previous work as a GK-12 fellow at the private middle school for girls that had participated in the 2005-2006 school year outreach; the others were personally recommended by individuals known to the project leadership.

The pilot-year BeeWorld Summer Education Workshop (BSEW07) was conducted over half-day sessions from July 16 to 20, 2007, in the project's quarters at the host university's Institute for Genomic Biology. The puzzle bringing focus to the workshop was Colony Collapse Disorder (CCD), the disappearance of large colonies of adult bees from their hives in large sections of the United States and elsewhere, without warning and without evident cause, which first became recognized as an agricultural threat in early 2007. Seven girls, ranging in age from 10 to 14, interacted with leading research scientists and used bioinformatics tools to discover the state of knowledge concerning CCD, and to inquire into possible causes of this vexing problem. The organizing instructor presented a curriculum that balanced advanced educational sessions conducted by leading scientists, with lighter activities such as playing educational games and visiting websites designed by the North Carolina undergraduates. Throughout the week, the learners evaluated each activity for its educational value and fun factor, with the understanding that their recommendations would help guide workshop organizers in refining and improving the materials for use by a larger-scale workshop the following summer. The week's activities, described more fully in Appendix A, included the following:

- Monday: Bee Dissection Laboratory and Colony Collapse online search.
- Tuesday: Learning About Pollinators, BeeLand game and honey tasting.
- Wednesday: Visit to a Bee Research Laboratory and Learning About Genome Bioinformatics.
- Thursday: Observing Pollinators at Work and Getting to Know Leafcutter Ants.
- Friday: Creation of Summary Posters and Nature vs. Nurture Game.

For several of the activities, the students were asked to complete a short "Activity Evaluation Form" at the end of each morning's session. The form stated the name of the activity and asked the following questions, each followed by four blank lines for written responses: 1. *Was it interesting?* 2. *Was the material presented appropriate to the target audience?* 3. *What did you learn?* 4. *Was it fun?* 5. *Suggestions for improvement.*

Information was collected for the bioinformatics talk, the honey tasting, the BeeLand game, the Capture the Nectar game, and the Nature vs. Nurture game. The students completed these quickly and their responses were fairly telegraphic in nature (e.g., students wrote that the bioinformatics talk was “informative, I liked it,” and learned from it that “genome stuff is complicated, honey bees are more complicated than they look”; about the BeeLand game, one wrote that “it was too simple and not engaging enough,” while another indicated learning from it that “bees have different jobs depending on age, move from innards of hive to foraging when oldest”). Their written responses, together with feedback we received from the learners during activities and subsequent to the workshop and review of the videotaping of activities conducted over the course of the week, showed fairly high levels of satisfaction with the week’s experiences overall, but also showed considerable room for improvement.

For the education team, the pilot workshop succeeded primarily as a proof-of-concept, providing support for the idea that a weeklong workshop built around BeeWorld Project activities had potential as set of learning activities which participants would find coherent and meaningful. We were coming to realize what the project’s educational strengths were, and also to realize that we wanted research into the emerging design to be among the project’s enduring outputs. As a group, the team and project leadership looked forward to refining and improving upon the design of the 2007 pilot workshop the following summer.

Episode 6: Camp for high school students in summer 2008. About six months prior to the 2008 BeeWorld Summer Education Workshop (BSEW08), the project’s educational organization team began planning the curriculum in earnest. Early on, team members reached consensus that the 2007 summer pilot workshop had shown the concept of a BeeWorld science-centered workshop to be feasible and educationally sound, and that a 2008 camp should focus on strengthening the outreach model in at least two key ways. First, organizers realized that although the 2007 workshop had benefited greatly from the participation of a lead instructor who was both a recently graduated PhD student in entomology and a seasoned middle school educator, this individual had not been a member of the honey bee research laboratory and thus had been unable to provide the workshop with the level of access to laboratory resources that a true “lab insider” could.

Second, the organizers recognized that although the 2007 students were very interested in the topics addressed in the curriculum and had expressed satisfaction with the workshop, the learners' lack of prior instructional exposure to basic principles of biology, especially concepts having to do with cell chemistry, genetic inheritance, and evolution, left them underprepared to understand well the scientific investigations with which the BeeWorld Project was engaged. In order to strengthen the workshop curriculum in each of these areas, the education team decided to target the 2008 workshop to high school-age learners who had completed at least a freshman-level biology course, and to engage a lead instructor with a direct affiliation to the honey bee laboratory around whose work the BeeWorld Project centered.

At the same time, project lead investigators had impressed upon the education team that their work would have to be subsidiary to the larger aims of the project. Substantive educational research would be an interesting outcome but could not be a primary rationale for the workshop, particularly since the educational funding had been earmarked for direct outreach expenses (e.g., students' meals and travel costs) and for development of related educational materials (e.g., a "science kit" that students could take home), rather than for research as was the case with the biology and computer science aspects of BeeWorld. It should be recognized that these constraints were not at all unique to the BeeWorld Project, but instead were fully consonant with the provisions under which the National Science Foundation has provided funding for initiatives that are intended to concern themselves primarily with leading-edge scientific discovery, and only secondarily with making broader educational impacts. At the direction of project lead investigators, and consistent with the educational team's own interest in developing materials through the workshop that would offer enduring value, the education team decided that it would be important to use the 2008 Summer Workshop as a means for creating prototype curricular materials, such as video-based lessons, that could later be disseminated via the project website as an enduring educational outcome with potential for broader impact.

One element of workshop curricular design that the education team believed would have particular interest for research proved not to be feasible, due to constraints of funding and logistics. For much of the spring, the team had given consideration to

recruiting a group of workshop learners that would be comprised equally of students from the participating school biology teacher's school, rural children with practical beekeeping experience who could be recruited through 4-H or similar organizations, and high school biology teachers. It was reasoned that this design would allow unique opportunities for learner-to-learner sharing of experiences, because each set of participants would bring to the workshop a distinct and potentially complementary set of perspectives and prior knowledge. However, it developed that the project budget would not allow for offering monetary reimbursement to adult teachers for their participation as workshop learners, as was customary for education-specific projects on the campus. Moreover, arrangements to recruit rural high school students with beekeeping experience as learners were still only at a preliminary stage when it became clear that accommodating them would require turning away some students at the biology teacher's high school who had already volunteered their participation. For this reason, it was decided relatively late in the planning process to offer the workshop only to students attending the high school.

The BSEW08 curriculum. "Experiencing BeeWorld" 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 BeeWorld Summer Educational Workshop 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. The students came to the project office at 9 a.m. each day 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 Daniel Stern, the high school biology teacher who had assisted with BeeWorld education outreach from the beginning of the project in 2004; Ned Nelson, the graduate student in honey bee genomics who had been selected to serve as lead instructor; and me, in my capacity as

overall project coordinator. As a team, we were directly responsible to the project's principal investigator, and received advice and assistance from other project investigators and from the recently graduated PhD student in entomology who had been a curriculum designer and lead presenter for the 2007 workshop. As the video-based curriculum that emerged from BSEW08 illustrates, roughly half of the 15 contact hours involved hands-on activities and tours, with the remaining time devoted to presentations by Ned and other researchers involved with the project. 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 Mr. Nelson, did the focus of learning shift from bees and bee research in general, to the behavioral genomics investigations being conducted by the BeeWorld Project itself. Days Three, Four, and Five featured increasingly complex slide-illustrated lectures by Mr. Nelson and project researchers, interspersed with hands-on activities such as tours and simulations that were intended to complement directly each major talk.

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, described more fully in Appendix B, 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 BeeWorld Research.
- Wednesday: Talk on Molecular Analysis of Bee Genetics; Talk on Conceptual Basis for BeeWorld 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 BeeWorld Bee Behavioral Research Initiatives; Outdoor Pollinator Observation; Talk on Computational Aspects of BeeWorld.

Participant-generated data from BSEW08 is the evidentiary basis for investigations into this dissertation's Research Questions 2 and 3, and so is dealt with in the next two chapters.

Interpretation of Findings for Research Question 1

The design narrative presented in this chapter illustrates the complex means by which the BeeWorld Project organizers arrived at the curriculum they offered to fourteen high school students in summer 2008 as a window onto the world of the project's research. Each of the five episodes that preceded BSEW08 brought into relationship in different ways the sometimes contrasting worlds of K-12 science education outreach and university research science. In some instances, the project was able to facilitate educational episodes that brought young learners into contact with the expertise, tools, facilities, and relationships that lay at the heart of the project's research enterprise. In other instances, the actual or perceived gulf between the project's research goals and its ability to provide educational outreach that its organizers considered worthwhile proved so great that planned forms of outreach did not proceed beyond the planning phases. BSEW08 emerged as something of a Goldilocks compromise that made what project participants considered to be effective use of project resources for educational ends. The path of progress toward BSEW08 illustrates how one scientific research project navigated a gulf in expectations between its own research goals and its secondary aim of offering meaningful education for a young, non-specialist audience.

In certain ways, the BeeWorld experience resonates interestingly with Yrjo Engestrom's (1987, 2001) conceptualization of a third-generation Activity Theory. Engestrom was building upon a half-century of Soviet-era scholarship that began with Lev Vygotsky's notion that all relations between humans and the objects of their activity

are mediated by artifacts (be they tools, languages, or societies) that themselves have a cultural and historical basis. This has often been depicted schematically as a triangle of “subject-tool-object.” A.N. Leontiev’s subsequent contribution, amounting to what is now considered second-generation activity theory, was to emphasize the collective nature of social activity. In doing so, he further proposed that collective *activity* could be regarded as being made up of constituent *operations*, the most basic level, and *actions*, often associated with individual knowledge and skills. In a famous example given by Leontiev, prehistoric humans engaged in a collective hunt might have divided their labors such that one or more individuals, “beaters,” would have shaken the trees and bushes in a forest to frighten game in a particular direction, where other individuals involved in the hunt could kill it. The beaters’ *actions* as individuals (shaking vegetation), can be understood only in context of the collective *activity* (hunting) in which they were engaged together with the attackers as a group (Barab et al., 2004).

As Barab et al. (2004) recount, Engestrom (1987) made two contributions to Leontiev’s Activity Theory that amount to a “third generation” understanding. First, he clarified the constituent elements of Leontiev’s framework with an expanded triangular schematic that accounts for subject, object, instrument (mediating artifact or tool), community, social rules, and divisions of labor. These in combination amount to an “activity system” whose object will lead to some sort of *outcome*, or result of the activity. Second, Engestrom proposed that activity systems can be regarded as perpetually in flux due to processes of *tension* and *contradiction*, which, so long as they are not altogether destructive, can potentially bring about conditions for what he called “expansive learning,” essentially the design and implementation of new practices (Cole & Engestrom, 1993). In Engestrom’s words (2001, p. 133), “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.” Engestrom (2001, pp. 136-137), sums up the current form of activity theory with regard to five principles:

1. *The first principle* is that a collective, artifact-mediated and object-oriented activity system, seen in its network relations to other activity

systems, is taken as the prime unit of analysis.... Activity systems realize and reproduce themselves by generating actions and operations.

2. *The second principle* is the multi-voicedness of activity systems. An activity system is always a community of multiple points of view, traditions and interests.... This multi-voicedness is multiplied in networks of interacting activity systems. It is a source of trouble and a source of innovation, demanding actions of translation and negotiation.
3. *The third principle* is historicity. Activity systems take shape and get transformed over lengthy periods of time. Their problems and potentials can only be understood against their own history. History itself needs to be studied as local history of the activities and objects, and as history of the theoretical ideas and tools that have shaped the activity....
4. *The fourth principle* is the central role of contradictions as sources of change and development. Contradictions are not the same as problems or conflicts. Contradictions are historically accumulating structural tensions within and between activity systems....
5. *The fifth principle* proclaims the possibility of expansive transformations in activity systems.... An expansive transformation is accomplished when the object and motive of the activity are reconceptualized to embrace a radically wider horizon of possibilities than in the previous mode of the activity....

I introduce Engestrom's ideas here in order to suggest that the design narrative presented in this chapter might be interpreted in part through considering K-12 science outreach and university research science as conceptually separate *activity systems*, which in BeeWorld and similarly situated projects have a *potentially shared object* of project-related educational outreach (*Figure 2*). Efforts by BeeWorld developers to draw directly from models of educational outreach like the six RSMSS prototypes described in Chapter Two can be construed as having brought to the surface various *tensions* and *contradictions*, among them resource availability and lack of relationship between typical education goals and the project's science. By this understanding, the various design

episodes in this chapter 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 “research science meets school science” educational outreach described in Chapter Two, its curriculum merits attention as a potential instance of *expansive learning* along the lines considered in Engestrom’s model.

Engestrom has suggested that the sharing of an object by two disparate activity systems can lead to the emergence of *contradictions*, or “historically accumulating structural tensions,” which act “as sources of change and development”; in consequence, expansive transformations in activity systems come about “when the object and motive of the activity are reconceptualized to embrace a radically wider horizon of possibilities than in the previous mode of the activity” (Engestrom, 2001, pp. 136-137). The design narrative presented in this chapter can be understood as describing processes by which an expansive transformation came about in the micro-history of the BeeWorld Project. The initial BeeWorld proposal (episode 1) suggested that, as a means of fulfilling the project’s mandate to contribute to broader societal impacts through involvement with school science, the project would offer content and topical expertise to an existing summer mathematics camp for at-risk middle school students. The disappearance of the mathematics camp appeared to leave BeeWorld with the choice of either organizing a general science camp for a similar set of learners, or finding ways to utilize the leading-edge science of the project to its utmost as curricular content for school-age learners (episode 4). School-year forays with middle school students involving a field trip to BeeWorld research facilities (episode 2) and an in-school visit incorporating significant hands-on contact with bees and tools of research (episode 3) yielded findings that these sorts of activities could themselves provide a basis for a weeklong summer workshop built around BeeWorld science content. A pilot camp with middle school-age learners (episode 5) indicated to project organizers that this sort of workshop was achievable, but that opportunities for learning in such workshops might be enhanced by minimizing the distance between learners and researchers -- first, by targeting such workshops to high school students who had prior knowledge obtained through freshman-year biology; and second, by employing as lead instructor a graduate student researcher who had “insider” access to the project’s research facilities. BSEW08, then, took shape as a sixth episode of

educational involvement by the BeeWorld Project, within which were worked out various contradictions between school science and research science that had become evident in the previous episodes. The working-out of those contradictions in ways commensurate with the affordances and constraints of the sponsoring research project shaped the BSEW08 curriculum in ways that might amount to an instance of expansive learning on the part its organizers. If expansive learning did occur, the shape of the BSEW08 curriculum might be expected to differ markedly from forms of outreach developed in more education-centric contexts. This leads to consideration of the second research question, which I take up in Chapter Five.

Chapter Five

Understanding the BSEW08 Curriculum

Research Question 2: What were the distinguishing features of this educational activity?

The 2008 BeeWorld Summer Education Workshop (BSEW08) grew out of prior educational design episodes undertaken by the BeeWorld Project, as a weeklong set of encounters offered to fourteen students who attended the elite public high school at which their project's affiliated biology teacher taught during the school year. In this chapter, I make 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 iterations to become an enduring product in its own right; instead, the goals were, first, to identify design features 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, this research is not meant to be a full-scale curriculum study. Instead, the aim is to inquire into the nature of BSEW08 as a unified whole, 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 I 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 I had prepared in my 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, I 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. In the course of analyzing data for this study, I began by annotating the textual data with 876 instances of novel descriptive codes, then engaged in an iterative process of data reduction and analysis that led to my identifying identify seven category codes, or terms. I offer these categories here as a set of descriptive “handles” that I found useful for making sense of the available data. Such grounding as I can claim for them is no more than intuitive, based on close contact with the data from which I derived them, but ultimately interpretive in nature.

Curricular Design Features of BSEW08

In the account that follows, I present evidence from developer and student accounts to support a claim that seven design features characterized the curriculum of BSEW08. Together, these comprise a model that may operate in somewhat nested fashion (*Figure 3*); the notion to be considered 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 BSEW08 fit in with their own *learning trajectories*. Readers should understand that this set of design features is presented as a tentative and partial account of the character of the curriculum, not as definitive. Identification of these design features in the BSEW08 curriculum is not meant to imply that these or similar design features might not also be present in RSMSS curricula grounded in other pedagogies, such as HOPSI, nor do I mean to claim that these seven are inclusive in scope. Rather, my intent is to draw out from participant data a set of features that help to explain both developers’ intent in shaping the curriculum as they did, and ways in which learners experienced that curriculum. In keeping with the goals of design-based research, I frame discussion in this way as a means of identifying curricular features that have potential for development into design principles that could be applied and tested in further instances of innovation. Design features I 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 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.

Characteristics of BSEW08 Learners

Fourteen students participated as learners in BSEW08. All workshop participants were students at a public high school affiliated with the university at which the research was conducted, and had volunteered to participate in the workshop after receiving an email invitation sent near the end of the school year by the school's biology teacher, Daniel Stern, to all of the school's freshman, sophomore, and junior year students. Every student who expressed interest in being part of the workshop was accepted, and the students were neither charged a fee nor received compensation for participating in the workshop or the related research. All students in the workshop were invited to participate in this research but were not required to do so. Eleven of the fourteen agreed to participate in the research; because all of the students were minors, research consent was also obtained from their parents or guardians. All of the students are referred to by pseudonym in this study. Of the eleven students who participated in the research, seven were girls: four of them (Ruth, Eileen, Karen, and Marge) had just completed freshman year; two (Debra and Audrey) had finished sophomore year, and one (Vivian) had completed junior year. Of the four boys who participated, two (Steve and Jeff) had completed freshman year, one (Arthur) had completed sophomore year, and one (Jonathan) had completed junior year.

The school that the volunteer learners attended has some unusual characteristics that bear mention. While it is part of the public school system in its city and does not charge tuition, it is administered by the local university as a "laboratory" high school; admission is by competitive examination and only a small percentage of the students who apply are admitted. The school is ranked annually by a national news magazine as among the ten most outstanding high schools in the United States, and 100 percent of its graduates go on to college. Many of the school's students, although not the majority, are children of parents who work for the university. Thus, it is fair to characterize the student population from which the workshop volunteers came as a somewhat elite group of learners; moreover, the individual students who volunteered to take part in BSEW08 should be recognized as individuals who were particularly keen on participating in an out-of-school educational initiative of this sort.

The students' responses in pre-workshop interviews supports the finding that these were a very interested group of learners who could be expected to enjoy and learn a great deal from the workshop week. As students in a highly regarded university-affiliated high school who were personally known to the school's biology teacher, Mr. Stern, and as (in several instances) children of parents who themselves were academics or scientists, all brought with them a strong general understanding of academic research science and a history of success in school science learning. Without exception, they are the sorts of students whom educational theorist Glen Aikenhead (2001, p. 181) would recognize as having little to no difficulty with "crossing borders" into advanced science learning; each of them could readily be pigeonholed into his category scheme as "Potential Scientists, whose transitions are smooth because the culture of family and friends is congruent with the cultures of both school and science." However, it would be erroneous to presume that these learners are wholly atypical of their age-mates in other high schools around the United States. As Mr. Stern remarked to me in a post-workshop interview, "Children are children, and volunteer children are volunteer children. I think sometimes we make the differences [of academic giftedness] greater than they actually are." Mr. Nelson, the entomology graduate student who served as the lead workshop instructor, commented to me in a separate post-workshop interview that upon first meeting the students,

I was relieved to see that we did have a bright audience, and an attentive audience. ... I would say that you could find that group of ten to twenty at any high school. But as a random cross-section, maybe that kind of student would be 50 percent to 80 percent of ... [this] high school, versus if you go to some rural high school somewhere, it might only be that 10 percent that have that, not necessarily ability so much as enthusiasm and willingness.

Throughout the workshop week, Mr. Nelson told me, "I saw a lot of people really paying attention, really trying to grasp what we were talking about. And it really seems to be more a matter of effort than of ability, although that's probably difficult to dissect. Dare we say 'nature-nurture'?"

Coherence of Experience and Connecting Worlds

A primary objective for the organizers of BSEW08 was to build Coherence of Experience through enactment of a curriculum that would support Connecting Worlds of students' everyday experience and the project's scientific exploration. Comments made by Mr. Stern in the course of an interview I conducted with him approximately one month after the workshop indicate how he regarded the curricular organization of the workshop's activities as offering a tightly sequenced set of activities that led from general knowledge of honey bees, to knowledge of bee biology, to an understanding of honey bee behavioral genomic research as conducted by the BeeWorld Project. His understanding of how curricular organization contributed to students' learning is supported by comments the students made in the interviews I conducted with them four months after the workshop week.

Mr. Stern's understanding. For Mr. Stern, a key aspect of the curriculum was the manner in which the week started by providing the learners with general information about honey bee anatomy and physiology, about beekeeping history, and about the ongoing dependence of human agriculture upon honey bees and other pollinating insects. At the same time, he valued the mixture of hands-on and receptive learning activities that were part of each day's sessions. During our interview session, I showed him early versions of the lesson videos that with further editing would become the online BeeWorld curriculum. This provided him the opportunity to offer comments about what he perceived to be the value of the sequencing of the workshop week's curriculum.

With regard to the week's opening activity, an hour-long, slide-illustrated talk by the lead biology researcher, Mr. Stern commented, "Our scheduling of that where we did was perfect. It also set the tone, just in terms of basic biology, for the kids to realize that whatever we did, we were going back to the basic biology." Of the visual microscope activity that immediately followed the biologist's talk, Mr. Stern remarked,

I thought that worked really well, for a couple of reasons. First, it gave the kids a chance to do hands-on examination of the bees. They were able to see some things externally, but just being able to go in internally and get a sense of what things looked like, I thought that was really valuable.

Likewise, the coupling of the microscope work with an opportunity for the students to handle live day-old bees, having exoskeletons still too soft to inflict stings, “gave the kids again more of a feel for the organism before we started delving into the genetics.”

Mr. Stern also commented on the value of following up with activities the next morning that first introduced moveable-frame hives and other beekeeping equipment in the classroom, then brought the students by van to the nearby bee research facility for the opportunity to observe bee colonies being managed for field experiments. “The big thing with student learning is exposure,” he commented. “You can have them read things, you can talk about things, but it’s not the same as being able to go and physically look at it and physically handle those things. There’s no better way.” This was the rationale behind having the students don protective suits and cluster around Mr. Nelson as he removed the cover from a working hive and pointed out honeycombs, brood cells, and the workers, drones, and queen bee, Mr. Stern said:

The kids know what the different bees do, they know about different ages and different things that the workers do. They know that it is controlled genetically. They know that it’s flexible also. So now we have a chance for the kids to go in and look at the bees. And the kids were less intimidated by the bees, because they had handled them, they had looked at them. Again, it seemed like a very logical way of doing things.

Likewise, he said, bringing the students indoors at the research facility to show them how researchers were manipulating colony environments in order to conduct field studies under controlled conditions was an important stage in structuring the curriculum. “The kids got a chance to see what’s involved in managing colonies,” he commented. “They were able to see the equipment, and then they were able to see a number of different setups that allowed for manipulation of the environment, in terms of temperature, light, and flight distance. So they went from seeing what’s involved physically with maintaining the facility, to different types of setup for experiments. So now the kids have a sense of the organism, they have a sense of what people do, they have a sense of what people examine, and what areas are being researched presently at the facility.”

This combination of activities on the first two days of the workshop prepared the students well to return to the genomics institute and begin to learn from Mr. Nelson and

the other project-affiliated presenters about the ways in which they were using honey bees to study about the genomics of insect social behaviors.

Students' understandings. During the individual telephone interviews conducted four months after the workshop week, each of the students told me they had learned a great deal over the course of the week about honey bee sociality and the importance of bees to humans as pollinators. Several made reference to particular activities that Mr. Stern had also remarked upon when he spoke about the workshop's curricular structure:

Audrey: [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 can move up as they go older.... The thing that stands out most for me was when we went to the actual bee place, and the bees were dancing to show the others where the honey was. I thought that was really neat.

Eileen: I never realized how important bees were. I always found them to be pesky because they stung me. But I never realized how important they are to our economy. Now I'm definitely more aware when I see bees' nests or wasp nests, so it does come back into my memory.

Jeff: 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 the bee researchers were doing.

Jonathan: 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.

Marge: [I learned about] understanding the honey bee genome ... [but] also about behaviors. I don't know if you could call it honey bee psychology.... Bees are so absurdly different from all other animals ... but I guess studying it on that level gives some indication of how to study it on human levels.... At some obscure level I suppose we're all related.

Ruth: 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 very specific types of bees, which I thought was fascinating. And it's just interesting how they can all communicate as a community. I really saw that a lot during the week, especially when we talked about and got to witness the waggle dance.

Steven: "I learned just about everything -- you know, the dance language, the colony structure, how they respond to changes in light and heat and all that sort of stuff.

Vivian: "I thought it was great 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."

Beyond their recall of general information about honey bees, the students said they themselves were surprised by the amount of highly detailed information they could recall four months after the workshop, on topics relating to the genetic basis of honey bee social behaviors. Some illustrative comments follow:

Arthur: [BeeWorld scientists] use bees as a model species to see how DNA can be used to figure out problems in different species. They're trying to use it as a species to model some things on, because bees are easy to work with and it's easy to get their DNA and stuff and keep on breeding them. And there are certain problems with bees that are also seen in other species, and if you can see how the genes in bees are affected, that can be transposed to other species.

Karen: [I learned] mostly about worker bees and their behavior, and just the way that 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.

Mr. Stern's and the students' comments support the importance of *coherence of experience* and *connecting the worlds* of everyday experience and school science to the organization of the BSEW08 curriculum, and to the ways in which the students subsequently recalled the workshop week.

Scientific Authenticity, Characteristics of Setting, and Necessary Simplifications. "The everyday conception of water is more available for ordinary uses of drinking, washing, irrigation, etc., than the chemist's notion of it," educational philosopher John Dewey has written. However, he continued,

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. (1916/1958, p. 224).

In much the same vein, it is useful here to draw a distinction between the honey bee, as an organism existing in nature that has been managed in ways useful to human agriculture, in contrast to *Apis mellifera*, the same biological organism as considered by biologists. From the familiarization activities about which Mr. Stern commented, the workshop curriculum proceeded to classroom activities led by entomology graduate student Ned Nelson and his research colleagues that introduced their laboratory's use of the honey bee as a research organism.

In planning meetings and discussions prior to the workshop week, the organizers repeatedly expressed a desire to build a curriculum that would utilize the research facilities and expertise of BeeWorld in as authentic a manner as possible, while avoiding interference with the ongoing research. They intended to go about this by bringing the students into the settings of the project's scientific work and providing detailed explanations and demonstrations of that work, using authentic tools and involving the

scientists themselves. Key to their planning was the research laboratory director's willingness to lend Mr. Nelson's services for the planning and conduct of the workshop. He began planning with the other education team members several months prior to the workshop, and came into BSEW08 ready to lead the learners through nearly a dozen separate activities that ranged from laboratory tours to multimedia-illustrated lectures. He was also present throughout activities led by other BeeWorld researchers, and on several occasions helped the students to understand how the other researchers' work fit into the project as a whole. Overall, Mr. Nelson's involvement in, familiarity with, and comfort with the research setting added much to the scientific authenticity of the workshop curriculum.

Mr. Nelson's understanding. In our interview one month after the workshop week, Mr. Nelson told me that he found himself surprised by the amount of detailed information he was able to convey to the students during his workshop talks. "Really, I felt like we covered absolutely everything and more," he said. "We packed a lot more in than I thought we would be able to get to. I was a little wary about cramming all of the activities we did have planned, and we still got to the vast majority of them." Asked about how he had gone about planning his talks, he said this:

I got all my outlines together, which for me is the biggest part of it, and I'd just go over the outlines over and over in my head, until I just knew exactly, until I could give the talk at three times the length if need be, just so many details, so many different things to include. And then going through it, you just kind of, depending on how much time we've already used, decide how much to throw in, how much to keep talking, because these topics are so broad. I mean, just the topic of gene expression, how do you limit that to one slide? Well, you just make one slide saying what it is, and then decide how many examples to give. So I'd spend a lot of time just reviewing the outlines, and then putting the actual presentations together came rather easily because I knew what I wanted to say, what examples I wanted to use, and it just became a matter of going online and finding a free-source picture of the random enzyme, or a picture of the DNA gel, or whatever.

Mr. Nelson said he had occasion to “talk enough about my work in general to people that know nothing about it, that I felt like I had some practice on what works and what doesn’t, what people can catch and what they can’t.” He acknowledged that he found “describing the lab work particularly intimidating in that way,” but added,

At the same time I did feel like I had a decent idea of where to start and where to go. But in so much of the lab work you just, when you’re doing it, you 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 in that way. You just have to find a way to explain it, and sometimes just leave out the small details and focus on the overall conceptual things.

Finding ways to succeed in making necessary simplifications to laboratory procedures in order to explain their essential workings to young students was an ongoing challenge for Mr. Nelson.

Mr. Nelson told me that he believed a major contribution of the workshop was to convey the work of research science in sufficient detail to enable the learners to come to an informed understanding of whether they might someday wish to be involved in such work:

I don’t know if it’s only my generation, but there seem to be many people who get all the way through their degree or into the job force and they say, “Oh my god, I hate this!” Or at least they say, “I have no passion for what I’m doing. I can do it, I’m probably even good at doing it, but I have no passion for it.” So the number one thing that I tried to do, and even including things like the little 15-minute lab tour and things like that, and keeping things as almost a narrative story in the research, was, “This is a person, this is what their background is, what they’re interested in, this is what they’re doing, why we’re interested in it.” Keeping that kind of story would help give this, “This is what we do. If you’re interested in becoming a research scientist, this is what to expect.” And that was really one of the main things I tried to keep in mind when planning things out.

Mr. Nelson told me that he believed the interdisciplinary nature of the BeeWorld Project was an important factor in making it a facilitative environment for educating young learners in a workshop setting. “Those great epiphanies, the ones that really transform science, are going to be through some sort of cross-modal interdisciplinary discussion that is going to spark that eureka moment,” he predicted. “And that’s also the value of having a project like BeeWorld conduct educational workshops. We had this coherent unified central core, but we were able to bring in so much extra. ... I think we’re a little lucky in that respect.”

Students’ understandings. During our interview, Mr. Nelson told me, “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.” However, this was one of multiple areas about which the students did claim to have gained a measure of understanding, as I learned when I had occasion to interview them individually by telephone four months after the workshop week. Arthur, for example, told me the following:

I was surprised at how committed these professors and students and researchers 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.

Ruth made a similar observation:

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 very interesting information to the researchers at this point.

Students also claimed substantial recall of some of the laboratory procedures they had learned about:

Arthur: 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.

Steven: The qRT-PCR was very cool, and the microarrays. I kind of liked it when we did that [microarray simulation activity] to figure out which genes were present.

Similarly, several students remarked on the importance of having the workshop take place in the research environment itself. These comments are illustrative:

Ruth: 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.

Jonathan: 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 up honey bees around me because they know I'll talk for half an hour.

Microarray analysis simulation. The necessity for simplification of scientific research procedures for educational purposes was particularly evident with regard to an activity that was decided upon to introduce students to microarray analysis, a laboratory technique that was critically important to the BeeWorld behavioral genomic research. As lead workshop presenter Ned Nelson commented in the post-workshop interview, 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, involves use of chemicals that are harmful unless handled with caution, and costs tens of thousands of dollars. Even so, Mr. Nelson, who was himself a graduate student working in the honey bee laboratory, 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 process 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, Mr. Stern also spoke about the value of the activity, commenting, “I thought that was particularly useful after the introduction to BeeWorld, 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 (Vivian) 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 (Steven, Debra, Jeff, Jonathan, and Karen) said they found it useful and would have liked the opportunity to do more activities of the sort.

Students’ Learning Trajectories

As noted earlier, the BSEW08 students could be regarded as having special characteristics that helped them learn from the week. All were participating voluntarily, all shared a background knowledge of having studied freshman-level high school biology with the project-affiliated science teacher, Mr. Stern, and all were familiar with the university setting by virtue of their being students in the university-affiliated high school. In their interviews four months after the workshop, each of the students spoke in enthusiastic terms about how their workshop participation related to their long-term interests and trajectories as science learners. Comments relevant to this topic include the following:

Arthur: 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.

Audrey: 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.

Eileen: Hopefully for my junior and senior science electives I'll take more biology classes, and this will play into those classes, so it definitely is important.

Ruth: I signed up because I am interested in science and the genomic sequence, and I feel like that strengthened my interest in science in general.... I know I will definitely go into some kind of scientific field. I was thinking generally of an area where I will work in a laboratory environment, ideally.

Jonathan: I've applied to the bioengineering department [of the local university], so it [the workshop curriculum] might be particularly relevant.... Biology is really sort of applied chemistry which is applied physics which is applied math, but if you take math and try to examine a biological system with it you'll just fail completely because it's so complex. So you can study things at the quark scale, but then if you have to scale that up to a cell, an organism, a molecule even, then you're just hopelessly adrift. But it's really fascinating and it's where all the new and cool things are happening. That's kind of why I want to study bioengineering.

Karen: 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. ... I'd like to see more opportunities like this.... It definitely leaves a different impression of going into science, as opposed to what you learn in schools. Biology [class] is a lot of learning about different animals and all that and doing small experiments, but the BeeWorld workshop was about what people are learning currently through a modern technology like microarray that you don't always get the opportunity to do inside school.

Marge: 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.

Steven: 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.

Vivian: What I got from BeeWorld is a new perspective on genetic research. I think BeeWorld 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 really good way to cement our understanding. I think BeeWorld also introduces students to a possible career path, which is also interesting.

Marge: I never really considered genomic research important before that week. I understood that it had some value to society, but I was never really interested in it, nor did I think that it was necessarily essential for further extension of our understanding of psychology in general -- people, animals, whatever. But I guess it really did expand my understanding.

Comments such as these suggest that students found multiple aspects of the BSEW08 curriculum highly relevant to their own emerging academic and career interests, whether or not they expected to continue studying science in university or to become scientists themselves.

From Outreach to Inreach: BSEW08 in Comparison with Education-Centric Outreach Models

Aspects of the BSEW08 curriculum bear resemblance to all six varieties of “research science meets school science” outreach described in Chapter Two. As with the “scientists in the classroom” model (RSMSS Type 1), heavy emphasis was placed on the role that expert scientists can play as explainers and demonstrators of scientific phenomena and relationships. In common with technology-centric initiatives (Type 2), much of the curriculum involved bringing students into close contact with the tools utilized in the BeeWorld Project’s scientific research, even if the degree to which the students had control of these resources was necessarily limited. In a sense, the entire week represented an extended field trip for science learning (Type 3), by virtue of its taking place within the BeeWorld research facilities; moreover, students had opportunity to immerse themselves more fully in the work of BeeWorld through visits to outdoor hive, bee research facility, and laboratories. Although students did not have opportunity to collect data that would be of direct use to project scientists, as in citizen-science

initiatives (Type 4), they did at least encounter opportunities to simulate engagement in this work through a microarray activity. (It is worth recalling here that citizen science was considered as a model for the proposed summer camp during the June 2006 meeting, but that this level of engagement with project science proved to be impractical.) In terms of overall organization, the week-long set of workshops was structured as a summer science camp (Type 5), even if the project's limited resources and enveloping engagement in leading-edge scientific research resulted in a camp much smaller in scale and less ambitious in scope than the camps described in Chapter Two. Finally, the manner in which BSEW08 took shape through close collaboration between project scientists and the affiliated high school teacher, Mr. Stern, attests to an important way in which the camp, although geared to high school age learners, also grew out of a sustained laboratory-to-teacher initiative (Type 6), albeit on an individual scale.

Even so, BSEW08 would not readily be mistaken for a full working-out of any of the aforementioned types of RSMSS model. To the contrary, the research design narrative presented in Chapter Four points to various ways in which attempts to instantiate one or more of those models more fully met with difficulties, owing to the subsidiary position of educational outreach within the larger project. On the one hand, little support emerged for outreach proposals that were held to involve too little project science, such as the original proposal to tie into an existing (and subsequently defunct) mathematics summer camp, and the subsequent proposal to sponsor and organize an arthropod camp. On the other hand, a proposal that would have involved middle or high school students directly in the carrying out of project science also failed to launch, for reasons having to do with complexity, research rigor, and safety. The curriculum that emerged as BSEW08 took shape, then, in Goldilocks fashion, neither too big nor too small for the resources of the BeeWorld Project as a whole. The result was a curriculum that differed overall from all six of the education-centric model types glossed in Chapter Two, in a key way: whereas each of the six education-centric models is supported by a rationale and accompanying literature emphasizing a primary role for what might be dubbed students' "hands-on, problem-solving inquiry" -- HOPSI in short -- this form of pedagogy was notably absent from the BSEW08 curriculum. 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 engaged audience members for multimedia-supported lectures designed to tap into the background knowledge and interest developed through the preliminary activities.

This overall curricular organization differs sufficiently from the six outreach models presented in Chapter Two that it merits consideration as something different from forms of outreach that borrow tools and expertise from laboratory science to enrich the world of school science. Instead, I would like to suggest here that the BSEW08 model amounts to a form not of outreach, but rather of “Inreach.” The essential difference is that Inreach does not aim to repurpose the actors, tools, and facilities of research science to fit school science purposes, but rather to bring young learners into the world of research science itself, even if primarily as tourists rather than as partners.

This is not to say that similar goals do not apply to some of the forms of education-centric RSMSS. However, where education-centric outreach is the primary concern, the form of engagement undertaken in order to achieve HOPSI pedagogies is often one form or another of play-acting: scientists in the classroom may be encouraged to act as if they know less than they do in order to facilitate student engagement, students may be enlisted to gather data as if that data will be of direct use to scientific researchers even when that is not actually the case, and the tools and facilities of research science may be adapted heavily in order to serve as tools for student learning instead. There is a great deal to say for the educational value of engaging resources of research science for these sorts of activities, and the education-centric projects supported by programs such as those of the National Science Foundation’s Education and Human Resources directorate can claim much success. Even so, the emergence of a markedly different sort of educational instance, through BSEW08, begs the question of whether Inreach models, even absent elements of HOPSI that are central to most outreach models, might hold promise for contributing meaningfully to the education of young learners. Accordingly, Chapter Six investigates how students might have learned from their participation in BSEW08.

Chapter Six

Students' Learning from the BSEW08 Curriculum

Research Question 3: How did the students learn and remember from this experience?

In the course of interviewing the eleven students four months after BSEW08, I was surprised to discover how much they remembered about the workshop week. The clarity of their recall, as evidenced by their responses to the interview questions (Appendix E), led me to review the psychological literature for theories that might help account for this data in terms of remembering, learning, and the relationship between them. In this chapter, I seek to interpret interview responses that relate to the memorability of the workshop curriculum, by utilizing the theoretical construct of “episodic memory” (Tulving, 1972). I begin by describing how episodic memory and related constructs have been developed in prior studies, and then consider how these theorized processes might help explain aspects of the students’ learning and remembering from BSEW08. Finally, I consider how an Inreach-oriented pedagogy might promote memorable and meaningful learning of science.

Discussion: Investigating Memorability of the BSEW08 Curriculum

As discussion of each of the episodes in the preceding chapters suggests, BeeWorld organizers were interested throughout the project in designing and offering educational experiences that would be meaningful. Educational theorists since John Dewey’s time have given thought to the concept of meaningfulness, and there is an enduring school of thought which holds that meaningful learning, in psychological terms, consists of the learner connecting new information to prior knowledge in ways that enable them to construct coherent and increasingly complex cognitive structures (e.g. Dewey, 1902; Ausubel, 1963; Hawkins, 1965; Prawat, 1993). In exploring a novel curricular approach within the context of, and utilizing the resources of, a limited-term project designed primarily to serve other ends, it would not be feasible to trace learners’ cognitive processes over the course of years or to isolate for all sorts of variables that might conceivably make for differences in learning across different sorts of learners (e.g., the various “types” proposed by Aikenhead, 1996). Moreover, it is doubtful that even this

level of rigor in research would yield especially useful and enduring outcomes, owing to the constant evolution of expert understandings and ways-of-seeing in circumstances of leading-edge scientific discovery. In any case, it would be inappropriate as well as unrealistic to embark on such a resource-intensive educational research enterprise without first attempting to gather some preliminary evidence as to whether a novel curricular approach might merit this level of scrutiny. However, it was at least within the project's means to collect learners' own accounts of what sorts of knowledge from the curricular encounter might endure over a period of some months following the time of presentation. If all was forgotten by then, what would be the use of looking further? If, on the contrary, learners were to recall much of the content of the curriculum, particularly in ways that gave an indication of how the learners were relating that new information to their own enduring interests and making use of it in considering their own expressed goals for the future, that would serve as some indication that the approach might have sufficient utility to merit closer scrutiny at some later time.

The construct of “episodic memory.” What do memories consist of? How can they be documented? How are they related to learning? Investigating such questions is far from straightforward. The present research is informed by notions similar to those espoused by Falk and Dierking (1997):

The products of learning (i.e., memories) are not discrete entities, like so many widgets warehoused and sorted into separate compartments in the brain, waiting to be pulled off the shelf at the appropriate moment. Instead, memories are a tangle of interconnected information and emotions -- people, places, things, ideas, feelings and sensations -- are all intermixed and intermingled into a single memory..... In this view, learning (and memory) is not absolute, but relative. Learning (and memory) is not permanent, but ephemeral. Learning (and memory) is not a part, but a whole. Learning is not a product or a process, but a combination of the two. In this view, learning emerges as very hard to document.... Memories are more readily retrieved when individuals can draw upon the full context being remembered -- all facets of the social,

physical, and personal context, not just the narrow, sometimes arbitrary, “school context” of facts and concepts.

Falk and Dierking’s comments point up the difficulty of attempting to account for what students might remember and learn from an experience like BSEW08. One useful starting point for such an enterprise is the distinction made by Endel Tulving (1972) between episodic and semantic forms of memory -- that is, between remembering and knowing. Tulving described 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*” (pp. 387-388). Tulving (1985) proposed existence of procedural, semantic and episodic as three distinct forms of memory:

Procedural memory enables organisms to retain learned connections between stimuli and responses, including those involving complex stimulus patterns and response chains, and to respond adaptively to the environment. Semantic memory is characterized by the additional capability of internally representing states of the world that are not perceptually present. It permits the organism to construct mental models of the world ... that can be manipulated and operated on covertly, independently of any overt behavior. 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 (1985, p. 387).

Only episodic memory is specialized with regard to acquisition and retention of experiential knowledge. Representation in both procedural and semantic memory systems is ahistorical, depersonalized, and generally similar in content to the information they represent (Martin, 1993).

Various sorts of studies that have utilized Tulving’s constructs to assess what and how people remember provide useful background to research I conducted in relation to BSEW08. Studies of learning in university classrooms conducted by Martin Conway (Conway et al., 1997) and Debra Herbert and Jennifer Burt (Herbert & Burt, 2004)

support a finding that there is a “remembering to knowing shift” or “R to K shift,” such that factual material that is initially recollected in connection with the circumstances in which it was learned, may in time become incorporated into learners’ conceptual knowledge, as the learners come to forget how they learned it. 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.

Other researchers investigating how learners remember certain out-of-school experiences, such as museum visits, have made use of Tulving’s constructs to examine the issue of *vividness* in memory. Anderson and Shimizu’s (2007) overview of studies of this sort point to several variables that affect vividness in episodic memory. In their summation:

First, there is strong evidence that memories of leisure-time experience have the potential to be rich and vivid. Second, there appears to be evidence that age influences the vividness of episodic memories, but that its influence varies as a function of stage of life. Third, the frequency of visitation to informal settings may decrease one’s ability to recall episodic detail -- events that are familiar (not novel) may be difficult to recall in detail. Finally, there is evidence that subsequent conversations, discussions, and reflections that visitors (young and old) have about their experiences positively influence the vividness of those memories.... [In addition] emotion tends to increase the likelihood that an event will be remembered later and that it will be remembered vividly.... Our most vivid memories tend to be of emotional events, and research has revealed that emotional events are more likely to be recalled than more neutral events (pp. 178-179)

Anderson and Shimizu found support for each of these ideas in their own study of recollections, at a distance of many years, by visitors to the 1970 Japan World Exposition in Osaka. Similarly, Falk and Dierking (1997) found that for 128 subjects they interviewed about school field trips they had once taken, the vast majority could recall when they went, where they went, with whom they went, and three or more specific aspects of what they did. “Even after many years, nearly 100% of the individuals interviewed could recall one or more things learned on the trip, the majority of which related to content/subject matter” (1997, p. 211). In researching episodic memories of visitors to a science museum, Medved and Oatley (2000) interviewed 39 adults in person at the conclusion of their visit and again by telephone one month later. On each occasion, participants were asked to recall details about an interactive science exhibit, to explain the scientific principle of the exhibit, and to report whether they experienced any emotion in connection with the exhibit. In the post-visit interview, they were also asked whether they had taken part in activities such as talking about or reading about the exhibit topic, thereby integrating their visit memories into their daily lives. They reported their results in terms of episodic memory, semantic memory, experienced emotion, and post-visit integration. Among their conclusions were that the interviews showed “a strong episodic memory in the mind”; that nearly three-quarters of participants had said that they had either thought about the exhibit after their visit or that it had affected their subsequent behavior in some way; and that both at the science center and one month later, nearly every participant “reported some type of emotion indicating that the affective connection to the science experience does not dissipate over time.”

Knapp and Benton (2006) conducted telephone interviews in fall 2002 with ten fifth-grade elementary school students who had, one year previously, traveled to Yellowstone National Park to take part in a five-day-long experiential education camp. The interviews were open and unstructured, and began with the interviewer’s asking what each participant could recall from the Expedition Yellowstone program she or he had participated in the previous year. Interview length varied from 30 to 40 minutes. Each interview was transcribed verbatim and a phenomenological analysis was conducted (Creswell, 1998): significant statements were extracted from each transcript that directly pertained to the phenomenon, and clusters of themes were organized from the statements;

this allowed for emergence of themes common to all subjects' descriptions, and clusters of themes were referred back to the original transcripts for validation of responses and preparation of a description of the phenomenon. The researchers identified three major themes: first, recollections were highly influenced by actions the students had taken; second, all students retained knowledge about program content and subject matter to varying degrees; and third, all students reported emotion reactions to the experience (Knapp & Benton, 2006, p. 170).

Collectively, the studies described in this section demonstrate that Tulving's construct of episodic memory has been useful for assessing participants' memories of a focal event at temporal distances ranging from weeks to years. Moreover, a growing body of evidence is demonstrating how episodic memories may be linked to epistemic memories, as with Conway et al.'s (1997) R to K shift, and to emotions and connections of various sorts. Some tension remains between sets of studies -- like Conway et al.'s (1997) and Herbert and Burt's (2004) -- that are based upon classroom learning and focus upon how episodic memories fade as epistemic memories emerge, and separate sets of studies that emphasize the capability of episodic memories to endure over long times and with vividness when the situations that give rise to them are particularly out-of-the-ordinary and when individuals engage closely and actively. In both instances, the emphasis is on psychological processes of learning. In my own research into learning with BSEW08, the emphasis is somewhat different: the aim is to examine learners' responses to a curriculum under review, in order to shed light on features of the curriculum that may affect learning in various ways. This is similar to the combination of interests that Jack Martin (1993, p. 178) has termed "core propositions" that motivate research into how episodic memories of learners may mediate their learning from instructions. These are:

1. Human learners remember specific details of events and experiences associated with classroom teaching and learning.
2. These episodic memories mediate revisions to learners' procedural and semantic knowledge and affect the attitudes and feelings that learners associate with such knowledge.

3. Instruction can be designed and delivered in ways that enhance learners' episodic memories for instructional events and information. The rationale for these instructional manipulations is that more extensive episodic memories will mediate superior retention and use of relevant procedural and declarative knowledge as well as the strengthening of supportive attitudes and feelings.

Building from these propositions, the research I conducted into student learning from BSEW08 examined eleven participating students' comments in response to a set of questions with which they were presented in a telephone interview in early November, 2008, four months after the week-long summer workshop. These interviews lasted between 15 and 25 minutes each, and were recorded and later transcribed. Owing to its brevity, I present this interview data as suggestive rather than definitive. Of eleven questions that were used as prompts during the interviews (the interview protocol appears as Appendix E), three (#1, #6, and #10) asked primarily about the students' recollection of aspects of the workshop itself. Three questions (#4, #5, and #7) inquired into whether the students had integrated knowledge gained from the workshop into connection with other learning or aspects of their lives. Two questions (#2 and #3) asked about sorts of knowledge they had gained from the workshop, and two questions (#8 and #9) yielded from them information about their emotional response to aspects of the workshop content. A phenomenological approach similar to that employed by Knapp and Benton (2006) was used to extract data from the transcribed interviews, allow for emergence of themes from the data, refer clusters of themes back to the complete transcripts, and develop descriptions of the themes. In the next section, I summarize students' responses to the various sorts of questions that were asked in the November post-interviews.

Responses focusing primarily on episodic memory. In Tulving's (1972) scheme, episodic memory "represents information stored about the experienced occurrence of an episode or event." The three questions that most frequently elicited answers focusing on learners' epistemic memories, without additional emphasis on epistemic knowledge, emotional responses, or integration to other knowledge, were these:

1. *Could you describe for me your understanding of what the BeeWorld Project is all about?*
6. *From the vantage point of these several months, what stands out most about the workshop week?*
10. *Is there anything else you'd like to mention, that might help me understand better your experiences with the BeeWorld workshop?*

Students' recollections concerning what stood out most about BSEW08 (Question #6) were quite varied, and serve to illustrate both the variety of topics that were covered during the week and the variety of interests that different learners held. Responses to this question included:

Arthur: What stands out most? How committed these professors and students and researchers are to solving this problem, using this as a model. There were many setbacks, and someone could easily have given up at that point and started something new. But they were very dedicated, and I'm sure that's what got them that big grant from ... NSF. You have to be very committed, and it showed by the amount of research they were doing.

Debra: 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.

Audrey: 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.

Jeff: 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.

Jonathan: It was actually really informative. I mean it was really cool to go out and look at hives, but I learned 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 they length of the day cycle just to see what happens, that was all really interesting.

Ruth: I think the laboratory environment was kind of 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.

Steven: The amount of information that I was able to absorb, or be bombarded with and then absorb. I mean, we learned a ton of stuff that one week, in a fifteen-hour total period.

Vivian: 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.

Responses suggesting “R to K shift.” Conway et al.’s (1997) research, as well as that of Herbert and Burt (2004), suggests that learning of conceptual knowledge comes about as learners incorporate content they have learned in particular circumstances, into conceptual schemes.

Two of the post-interview questions proved apt to yield responses indicative of this sort of “R to K shift.” These were:

2. *What would you say you learned about bees and behavior, during the week?*
3. *What would you say you learned about genomic research, during the week?*

These responses to Question 2 provide evidence of the sorts of knowledge that students recollected learning from the workshop week:

Ruth: 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 very specific types of bees, which I thought was fascinating. And it's just interesting how they can all communicate as a community. I really saw that a lot during the week, especially when we talked about and got to witness the wiggle [sic] dance.

Arthur: 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.

Steven: Um, well, just about everything. You know, the dance language, the colony structure, how they respond to changes in light and heat and all that sort of stuff.

Debra: 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.

Eileen: 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.

Audrey: The thing that stands out the most was when we actually went to the actual bee place.... And the bees were dancing to show the others where the honey was. I thought that was really neat. And I thought it was cool how they don't show individual hunger but it's more for their community as a whole I guess. And I just thought those were really cool.

Jeff: 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.

Jonathan: 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 that you handed out right at the end. I mean, they're programmed so that they waggle dance less accurately the closer the flower patch is. And the bees will go out and spread over a wider 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.

Karen: 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.

Vivian: 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.

Responses focusing on knowledge integration. Three questions yielded responses that focused on integration of workshop knowledge with students' learning subsequent to the workshop, and with their intentions or aspirations regarding future learning. These were:

4. *Have there been any points in your learning since the workshop, where you might have had occasion to think, "That relates to something I learned in the workshop"?*
5. *How do you think that what you learned during the week might relate to your educational and career paths beyond high school?*

7. *Are there still things that came up during the workshop week, that you'd like to learn more about?*

Students' comments regarding the relationship of workshop topics to aspirations for their learning beyond high school (Question #5) varied according to their interests and their grade level. Each of the interview participants had no difficulty offering well-reasoned answers to this question:

Ruth: Actually, I signed up because I am interested in science and the genomic sequence, and I feel like that strengthened my interest in science in general.... I know I will definitely go into some kind of scientific field. I was thinking generally of an area where I will work in a laboratory environment, ideally.

Arthur: I actually really enjoyed what we learned during the week, and I thought it would be a great career path to follow – because 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 of those problems are traced back to the DNA or some evolution of the DNA. And so it actually influenced what I wanted to study in quite a bit, and made me think that this is something I would really enjoy doing.

Steven: If I ever do anything with genomes of any sort, that would be terrifically useful. I was really considering entomology more like a major, so that would be useful too.

Debra: I thought the genetics thing was really interesting, so I think I might take genetics next year with Mr. Stern.... I didn't really know anything about genetics before, so I guess BeeWorld was my introduction to it.

Eileen: Definitely for education we do some of this stuff in biology class. Hopefully for my junior and senior science electives I'll take more biology classes, and this will play into those classes. So it definitely is important and it probably will come back.

Audrey: Well, I really liked the feel of just being in the bee lab when we took the tour around – the bee and the bird lab. Just seeing other people working. 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 English is 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.

Jeff: The only thing that would really relate for me was the actual networking and the computational aspects of BeeWorld – the databases, trying to connect everything in a meaningful way for the researchers. I did the week mostly because I enjoy biology, but I'm not really looking at it as a career choice.

Jonathan: I applied to the university's bioengineering department, so it might be particularly relevant.... I mean, biology is really sort of applied chemistry which is applied physics which is applied math. But if you take math and try to examine a biological system with it you'll just fail completely because it's so complex. So you can study things at the quark scale, but then if you have to scale that up to a cell, an organism, a molecule even, then you're just hopelessly adrift. But it's really fascinating and it's where all the new and cool things are happening. That's kind of why I want to study bioengineering.

Karen: It definitely leaves a different impression of going into science, as opposed to what you learn in schools. Like, biology is a lot of learning about different animals and all that and doing small experiments, but the BeeWorld workshop was about what people are learning currently through a modern technology like microarray that you don't always get the opportunity to do inside school. I think seeing what researchers are doing today made me a lot more interested in considering a scientific path. I think it just made me more interested in science in general.... Science is

definitely one of my higher-interest areas, some fields in science. Something to do with bees might very well be what I decide I'm most interested in.

Marge: For the past two years I guess, because I'm nearing college age, I've been thinking about what I want to major in and what school would be good for that. And 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 it anyway, because in the end science ends up affecting almost anybody who's even part of that world.

Vivian: I actually thought that getting to study the honey bee genome and using that for genetic research could be interesting. While at the same time going into entomology could be interesting, because bugs are engineered really well.

Responses indicating emotional response. Participants' emotional responses to the BSEW08 curriculum may be discerned in responses to nearly all of the post-interview questions. However, two questions were particularly likely to yield responses that involved expression of feelings they recalled having about BSEW08. These were:

8. *What advice might you have for organizing future learning workshops for leading-edge science projects like BeeWorld?*
9. *What advice might you have for taking the videos, slide sets and so on from the workshop, and making them useful for additional learners via the Web?*

Perhaps more than questions about the workshop itself, this set of questions seem to have encouraged students to speak freely about aspects that they felt did or did not make for a successful educational activity. Students' suggestions with regard to future

workshops (Question #8) typically included information about their emotional response to various aspects of BSEW08. In some instances, the responses below show quite different reactions to the same curricular events:

Ruth: The camp was very interesting and it really held my attention very well. The material was pretty in-depth as a whole. However, I felt like the lectures were really rushed.... I didn't feel like some things were explained enough. I felt like the lectures were really pushed together, and there didn't seem to be enough time to really elaborate what the speakers were trying to convey. That was difficult for me because either I would try to understand it and forget it later, because it was so fast, or I wouldn't understand it altogether. So I felt that part could be, I guess, improved.... An extra hour or two every day just for that week would be nice.

Arthur: I think a problem for some people was that the lectures were a little long-winded. But the problem with shortening lectures is that you don't get the information needed, that shows how you're working on this. So I don't know, but I think if it was a longer workshop instead of just a week it would be better, because you can spend more than one day on one specific thing – spend three or four days, or maybe do some experiments of our own, and see how they work out and learn how to analyze them. So in the future, I would like a longer workshop, to be concise, because then we don't have to digest all this information in one day. We can digest it over a few days and do some experiments.

Steven: I would make the workshop a week longer, so that we have more time to absorb each subject. And I would find it cool if there were more hands-on experiments, like with the microarrays and when we dissected those bees. 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.

Debra: I'd have to say the things that worked the best were probably the hands-on things, like dissecting the bees and stuff. But I felt like it worked pretty well.

Eileen: I definitely like how you guys have all the speakers. That's always a strength for me. It's good to have hands-on, but you get a little bored after a while if it's all hands-on activities, and the same thing for just having the speakers. So I thought the BeeWorld camp had the perfect amount of that.... When we went to the little house [the bee research facility], it was hands-on but it was listening and it was interactive, so that was a tremendous strength that the BeeWorld camp had.... Also something I really liked was that you could ask questions at any point.

Audrey: That was great organization. We mixed in a lot of fun things with the actual hard research stuff, and I thought it was a really great balance.

Jeff: I really liked the small group aspect. I thought that worked pretty well. You really learn more when you're not working with too many people. I would keep doing as many hands-on demonstrations as you can, because that keeps people interested in it. Too many lectures and people fall asleep.... I think you could have gotten rid of one or two of them. Some of them I didn't really follow the whole thing. Some of them weren't all that interesting. But I remember all the hands-on demonstrations, so I think those are more important for keeping people's interest. I think people learn more when they're looking at something than when they're just looking at somebody talk.

Jeremy: Lots of descriptions of the experiments and just some of the information about general bee biology was really fascinating. I personally would have liked more of that, but that might just be me. And it was – lots of the presentations on the expression data, and gene arrays, that stuff was all really cool, it was interesting. It

was a bit charty and graphy at times I guess, but that's good.... it was a blast, I learned a lot, I would sign up for it in a second if I could, and all of my friends.

Karen: I thought just overall the whole idea of the project was really good. I thought having students who have 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. And I just thought the project was a wonderful experience, and I'd like to see more opportunities like this.

Marge: I guess personally I really enjoyed the hands-on things. I'm not sure about other kids my age or not my age, but I think incorporating plenty of those should be pretty successful. I guess conducting interviews beforehand to see what students are interested in, before actually making up the lesson plans, might hold interest in some of the areas that students might not otherwise think are interesting.... It was all pretty cool anyway.

Implications

From the standpoint of assessing the merits of the BSEW08 curriculum, the post-interview responses above 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, finding 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 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 or emotions or as integrated with other learning. 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.

Chapter Seven

Inreach and Meaningful Science Learning

The Inreach pedagogy that emerged from the BSEW08 curriculum stands in counterpoint to the hands-on-problem-solving-inquiry (HOPSI) pedagogy that undergirds the various models of research-science-meets-school-science (RSMSS) outreach described in Chapter Two. Supporters of RSMSS outreach frequently point to conceptual literature in the areas of educational psychology and science education to argue that HOPSI-oriented curricula are especially well positioned to bring young learners into meaningful contact with the content of scientific knowledge. To the extent that the design features of BSEW08 might merit consideration by funded leading-edge scientific research projects positioned similarly to BeeWorld, it is worthwhile to inquire into how Inreach might challenge and enrich these assumptions. In this chapter, I present brief overviews of a half-dozen theoretical arguments that have been raised in the conceptual literature of science learning: the child-curriculum continuum (John Dewey), modes of meaningful learning (David Ausubel), shapes of meaningful curricula (David Hawkins), border crossing into science (Glen Aikenhead), narrative continuity as an aid to learning (Steven Norris and others), and the importance of “big ideas” to learning (Richard Prawat). I analyze each in turn with regard to the seven design features that emerged from consideration of BSEW08: coherence of experience, scientific authenticity, connecting of worlds, characteristics of setting, necessary simplifications, characteristics of learners, and learner trajectories. In each instance, I illustrate how the conceptual literature can be taken to support Inreach as well as HOPSI pedagogies. The picture that emerges illustrates how the precepts of Inreach are consonant with philosophical conceptualizations of meaningful science learning. To the extent that both HOPSI-oriented and Inreach models can be regarded as capable of promoting meaningful learning of science, I would suggest that Inreach merits consideration as a pedagogical model by leading-edge science research projects that aim to make broader educational impacts as one aspect of their mission.

The Child-Curriculum Continuum (Dewey)

In his treatise *The Child and the Curriculum* (1902), Dewey took issue with opposing camps of reformers who, at one extreme, regard school curriculum as “an objective universe of truth, law, and order” (1902/1956, p. 7) and expect the child to be “ductile and docile” (p. 8), and those who, at the other extreme, regard the child as “the starting-point, the center, and the end” and see the goal of education as “not knowledge or information, but self-realization” (p. 9). Dewey rejected altogether “the fundamental opposition of child and curriculum set up by these two modes of doctrine” (p. 9). He counseled instead:

Abandon the notion of subject-matter as something fixed and ready-made in itself, outside the child's experience; cease thinking of the child's experience also as something hard and fast; see it as something fluent, embryonic, vital; and we realize that the child and the curriculum are simply two limits which define a single process. Just as two points define a straight line, so the present standpoint of the child and the facts and truths of studies define instruction. (Dewey 1902/1956, p. 11)

Dewey's resolution to the instructional dilemma rests in relating to one another “the logical and the psychological aspects of experience – the former standing for the subject matter itself, the latter for it in relation to the child” (p. 19). He likened the contrast to “the difference between the notes which an explorer makes in a new country, blazing a trail and finding his way along as best he may, and the finished map that is constructed after the country has been thoroughly explored” (p. 19). “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 the 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 the Deweyan perspective, an important aspect of the scientific research project whose educational outreach forms the basis for this study is that the curriculum traverses new scientific territory where mapping is still actively being done. For this reason, this study analyzes data from pre- and post-instructional interviews and close observation of instructional interactions, to investigate how learners translated into their own experience the curricular material they encountered.

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, 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*, 1916/1958), 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 this 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 investigated for this dissertation, interviews of learners and observational accounts are examined for the ways that the BeeWorld workshop curriculum moved learners from everyday knowledge of honeybees, 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 BeeWorld 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.

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*. This has happened in part because Dewey’s own most thoroughly worked-out example of pedagogy comes from the elementary grade-level Laboratory School at the University of Chicago, which he directed for several years and about which he wrote at length in *The School and Society* (1899/1956). There, the curriculum involved children up to about age 12 in home- and farm-based trades and skills as an introduction into human history and society. The work of sewing and weaving, he wrote, “gives the point of departure from which the child can trace and follow the progress of mankind in history, getting an insight into the materials used and the mechanical principles involved. In connection with these activities the historic development of man is recapitulated” (1899/1956, p. 20). Yet Dewey’s point was not to insist on a particular pedagogy so much as to present an epistemological argument about the nature of learning: “It is as true in the school as in the university that the spirit of inquiry can be got only through and with the attitude of inquiry. The pupil must learn what has meaning, what enlarges his horizon, instead of mere trivialities. He must become acquainted with truths, instead of things that were regarded as such fifty years ago or that are taken as interesting by the misunderstanding of a partially educated teacher” (1899/1956, pp. 78-79). For Dewey, it is this understanding of learning that provides the soundest basis for a curricular pedagogy. As he put it in *The Child and the Curriculum*, “[N]o 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). It is for this reason that this dissertation examines the case of the BeeWorld curriculum primarily through its impact on learners, as evidenced by observational accounts and a series of individual interviews.

The pendulum swings in pedagogical fashion that vexed Dewey at the beginning of the last century have not disappeared from educational practice. Thus it is no surprise that three decades after publication of *The Child and the Curriculum*, he was compelled to address would-be child-centered reformers once again in *Experience and Education* (1938/1963):

The problems are not even recognized, to say nothing of being solved, when it is assumed that it suffices to reject the ideas and practices of the old education and then go to the opposite extreme.... We may reject knowledge of the past as the *end* of education and thereby only emphasize its importance as a *means*. When we do that we have a problem that is new in the story of education: How shall the young become acquainted with the past in such a way that the acquaintance is a potent agent in appreciation of the living present? (1938/1963, pp. 22-23).

Dewey’s question remains pressing today.

Implications for analysis. Dewey’s ideas as glossed in this section carry implications for the seven identified design features of the Inreach curriculum of BSEW08. 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.

Modes of Meaningful Learning (Ausubel)

Others since Dewey have worked to transcend the seeming dichotomy between child-centered and curriculum-centered approaches. For educational psychologist David Ausubel, writing in the 1960s, the essential move was to disentangle the notion of meaningful vs. rote learning, from the issue of a best pedagogy. Ausubel's particular nemeses were advocates of *discovery learning*, a variety of child-centered pedagogy which held that children learn best when they set their own problems and proceed, with minimal instructional guidance, to discover the means for solving them. A leading advocate for discovery pedagogy, Jerome Bruner, had put the claim this way:

Emphasis upon discovery in learning has precisely the effect upon the learner of leading him to be a constructionist, to organize what he is encountering in a manner not only designed to discover regularity and relatedness, but also to avoid the kind of information drift that fails to keep account of the uses to which information might have to be put. It is, if you will, a necessary condition for learning the variety of techniques of problem solving, of transforming information for better use, indeed for learning how to go about the very task of learning. (Bruner, 1961).

Such claims were distressing to Ausubel, for he believed that *telling* could also be an effective form of pedagogy, in circumstances where learners could engage meaningfully with the information being presented. For either discovery or reception pedagogy to be successful, learning had to be meaningful, and that depended crucially on learners' motivation, Ausubel contended. As he put it in his 1963 book, *The Psychology of Meaningful Learning*: "The unmotivated student who assembles his own learning material manifests no greater intellectual activity than the unmotivated student who receives expository instruction. The motivated student, on the other hand, reflectively considers, reworks and integrates new material into his own cognitive structure,

irrespective of how he obtains it” (Ausubel 1963, p. 12). Ausubel esteemed Dewey for his insistence that learning required experiential grounding at the elementary level, but faulted discovery learning advocates for misappropriating Dewey’s lessons in order to criticize reception learning. He wrote:

John Dewey had correctly recognized that meaningful understanding of abstract concepts and principles in childhood must be built on a foundation of direct empirical experience, and for this reason advocated the use of project and activity methods in the elementary school. But he also appreciated that once a firmly grounded first-story of abstract understandings was established, it was possible to organize secondary and higher education along more abstract and verbal lines. Unfortunately, however, although Dewey himself never elaborated or implemented the latter conception, some of his disciples blindly generalized childhood limiting conditions with respect to meaningful verbal reception learning broadly enough to encompass learning over the entire lifespan. And this unwarranted extrapolation, frequently but erroneously attributed to Dewey himself, provided a pseudonaturalistic rationale for, and thus helped to perpetuate, the seemingly indestructible myth that under any and all circumstances, abstractions cannot possibly be meaningful unless preceded by direct empirical experience (Ausubel 1963, p. 20).

If the “seemingly indestructible myth” that Ausubel decried persists, it does not lack for more contemporary critics. Much the same point as Ausubel’s has been made, for instance, in the National Academy of Sciences publication *How People Learn: Brain, Mind, Experience, and School*, where the authors comment:

A common misconception regarding “constructivist” theories of knowing (that existing knowledge is used to build new knowledge) is that teachers should never tell students anything directly but, instead, should always allow them to construct knowledge for themselves. This perspective confuses a theory of pedagogy (teaching) with a theory of knowing.

Constructivists assume that all knowledge is constructed from previous knowledge, irrespective of how one is taught ... -- even listening to a

lecture involves active attempts to construct new knowledge. (Bransford, Brown, & Cocking, 2000, p. 11)

Ausubel set two conditions for the learning process to be meaningful: “that the learner employs a meaningful learning set, and that the material he learns is potentially meaningful to him” (1965, p. 91). A *meaningful learning set* positions the learner “to relate substantive (as opposed to verbatim) aspects of new concepts, information or situations to relevant components of existing cognitive structure in various ways that make possible the incorporation of derivative, elaborative, descriptive, supportive, qualifying or representational relationships” (p. 92). Ausubel specified two criteria for material to be *potentially meaningful* to a learner. One, “non-arbitrary relatability to relevant concepts in cognitive structure,” is a property of the material to be learned (1965, p. 93). The other, relatability of the material “to the particular cognitive structure of a particular learner,” will vary “with such factors as age, intelligence, occupation, cultural membership, etc.,” he wrote (1965, p. 94).

Ausubel’s idea of meaningfulness is quite compatible with Dewey’s insistence that for learners to bring curricular material into their own experience, the material must be “*psychologized*; turned over, translated into the immediate and individual experiencing within which it has its origin and significance” (Dewey 1902/1956, p. 22). Likewise, Ausubel’s idea of meaningful learning resonates with Dewey’s characterization of curricular facts as *symbols*, “tools by which the individual pushes out most surely and widely into explored areas,” and with Dewey’s warning that such symbols will remain “dead and barren” unless they are “led up to and into out of something which has previously occupied a significant position in the child’s life for its own sake” (Dewey 1902/1956, p. 24). Ausubel’s *meaningful reception learning* consists of apprehending and incorporating relationships between ideas, or symbols, which the learner already holds and with which she is presented. This variety of learning contrasts with *meaningful discovery learning*, which is characterized by insightful problem-solving; with *rote discovery*, characterized by trial-and-error manipulations; and with *rote reception*, characterized by verbatim memorization. *Figure 4* illustrates these distinctions.

In accord with Dewey, Ausubel recognized that younger students -- typically up to about age 12, he believed -- would be well served by instructional methods building on

meaningful discovery. “Until they consolidate a sufficiently large working body of key verbal concepts interrelating abstract propositions without reference to specific instances, children are closely restricted to basic empirical data in the kinds of logical operations they can relate to cognitive structure,” he wrote, and so “during the elementary school years, directly presented and verbal materials are too distantly removed from empirical experience to be relatable to cognitive structure” (1965, p. 96). However, for the junior high school period and beyond, he believed, “prior empirical and nonverbal experience is no longer essential before concepts and generalizations become potentially meaningful.” He acknowledged that “the pupil’s established verbal concepts must have been preceded sometime in the past by direct, nonverbal experience with the data from which they were abstracted,” but insisted that “once those concepts are sufficiently well consolidated and the pupil is able to manipulate and interrelate them adequately on a purely abstract basis, new learning material is logically relatable to cognitive structure without any direct or nonverbal *current* reference to empirical data” (1965, p. 96, emphasis in original). For Ausubel, the choice of instructional pedagogy between methods intended to foster insightful problem-solving (meaningful discovery) and methods intended to foster the apprehending and incorporating of relationships (meaningful reception) amounted to a matter of efficiency: “[A]fter the elementary school years, verbal reception learning constitutes the most efficient method of meaningfully assimilating the substantive content of a discipline,” he concluded. “Problem-solving methods are too time-consuming to accomplish this objective efficiently, but are useful for communicating certain insights and for measuring the meaningfulness of reception learning” (1965, pp. 101-102).

Implications for analysis. Ausubel’s ideas as summarized in this section carry several implications for the design features that I introduced earlier. With regard to *coherence of experience* and to *connecting worlds*, Ausubel’s notion of subsumption suggests a psychological mechanism by which learners can make meaningful connections between known and new material. Moreover, Ausubel’s claims regarding meaningful reception learning hold implications for the analytic notions of *learner readiness*, *learning trajectories*, and *necessary simplifications*. Discovery learning, he held, will be slow and inefficient but is a necessary starting point for younger learners; from that base, older learners can pick up quite complex information meaningfully through reception

processes, which are more efficient and can be applied to materials for learning, such as prepared texts, that are readily available and accessible. Ausubel's analysis makes clear that meaningfulness of material encountered in the curriculum depends less upon how that matter is presented than upon how the learner makes connections and apprehends relationships between prior knowledge and new information.

Shapes of Meaningful Curricula (Hawkins)

Where Ausubel would approach the child-curriculum continuum from the curriculum side, science educator David Hawkins (1965) makes his approach from the child side. In an essay published in the National Science Teachers' Association journal *Science and Children*, Hawkins advocates for the importance of "Messing About in Science." Drawing from his experience with the federally funded Elementary Science Study (ESS) of the early 1960s, he identifies a need for three "patterns or phases of school work in science ... [that] differ in the way they make a classroom look and sound" (p. 1) These he denotes the *circle*, *triangle*, and *square* (O, ▲, and []) phases of instruction. Of the "O" phase, he writes, "There is a time, much greater in amount than commonly allowed, which should be devoted to free and unguided exploratory work (call it play if you wish; I call it work)" (p. 1). He calls this O phase "Messing About," after the philosophy of the Water Rat in Kenneth Grahame's classic children's tale *The Wind in the Willows* (1908/1989), and quotes that character as follows: "Whether you get away or you don't; whether you arrive at your destination or somewhere else, or whether you never get anywhere at all, you're always busy, and you never do anything in particular; and when you've done it there's always something else to do, and you can do it if you like, but you'd much better not" (p. 2). Hawkins offers the example of a curricular unit on pendulums conducted for ESS in a fifth-grade classroom, which opened by providing each pair of children with a simple frame designed to support two or three weights on strings. The guidance provided to the students "came only from the apparatus -- a pendulum is to swing!" he recounts. "In starting this way I, for one, naively assumed that a couple of hours of "Messing About" would suffice. After two hours, instead, we allowed two more and, in the end, a stretch of several weeks. In all this time, there was little or no evidence of boredom or confusion. Most of the questions we might have

planned came up unscheduled.” Hawkins regards this approach as going even beyond the “discovery method” as he understands it: “When learning is at the most fundamental level, as it is here, with all the abstractions of Newtonian mechanics just around the corner, don’t rush! When the mind is evolving the abstractions which will lead to physical comprehension, all of us must cross the line between ignorance and insight many times before we truly understand. Little facts, “discoveries” without the growth of insight, are *not* what we should seek to harvest” (pp. 2-3).

In moving beyond the O phase to his ▲ and [] phases, Hawkins remains firmly opposed to what he denigrates as “rote or merely verbal learning” (p. 5). The ▲ phase he envisions revolves around “multiply programmed material ... that contains written and pictorial guidance of some sort for the student, but which is designed for the greatest possible variety of topics, ordering of topics, etc., so that for almost any given way into a subject that a child may evolve on his own, there is material available which he will recognize as helping him farther along that very way.” Development of this sort of material, he confesses, remained an ideal: “We did not have this kind of material ready for the pendulum class I spoke about earlier and still do not have it” (p. 4). His [] phase, in contrast, “includes lecturing, formal or informal” but also “discussion, argument, the full colloquium of children and teacher. Theorizing in a creative sense needs the content of experience and the logic of experimentation to support it. But these do not automatically lead to conscious abstract thought. Theory is square![]” (p. 6). “Prevailing styles of science teaching are [] most of the time, much too much of the time,” he concludes. “But what we criticize for being too much and too early, we must work to re-admit in its proper place” (p. 6).

In an important sense, Hawkins’ pendulum curriculum in its O phase resembles the manner in which Dewey’s laboratory school approached textile-making as a “point of departure from which the child can trace and follow the progress of mankind in history.” There is clearly great benefit to be had from approaching large areas of curriculum via open-ended discovery. This may be particularly apt in areas where the insights that curriculum developers mean for learners to discover are recapitulations of key discoveries in human history, as with textile-making and Newtonian physics. Dewey’s and Hawkins’ examples fit well with what Ausubel would term “meaningful discovery”

learning; while scope for such learning exists throughout a learner's lifetime, it is likely more than coincidence that both Dewey and Hawkins base their examples on education in the elementary school years. Ausubel differs from these other theorists in emphasizing a role for "meaningful reception learning" at secondary school and beyond, but nothing in their writings would preclude scope for such learning, when the learners are adequately prepared to benefit from its efficiencies.

Implications for analysis. With regard to the features I have identified as elements of the Inreach curriculum of BSEW08, Hawkins exemplifies one set of curricular approaches that enjoy enduring popularity as a means of providing science learners with *coherence of experience* through a prescribed *learning trajectory* that progresses from the "circle" of "messing about," to the "triangle" of guided yet self-directed exploration mediated by meticulously crafted curricular materials, to the "square" of theory as articulated and understood by expert scientists. While he acknowledges that the requirements for such an approach are high in terms of both time and resources, he holds it as axiomatic that the only way for learners to attain a quality of understanding that is *scientifically authentic* is for learners to begin by drenching themselves in an area of study in an impressionistic manner. The specifics of his approach differ markedly from those espoused by Ausubel, but the authors are at one in their insistence that meaningful learning opportunities must facilitate *connecting worlds* of personal and scientific understanding, and therefore united in their disdain for varieties of instruction that in their opinion encourage learners to make only superficial connections between curricular topics and their own understanding.

Border Crossing Into Science (Aikenhead)

It should also be understood that at high school and beyond, learners will differ markedly in their readiness and willingness to approach science content verbally. This point is well captured by science curriculum specialist Glen Aikenhead (2001) in the journal *Science Education* with his discussion of "crossing cultural borders into school science." Building on previous research by others and his own case studies involving Canadians of First Nations heritage, Aikenhead offers a typology of science learners that

is grounded in “similarity between their life-world culture and the culture of school science” (p. 180). The scheme’s six categories (p. 186) are:

1. *Potential Scientists*: smooth border crossings that lead to an in-depth understanding of science. Their self-image and lifestyle resonate with the world of Western science.
2. *“I Want to Know” Students*: adventurous border crossings that lead to a modest yet effective understanding of science (there are hazards, but students want to know). Their self-image and lifestyle resonate with the world of science, but the intelligibility, plausibility, or fruitfulness of Western science concepts is often a challenge to them.
3. *Other Smart Kids*: easily managed border crossings but with no personal interest in pursuing science. These students do not fit the self-image and lifestyle they associate with Western science, but they do have strong self-esteem and self-perceptions related to academic success.
4. *“I Don’t Know” Students*: hazardous border crossings into a superficial understanding of science (there are hazards, but students do not want “to look stupid” in the eyes of their peers or teacher). Science does not fit their self-esteem or their lifestyle, but they have enough self-esteem and self-perception to persevere.
5. *Outsiders*: impossible border crossings that lead to dropping out, physically or intellectually. Science fits neither their self-images nor their lifestyles.
6. *Inside Outsiders*: impossible border crossings due to institutional discrimination in spite of personal interest in understanding science.

The scheme’s categories “have direct implications for science curriculum, instruction, and assessment,” Aikenhead argues. “Imagine if teachers were able to reflect on the different ways their students experience cultural border crossing into their class (smooth, adventurous, managed, hazardous, or impossible border crossings),” he suggests. “When we perceive our students differently, our instruction can change accordingly” (p. 187). In the 2001 article, Aikenhead confines his discussion of differential pedagogies to considering what sorts of instruction might best suit learners

belonging to the categories Potential Scientists, “I Want to Know” Students, and “Other Smart Kids” (pp. 186-187, emphasis added):

For “Potential Scientists,” borders do not seem to exist at all. Much has been written about enculturating such students into the practice of Western science in ways like apprentices are initiated.... The teacher’s role is one of **coaching apprentices**. These students comprise a very small proportion of any student body.

“I Want to Know” Students are usually challenged by adventurous border crossings into school science. A sensitive teacher provides guidance for these students to support their self-esteem and to nurture their interest in a scientific apprenticeship. This explicit support is captured by the notion of **tour guide**. A teacher would modify the apprenticeship approach by giving “I Want to Know” Students the guidance and support that one would expect from a tour guide in a foreign culture. ...

“Other Smart Kids” often manage their border crossings into school science either by relying on their capacity to handle academic abstractions easily or by playing Fatima’s rules that help them pass courses without understanding the course content meaningfully (Aikenhead & Jegede, 1999). Manageable border crossings could become smooth if students perceived the content of the course as relevant to their personal world. ... Because “Other Smart Kids” are travelers in an unfamiliar culture, they require a degree of guidance from a **travel-agent** type of teacher who provides incentives for them to travel into the culture of science, incentives such as topics (water quality), issues (genetically altered food), or events (scientific controversies such as cold fusion) that create the need to know more about the culture of science. The teacher’s travel-agent role is often one of co-learner.

Aikenhead’s research agenda is motivated by the conjecture that, “If only we could understand how students make sense of their natural world, we could design a science curriculum so that science makes sense to all students” (Aikenhead 1996, p. 2). While the goal is noble, the Aikenhead typology might strike some readers as

uncomfortably or unrealistically deterministic in its emphasis on linkages between cultural identity and potentials for success in science learning. Regardless, his suggestion that science teachers can meet different learners' needs by playing roles of *coaches*, *tour guides*, and *travel agents* is worth bearing in mind. It may well be that curricula which engage teachers in each of these roles concurrently can meet the learning needs of the broadest possible range of students.

Implications for analysis. With reference to the analytic frame adopted for this dissertation, Aikenhead contributes the understanding that somewhat different pedagogical approaches might facilitate meaningful learning of science content, depending upon the individual learner's perceived membership in cultural groups having "worlds" that intersect with the curriculum of science in different ways. Aikenhead's aim, like that of the other authors whose views were introduced earlier in this section, is to afford learners *coherent experiences* that assist them in *connecting worlds* of personally held and socially constructed understandings. For Aikenhead, *learner readiness* is determined in large part by individuals' membership in cultural groups operating at particular distances from science. *Situating* the learner in relationship to the curriculum of science can be facilitated in part by having instructors position themselves as coaches, travel agents, and tour guides in order to assist the learners in the work of "border crossing." In effect, this amounts to a sort of storying that positions the learners themselves as travelers, engaged in an ongoing journey between worlds of personal and scientific understandings.

Narrative Continuity in Science Texts and Educational Multimedia

A case for narrative genre in science (Norris). Aikenhead's likening of science teachers to tour guides and travel agents highlights an additional way in which the meaningfulness of instruction might be enhanced. In roles like these, teachers are in a position to offer *narrative continuity*, as a means of providing learners with a way to connect sets of facts that they might otherwise be tempted to regard as unconnected either to one another or to lived experience. Narrative roles played by science instructors in the classroom have been little studied, but the facilitative role of narrative genre in science learning is beginning to be explored with regard to textbooks (Norris, Guilbert, Smith,

Hakimelahi, & Phillips, 2005), and educational films (Michel, Roebers, & Schneider, 2007) and television programs (Fisch, 2000). One point worth bearing in mind about all such resources is that they depend on verbal reception learning, in the Ausubelian sense of that term; to an even greater extent than is true of information presented live in classroom lectures, readers and viewers cannot directly manipulate or interrogate information provided in printed texts and audiovisual productions, and so the success or failure of these media as educational tools hinges upon how learners can take meaning from them via reception. In proposing that exploitation of a “narrative effect” might facilitate learning from science textbooks, Stephen Norris and fellow education researchers at the University of Alberta (2005, p. 545) ascribe the following elements to narrative prose:

- Event-tokens: particular occurrences involving particular actors at a particular place and time that are chronologically related, involve a unified subject, are interconnected, and lead to changes of state.
- A narrator: the agent relating a narrative, who determines the purpose of the story to be told, selects events and the sequence in which they are told, and fashions sequences of events into a significant whole.
- Narrative appetite: the desire created in readers and listeners to know what will happen, based on a range of possibilities that creates anticipation and suspense.
- Past time: narratives concern the past, and narrators can manipulate time in relating narratives.
- Structure: narratives typically start with imbalances, introduce complications, and end in success or failure.
- Agency: Actors cause and experience events in narratives; actors are responsible for their actions.
- Purpose: To help us better understand the natural world and humans’ place in it; to help us imagine and feel the experience of others.
- Reader: the reader must interpret the text as a narrative in order to approach it with appropriate expectations and anticipations.

Review of studies involving narrative leads Norris et al. to state (pp. 552-553):

We believe that empirical evidence provides moderate support for a claim that there is such a thing as a narrative effect in a very broad and general sense. For example, there is research showing that narrative passages are read faster, comprehended better, and tend to be more absorbing than expository passages and perhaps than other genres as well.... Other research has suggested that a good narrative can increase the plausibility and persuasiveness of information presented ..., a finding that would be important for science education, which places considerable emphasis on information. It has also been found that narrative passages positively affect memory ... and that readers apply themselves more when reading narrative compared to expository prose....

In proposing that use of narrative might facilitate learning from scientific texts, Norris et al. were responding to Nagel's (1961) influential analysis of the structure of scientific explanations. In that work, Nagel identified four distinct patterns of scientific explanation: *deductive*, involving use of covering laws to provide explanations for particular facts; *probabilistic*, involving use of statistics to show a high probability of relationship between phenomena; *functional*, wherein the puzzle concerns the purpose or function of feature ("Why do X's have Y?"); and *genetic*, involving construction of explanations from narrative accounts (Norris et al., 2005, pp. 546-548). Nagel believed that the distinctiveness of genetic explanations was questionable, holding that they were "by and large probabilistic" (1961, p. 26; quoted in Norris et al., p. 548). From their own analysis, Norris and his colleagues acknowledge that "the role of narrative in scientific explanation is limited whenever science aims for generality and is not interested in the particular, which is frequent" (p. 560). Even so, they argue, "there may well be reasons to use narratives in science education that have little to do with scientific explanation. ... [N]arratives may be used to introduce content and inspire interest in scientific investigation, which would lead to more involvement with scientific texts" (p. 558).

Narrative genre in science publications and textbooks. While Norris et al. may be correct in concluding that use of narrative is somewhat limited in science publications, it is certainly not absent. The major weekly international journals for scientific audiences, *Science* and *Nature*, prominently feature news articles that employ a narrative approach

in describing new laboratory discoveries, including biographical information about researchers and narratives of their discovery processes to bracket highlights of their research findings. In the life sciences, a rich tradition of books offers narrative accounts of great discoveries penned by scientists themselves, prominent among them Charles Darwin's *The Voyage of the Beagle* (1839/1989) and James Watson's *The Double Helix: A Personal Account of the Discovery of the Structure of DNA* (1998). In the arena of science education, at least one recent introductory biology textbook is built primarily around narrative accounts of major research discoveries in the history of science (Pruitt, Underwood, & Surver, 2003). The authors of that textbook, *BioInquiry: Making Connections in Biology*, are explicit about their reasons for taking this approach. As they write in their Preface:

BioInquiry is a bold new approach, different in important ways from traditional methods of teaching in the life sciences. Conventional pedagogies follow the order of biological *analysis*. This has always meant starting with chapters on the atom and working toward ever larger entities -- biomolecules, DNA, genes, cells, organisms, and so forth -- ending finally with the largest levels of organization, ecosystems and the biosphere. Many students, however, find this approach unsatisfying. Chemistry seems abstract to beginning students, and it may be several weeks before they encounter their first truly biological idea. Rather than present biology as a series of analytical levels of organization, *BioInquiry* takes students on an intellectual journey that follows the order of biological *understanding*.

Most biologists agree that the real story of modern biology began with Darwin's theory of evolution by natural selection, and we believe introductory courses should not teach otherwise. Hence, our story begins with Darwin and the enduring question of why there are so many different living things. Because Darwin's theory provided an intellectual environment ripe for the rise of classical genetics, our chapter on evolution (Chapter 2) guides students through a process of discovery to Mendelian genetics (Chapter 3). From Mendel's garden came insights that led

biologists to discover cells (Chapter 4), chromosomes (Chapter 5), and ultimately DNA and modern molecular biology (Chapter 6). ... The organization of chapters in *BioInquiry* emphasizes methods and theoretical foundations of ideas, and minimizes isolated facts -- an approach we believe makes biology more meaningful and accessible to introductory students. Concepts are given a place in the history of ideas and are connected historically and intellectually to illuminate their importance (Pruitt, Underwood, & Surver, 2003, pp. iii-iv)

Narrative continuity for learning via television and films. The use of narrative genre to offer connectedness and continuity to science education has also been explored in recent studies of children's television programming (Fisch, 2000) and short educational films shown in classrooms (Michel, Roebbers, & Schneider, 2007). From extensive analysis of how children learn from the long-running Public Broadcasting System series *Sesame Street*, educational researcher Seymour Fisch (2000) has developed a Capacity Model that, in part, links effective use of narrative structuring to greater comprehension of educational content. The model consists of three basic components: processing of narrative, processing of educational content, and the degree to which educational content is integral to the narrative. Narrative aspects he credits with facilitating learning include conformity to story schemas, temporal ordering of events, and viewers' prior knowledge of stories and characters gained from watching previous episodes (pp. 83-84).

Another study also audiovisual media (reported in Michel, Roebbers, & Schneider, 2007), compared 6-, 8-, and 10-year-old children's comprehension of an expository short film on sugar production with their comprehension of a narratively structured adventure film involving a treasure hunt, each one week after viewing. Comprehension measures consisted of free recall, open-ended questions, and recognition questions.

These analyses revealed that for children's answers to the open-ended questions, there was a significant advantage of the narrative film compared to the science film. Because there were no consistent differences in free recall and in recognition when comparing memory performance across films, the performance differences in response to the

open-ended questions could not be attributed to general differences in difficulty. One of the questions that emerges from this study is why memory performance with regard to the open-ended questions is worse for the science film compared to the narrative film. In our view, one possibility is that children lack a coherent cognitive representation that would enable a reliable retrieval of crucial semantic information. (Michel, Roebbers, & Schneider, 2007, pp. 173-174)

Michel et al. connect their discussion explicitly to Ausubel's notions of meaningful receptive learning. As they point out, "Although most of the learning in school, including learning through televised material, is *receptive* (i.e., all information is provided readily for learning), this learning can still be meaningful if the child has enough prior knowledge to integrate new information" (p. 174). They recommend that teachers provide Ausubelian advance organizers "prior to the introduction of new topics in the classroom, including the introduction of central and new concepts, as well as summaries of information units" (p. 174) for televised as well as text-based material. They do not specifically recommend tailoring instructional materials to emphasize narrative elements, but the findings they present regarding the facilitative effect of narrative presentation on open-ended responses can be construed as offering further, albeit limited, support for such an endeavor.

Implications for analysis. The ideas of Norris, Fisch, Pruitt, Michel and others as presented in this section relate to the features of Inreach in several ways. For this set of authors, the *characteristics of setting* can be regarded as a paramount concern. The storying of science provides a narrative structure that they regard as highly facilitative for *connecting the worlds* of learner and curriculum, in a manner that would also be recognized by Dewey, with his talk of discovery and maps, and Aikenhead, with his consideration of teachers as embodying roles of travel agents and tour guides to assist with "border crossing." Moreover, some of the authors in this section connect their work explicitly with that of Ausubel, making the point that printed texts and educational films and television present themselves to learners as material for receptive learning. The ideas discussed in this section suggest that narrative continuity can be a powerful means for situating learners in contexts wherein they can recognize and experience the relationships

and connections that characterize scientific understanding and can to an extent story themselves into those contexts. At the same time, narrative continuity might conceivably afford a sort of head start for the development of personal *learning trajectories*, by enabling learners at least somewhat to identify with and imagine themselves as participants in the narratives they encounter.

Big Ideas in Learning (Prawat)

A common thread running through this conceptual framework is that meaningful science learning is woven of the cloth of “big ideas.” The practice of Dewey’s lab school in treating textile making as an entry point to human history, Hawkins’ exhortation to let students “mess about” with the big ideas of physics through pendulum play, Ausubel’s recognition that learning consists of connecting new ideas with subsuming cognitive structures, and the decision of curriculum designers like Pruitt to organize texts around the historical development of understandings in biology, all attest to the importance of grounding science education in overarching ideas in ways that connect intimately with learners’ lived experience and their desire to learn meaningfully about the world around them and their own place in that world. Modern-day Dewey scholar Richard Prawat (1993) goes so far as to propose that the grounding of learning in “big ideas,” even more than a focus on problem-solving as a means of inquiry, ought to be the true legacy taken from Dewey’s works. He suggests that big ideas “function like perceptual schemata. They help educate attention, opening us up to aspects of the world that are a potential source of wonder or awe” (1993, p. 5). A focus on big ideas yields a depth of learning that “skills-oriented, problem-solving approaches to cognition are ill-equipped to deal with” (p. 8). He argues that this comes about in large part because problem-solving inquiry puts “too great a focus on negative freedom” -- getting to the answer so as to ease discomfort -- and in so doing gives short shrift to the “positive freedom” that big ideas offer for opening new vistas. For instance, he writes, imagination led Albert Einstein to his big idea: that reference points render observations relative. For Prawat, scientific discovery and understanding are bound up with ways of seeing, in a manner that could hold great utility for structuring science education so as to enhance its meaningfulness for young learners.

A group of Dewey scholars led by Prawat has given further consideration to how big ideas can inspire science learning (Wong, Pugh, & the Dewey Ideas Group at Michigan State University, 2001). They summarize their argument as follows (p. 322):

The central goal of a Deweyan view of education is to help students lead lives rich in worthwhile experiences. The task of the school is to provide students with transformative experiences: experiences that are valuable in themselves and valuable in their potential to lead to other worthwhile experiences. We assert that anticipation is at the heart of dramatic educative experiences. It follows, then, that effective teaching should be about creating anticipation in students. We introduce another Deweyan construct, the idea, as the subject-matter entity which can create anticipation. The goal of effective teaching is, thus, to create worthwhile experiences by creating anticipation, such as engaging students with ideas.

According to this view, Wong et al. write, “the worth of an idea lies in the possibilities that it yields in the world of the student. This is what Dewey meant by student-centered learning. This is why ideas are educative only to the degree that they inspire action” (2001, p. 323). Effective education, they hold, depends crucially on the feeling of anticipation:

Anticipation distinguishes simple experience from *an* experience and is *the* engine that gives an experience life and direction. The tension between where one is and where one might be energizes feelings of excitement and fear, of disappointment and hope -- the very qualities that give vitality to life. These are the emotions that matter in science learning and are a sophisticated complement to “liking and disliking” and “being interested or not interested” -- the common taxonomy used to describe students’ feelings about science. “Experience, in the degree in which it is experience, is heightened vitality” (Dewey, 1934). To anticipate, then, is to feel fully human, fully alive. (2001, p. 324)

It is in this sense that a biology curriculum organized around big ideas holds promise for engaging young learners’ interest and providing meaningful scaffolds for further explorations in the quest for ever-deeper understanding. The authors of one

recently published biology textbook go so far as to identify seven such overarching theories, commenting: “The science of biology is as diverse as the living forms with which it is concerned. But there are unifying themes, ‘big ideas,’ that emerge from this diversity to make sense of it all and provide a framework for understanding biology” (Pruitt, Underwood, & Surver, 2003, p. 9). In these authors’ estimation, the big ideas that undergird biology are: *evolution by natural selection*, building from Charles Darwin’s theory that species change over generations in response to environmental pressures that favor some individuals over others; *inheritance*, stemming from monk Gregor Mendel’s notion that the characteristics of organisms pass from one generation to another via hereditary “factors” now called genes; *cells* as the basic components of all organisms, an understanding that flows from the work of Matthias Schleiden and Theodor Schwann, contemporaries of Darwin and Mendel; *biological classification* of species based on similarities and differences, drawing from the system established by Carolus Linnaeus in the late 1700s; *bioenergetics*, the understanding that the energy powering life operates according to the same rules that govern energy in the inanimate universe, first given experimental support by Antoine Laurent Lavoisier around the time of Linnaeus; *homeostasis*, the concept pioneered by Claude Bernard in the mid-19th century which recognizes that that organisms maintain stable conditions internally, so as to function well in changing and diverse environments; and the modern notion of *ecosystems*, which recognizes that organisms do not exist alone but belong to populations of similar beings, communities consisting of many different living things, and environments that include important nonliving features (Pruitt, Underwood, & Surver, 2003, pp. 9-11). This study builds on a supposition that a scientific research project where “big ideas” of these sorts form the backdrop for new discoveries can hold great potential as a setting for educating newcomers to science in meaningful ways.

Implications for analysis. With regard to Inreach features, Prawat’s emphasis on the power of big ideas as drivers for learning, and his evocation of the ideas of Dewey in making this point, return us to the notions of *coherence of experience* and *connecting of worlds* that are central aspects of design features that were introduced in Chapter Four. The power of big ideas stems both from the manner in which they help render large swaths of experience coherent, and from the fact that these same big ideas are themselves

often drivers for new discovery. For young learners and scientists operating at disciplinary frontiers alike, *scientifically authentic* big ideas can function as spurs to anticipation and imagination in ways that can extend *learning trajectories* into new areas of understanding. Such is the unifying power of the set of major biological theories identified as “big ideas” by Pruitt and her colleagues: evolution by natural selection, inheritance, cells, biological classification, bioenergetics, homeostasis, and ecosystems.

Considering Design Features of BSEW08 as Potential Design Principles for Meaningful Science Learning

The discussion laid out so far in this chapter supports in conceptual terms the relevance to meaningful science education of design features similar to those that emerged from developers’ and students’ comments about the 2008 BeeWorld Summer Education Week, BSEW08. In the remainder of this chapter, I consider how the seven identified design features might shed light on ways in which BSEW08, its predecessor episodes, and the various sorts of HOPSI-oriented RSMSS outreach discussed in Chapter Two, can all contribute to meaningful learning of science in certain circumstances. The intent of this discussion is to open up space for conjecture that the identified design features might usefully be treated as a set of proto-design principles for meaningful science learning, which could potentially be implemented through discovery and receptive pedagogies alike.

BSEW08 as an instance of meaningful science learning. Summer intensives a week or more in duration have potential value as scientific outreach for their ability to bring learners into sustained contact with a field of inquiry. For the experience to be coherent, elements of the curriculum must be integrated in such fashion that each activity builds upon prior foundations and flows logically into the next. A key aim for the organizers of BSEW08 was to create a curriculum that had this strength, and two key goals of my research were to trace the paths by which the intended coherence was developed, and to investigate whether and to what extent the learners experienced the curriculum as a unified whole. A recurrent theme that emerged from interviews with students and organizers of BSEW08 related to the way in which the workshop week’s curriculum appeared to them as a unified and coherent set of educational activities with a

clear central focus that was progressively refined over the course of the week, rather than a disconnected assortment of activities. Four months after the workshop, all eleven students who participated in the research could readily offer a summary description of the principal aims of the BeeWorld Project as they learned about it over the course of the week. Most went on to remark that the organization and sequencing of curricular activities enabled them to learn a great deal about the workshop topics.

The students' experiencing of the BeeWorld curriculum as a unified whole resonates with Dewey's (1902) insistence that subject matter be seen as "something fluent, embryonic, and vital" (p. 11), as a map produced from "notes which an explorer makes in a new country, blazing a trail and finding his way along as best he may" (p. 19), and leads him to suggest that the primary goal of instruction is to bring child and curriculum into alignment through the internalization of external experience, what he calls "psychologizing." In Dewey's estimation, psychologizing is thus the primary means by which learners come to connect the world of their everyday experience with the world of science: "[N]o 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." Just this sort of psychologizing can be found in the BSEW08 learners' post-workshop comments. Likewise, the learners' comments resonate with Ausubel's (1963) assertion that for students to learn meaningfully, the curriculum must enable making of meaningful connections and the students must enter into the curricular experience prepared to learn from it. As he wrote, "The unmotivated student who assembles his own learning material manifests no greater intellectual activity than the unmotivated student who receives expository instruction. The motivated student, on the other hand, reflectively considers, reworks and integrates new material into his own cognitive structure, irrespective of how he obtains it" (Ausubel, 1963, p. 12).

The Inreach curriculum design of BSEW08 was structured so that learners' *coherence of experience* was supported equally by attention to *scientific authenticity* and to developing and sequencing activities in ways that enhanced the learners' engagement in *connecting worlds* of personal experience and scientific discovery. What is more, each of these major aspects was personified in narrative manner through active, sustained participation throughout the week by two individuals, Ned Nelson and Daniel Stern, who

between them embodied the scientific world of the honey bee genomic laboratory and the familiar world of school biology. Between them, the pair took on roles as coach, tour guide, and travel agent that Aikenhead (2001) suggests can make science instruction meaningful for the broadest possible range of learners. At the same time, Nelson's daily participation as guide and presenter in the classroom, laboratory, and field lent strong narrative continuity to the week, in ways that the learners remarked upon in their post-workshop interviews and that resonate with arguments for the efficacy of narrative structuring of science curricula along lines suggested by Norris et al. (2005), Michel et al. (2007), Pruitt et al. (2003), and Fisch (2000). In addition, the building of the BSEW08 curriculum around the BeeWorld Project research itself as a scientifically authentic instance of leading-edge scientific discovery is altogether consonant with Prawat's (1993) suggestion that deep and meaningful learning can best be supported through engagement with "big ideas" of science that "function like perceptual schemata" and so "help educate attention, opening us up to aspects of the world that are a potential source of wonder and awe" (p. 5). It is evident from the students' post-workshop comments that they made deep connections with the scientific content and process of the BeeWorld Project, taking from their participation in the workshop week a long-lasting set of impressions that they recognized as holding relevance for their ongoing lives as learners. Although the workshop occurred over a single week, the learners' remarks show clearly how the students conceived of the workshop knowledge as relevant to their ongoing *learning trajectories* as high school students looking back to abiding scholarly interests and ahead to looming college and career choices.

The students' and organizers' comments also revealed the BSEW08 curriculum to be very much a balancing act between hands-on and receptive learning pedagogies, and between the workshop's brief time frame and the project's own complex, resource-intensive and ongoing investigation of the big ideas that served as the impetus for the larger project and the summer workshop alike. It was recognized by all that BSEW08 could present no more than a slice or snapshot of the complex world of scientific research that was its central focus. The BSEW08 learning environment was not a school classroom but a functioning scientific laboratory where high-stakes and even potentially dangerous research work was ongoing during the workshop week. Bees sting, chemicals used for

genetic analysis have potential for damaging researchers' and learners' own DNA, a tripped-over laboratory table or hive box can potentially set back research agendas and careers for a field season or longer, and so the safety and security of visiting learners and scientific researchers alike will place substantial limitations upon the sorts of learning opportunities that can be provided in such an environment. Time and safety alike, then, imposed *necessary simplifications* as limits to the degree of scientific authenticity that the curriculum could provide.

Interpreting predecessor episodes in light of Inreach design features. The design features drawn from BSEW08 organizers' and learners' interview comments comprise a prismatic sort of lens that can be useful for considering the predecessor design episodes described in Chapter Four. This section discusses how these episodes illustrate various degrees of attention to the categories of coherence of experience, connecting of worlds, scientific authenticity, characteristics of setting, necessary simplifications, characteristics of learners, and learning trajectories.

Episode 1: The original project proposal. In terms of the seven categories introduced above, the initial proposal's calls for the project to contribute curriculum to a summer camp add-on and to a high school teacher's courses represented "first drafts" of attempts to *connect the worlds* of the project's leading-edge scientific research and sets of school-year and summer experiences for young learners. In retrospect, it can be seen that the proposals offered little in the way of *coherence of experience*, particularly as the curricular offerings that were considered for development bore little relationship to the project's scientific work. With regard to the *characteristics of setting*, major gaps existed between the educational aims of the summer mathematics camp that was to have somehow incorporated BeeWorld-related content, and also between the project's scientific work and the existing curricula of the high school biology teacher's courses. The notion of having undergraduates from North Carolina serve as camp counselors also worked against the notion of *scientific authenticity*, as the undergraduates themselves were outsiders to the scientific work of the project. With reference to *characteristics of learners*, the proposed middle school outreach would have intentionally been directed to a set of students that would likely have fallen toward the more challenging side of Aikenhead's typology, namely learners he would classify as "outsider," "inside outsider,"

or “I don’t know” students. With regard to students’ ongoing *learning trajectories*, it could be argued that involvement in the camp curriculum might conceivably result in the middle school-age learners becoming interested in the work of bee scientists and that this might somehow lead to their becoming more successful students in school, but just how this might have been expected to come about was left unstated. Specifics of the proposed middle school curriculum were never developed past the point to which the North Carolina undergraduates took their prototype lessons, but that body of work makes clear that *necessary simplifications* were vast and highly artificial. With middle school mathematics as a basis, likely activities would have involved figuring the speed and trajectory of model bees in flight, and dancing to signify the distance and location of food sources. The challenges arising from this initial attempt to use resources and issues that were integral to the work of a leading-edge scientific project for general educational ends led to a sharpened focus on the part of project organizers regarding what had initially appeared to be a fairly simple question: How could the project contribute substantially to important educational outcomes for young learners?

Episode 2: The December 2005 outreach. In terms of the design features introduced above, *coherence of the experience* was enhanced by the organization of the workshop as a two-part set of activities bridging across classroom and curricular settings, occurring at a point in the course curricular sequence soon after students had learned about basics of insect morphology and environmental impact. Placement of the outreach activities at this point in their studies was intended to extend *learning trajectories* beyond what the students had learned about in their course curriculum. Regarding *characteristics of setting*, the intent was to begin by bringing students into the learning experience through an introduction in their home classroom setting, but then to follow up by using the laboratory setting itself as a key teaching tool. Involvement of project researchers as content presenters contributed to the perception of the outreach activities as *scientifically authentic*; this was true despite the degree of *necessary simplification* arising from the brief time available for the school and lab visits, and from organization of the activities primarily as opportunities for receptive learning, built around brief lectures and onsite tours that included opportunities students to ask and receive answers to their questions. With regard to *learner characteristics*, it should be noted that not only did the project’s

choice of a private middle school near campus as an outreach partner skewed the participants toward learners who were children of highly educated parents belonging to a social class that could both afford to pay tuition for the education of their middle school-age daughters and recognized value in doing so.

Episode 3: The May 2006 outreach. In terms of the design features introduced above, this day's activities contributed to *coherence of experience* in three key ways. First, although the outreach was limited to a relatively brief session conducted on a single day, one of the two groups of participants had previously been involved in the first round of school-year outreach the previous winter, contributing to the readiness of this group of learners to engage meaningfully with the lesson content. Second, unlike the initial outreach sessions, this day's events featured a sequencing of activities that was meant to show the breadth of the project's scientific investigations through a combination of hands-on activities and question-and-answer opportunities interspersed with a lecture component. Third, this was the first outreach activity undertaken by the project that attended carefully to selecting optimally engaging and engaged presenters, by teaming a project insider with another entomology scholar who had prior experience with the group of participating learners.

With regard to *characteristics of setting*, the decision to conduct the day's outreach activities in the middle school gymnasium showed organizers both the feasibility and limitations of bringing substantial content for hands-on investigation, such as live day-old bees and a small working observation hive, into a school setting. From the point of view of the organizers, the success of this set of activities taught us that we could hope to meaningfully *connect the worlds* of project research and school science education through activities that were engaging, fun, and educationally rich, by attending carefully to choice of instructional assistants and to affordances and constraints of the scientific research project.

Episode 4: The June 2006 meeting. With reference to the design features introduced previously, the outcome of the June, 2006 meeting attested to the strong interest on the part of project organizers in offering a *coherent set of experiences* intended to bring young learners meaningfully into the world of the project's scientific research. On the whole, the project organizers made clear in this meeting and subsequently that to

the extent that project affordances and constraints necessitated a choice, their preference was to use the *scientific authenticity* and unique strengths of the project to deliver educational value to a set of learners presumed ready for the experience, rather than to concentrate on investigating ways to connect meaningfully with groups of learners facing educational challenges. With regard to the *characteristics of setting*, then, the choice was made to design and deliver educational activities that would most directly ally the strengths of the project to educationally valuable outcomes for young learners. *Scientific authenticity* was to be promoted through use of actual resources of the project in educationally valuable ways, to the extent possible. While all recognized that this use would involve *necessary simplifications*, the organizers came to the conclusion that the proposed general arthropod camp involving children who faced academic difficulties would too greatly challenge the vision of adapting project science to meet school science, and so they instead chose the alternative of seeking ways to engage a carefully selected group of young learners in the conduct of project-relevant science to the fullest extent possible. For the organizers, the crux of their selected approach to seeking to broaden the project's societal impact through educating young learners boiled down to starting from the world of emerging science exemplified by the BeeWorld project, and *connecting that world* with the needs of middle school science learners through development and delivery of particularly worthwhile educational experiences.

Episode 5: The 2007 pilot year camp. With regard to the design features introduced above, the pilot camp for middle school students took shape as an especially promising model holding promise for meaningful science learning in areas closely related to the major scientific outputs of the BeeWorld project. Operating as a weeklong summer camp afforded opportunities for developing *coherence of experience* in ways beyond those that were possible in the case of school-year outreach. With regard to the *characteristics of setting*, hosting the group of learners at the research institute that was the BeeWorld project's home provided easy access to resources while enhancing the sense of *scientific authenticity* experienced by the learners. Another key contributor to scientific authenticity was the close involvement of presenters who were themselves project investigators and affiliated faculty. With regard to *learner characteristics*, the education team recognized that having selected the pilot-year learners on the basis of

their having ties to project investigators, and involving some learners who had previously participated in the school-year outreach, had provided us with a group of students who were likely to encounter little difficulty, relative to their age mates, with the complexity of material they encountered over the course of the week. Even so, the team recognized from feedback we received from the students -- including daily “writeback” notes and the content of learners’ end-of-week presentations -- that the students did not enter the week with sufficient prior knowledge of core principles of biology to assist them with making *connections between the worlds* of school science and the project’s scientific research work.

Using the categories to interpret the various RSMSS types. The seven concepts identified in BSEW08 organizers’ and learners’ interview comments can also be useful for considering the sorts of “research science meets school science” outreach described in Chapter Two. This section discusses how the various RSMSS outreach types might be considered with regard to categories of coherence of experience, connecting of worlds, scientific authenticity, characteristics of setting, necessary simplifications, characteristics of learners, and learning trajectories.

RSMSS type 1: Individual scientists in the classroom. In terms of the set of design features that was introduced above, this class of outreach initiatives can be recognized as seeking to *connect worlds* of scientific research and school settings by bringing scientists into the schools as individuals, where they serve as exemplary role models and are called upon to assist teachers and school administrators in updating and enhancing existing curricula. Often, science educators advise scientists coming into these settings to avoid asserting themselves as content experts, and instead to work with teachers to develop and support hands-on, problem-solving activities that engage students directly in carrying out processes and practices that are meant to model practices of scientific discovery. A controlling presumption of such activities is that involvement of the scientists will enhance young learners’ perceptions of the real-world applicability of school-based science activities, and thereby assist learners on the path to developing *learning trajectories* that will move them toward meaningful lifelong engagement with the world of science.

RSMSS type 2: Technology-centric initiatives. In terms of the design features introduced above, technology-centric outreach initiatives can be regarded as endeavoring to *connect learners with the world of science* by offering them access to the tools that scientists use in their own work. Educational interactions are largely built around use of the tools, offering a *coherence of experience* as various sorts of content (e.g., genomic sequences of different organisms in the case of Biology Workbench, or the carcasses of various arthropods in the case of Bugscope) are manipulated using a common set of tools. With regard to the *characteristics of setting* of the activity, use of the tools is typically mediated by web interfaces that provide learners the opportunity to control the tools remotely and in limited ways. *Necessary simplifications* involved with use of these sorts of activities may include provision of a simpler or less powerful interface to the technology than is utilized by professional users, and involvement of technical support staff working directly with the tools (e.g., with Bugscope, students send in samples of their own, but technicians prepare the slides and place them in the scanning electron microscope; students can use the web interface to pan and zoom visually across the prepared slides).

RSMSS type 3: Field trips. In terms of the design features introduced above, outreach activities centering on field trips for science learning can be recognized as centering on the *characteristics of setting* to meaningful engagement with science. Although some literature exists attesting to the efficacy for science learning of field trips to outdoor settings and museums, I have been unable to find any research involving visits to scientific research facilities. It stands to reason that such visits would be at least as advantageous for meaningful learning of science as field and museum outings, because in the research laboratory setting learners would have opportunities to encounter not only rich material for scientific inquiry but also a community of scholars actively engaged in the conduct of scientific work.

RSMSS type 4: Citizen science. With regard to the identified design features, outreach initiatives centering on citizen science can be viewed as emphasizing a variety of *coherence of experience* arising from shared engagement in scientific activity with professional scholars. Citizen science activities also emphasize the importance of *characteristics of setting* of learner activities within an ongoing research activity. Citizen

science deals with the issue of *necessary simplifications* through directing young learners in the activity of collecting data using simple instruments readily available to them, such as weather measurement stations, digital cameras, pH paper, and the like. *Scientific authenticity* is promoted through having learners contribute directly to work having research worth, even if their involvement typically centers on collection rather than analysis of data. For all these reasons, citizen science projects may be regarded as especially rich opportunities for the making of meaningful *connections between the worlds* of school science and research science.

RSMSS type 5: Summer camps. With reference to the design features introduced above, outreach activities organized as summer camps can be regarded as offering learners the opportunity for especially *coherent learning experiences* during which they work intensively with a committed cohort of fellow learners, in settings rich in *scientific authenticity* and in close partnership with scientists and science educators. It is important to the organization of these camps that they typically take place in university or occasionally in laboratory settings, rather than in schools; as has been observed, this sort of attention to the *characteristics of setting* of activities can enhance opportunities for meaningful learning. With regard to the aspect of *necessary simplifications*, the foregoing descriptions of camps present a picture of activities that in the main put learners into positions involving some research responsibility, but do so by taking care either to limit tasks to ones that the learners can themselves lead safely and with confidence, or to position the learners as apprentice helpers to researchers and other laboratory insiders. Regarding the areas of *learner readiness* and *learning trajectories*, it is worth noting here that camps of these sorts typically serve learners who have volunteered to participate, and who often have paid a fair amount of money for the privilege in addition to devoting a measure of out-of-school time. Presumably, these are learners who, in comparison with their age mates, are particularly interested in the activities of the camps.

RSMSS type 6: Laboratory-to-teacher initiatives. With regard to the design features introduced above, laboratory-to-teacher initiatives can be considered as endeavoring to contribute to *connecting the worlds* of school teaching and research science, by bringing teachers into various sorts of apprenticeship experiences with research scientists and their laboratories. The array of activities described in this section

can take place across multiple settings and *situations*, including school classrooms, research laboratories, and the virtual space of the Internet. With regard to *learning trajectories*, the expectation is that the teacher-learners are being prepared and encouraged to bring the research practices and knowledge base of professional scientists into their own classrooms. In terms of *learner readiness*, the teacher participants are volunteers who have elected to participate in the partnerships on the basis of their interests and availability.

Considering the six sorts of RSMSS outreach with regard to the seven design features that were found to characterize Inreach in the case of BSEW08 suggests that both Inreach and HOPSI-oriented outreach pedagogies might be capable of involving learners in worthwhile educational interactions that connect worlds of everyday experience with scientific research. Focusing on common characteristics like these seven as a set of potential design principles for meaningful science learning might give scope for considering the merits of various pedagogical approaches to science education without beginning from a presumption that one sort will be superior in all circumstances.

Chapter Eight

Conclusions

In Chapter Five, I introduced the idea that the 2008 BeeWorld Summer Education Workshop (BSEW08) exhibited characteristics of pedagogy that merit consideration as Inreach rather than educational outreach as traditionally described. Whereas outreach by scientists to young learners and their teachers typically involves either sharing the products of scientific discovery, or assisting with construction of artificial educational environments intended to mimic aspects of the scientific laboratory, Inreach instead attempts to turn the ongoing *process* of leading-edge scientific discovery in authentic settings to educational ends. BSEW08 thus operated in a distinctly different fashion from any of the six types of “Research Science Meets School Science” (RSMSS) educational outreach that I summarized in Chapter Two as *individual scientists in the classroom*, *technology-centric initiatives*, *field trips to science laboratories*, *citizen science projects*, *summer science camps*, and *laboratory-to-teacher initiatives*. The shape of RSMSS outreach over the past decade or so owes much to 1990s-era standards for science education that have promoted hands-on, problem-solving inquiry (here abbreviated HOPSI) in the classroom as a model of the scientific discovery process, with the stated intent of promoting scientific literacy for all students. Each of the instances of RSMSS outreach benefited from high levels of program resources and research attention, and the research shows each of these sorts of outreach to be worthwhile. Many of the most successful and best-researched RSMSS outreach efforts have benefited from support from the National Science Foundation, and in particular NSF’s Education and Human Resources directorate, which offers some \$873 million in annual funding (FY2010).

At the same time, NSF has since the late 1990s called on all projects receiving funding (amounting to some \$6.9 billion in FY2010) to contribute “broader impacts” on public knowledge, as a separate consideration alongside the aim of “scientific merit” that is the primary funded purpose of the projects that are not primarily educational in nature. It is generally presumed that education-centric projects of the sorts I summarize as RSMSS outreach in Chapter Two ought to serve as the primary means by which to approach this broader-impact criterion. As I wrote in Chapter Four, BeeWorld was no

exception to this presumption, having initially proposed to provide supplementary funding and bee genomics research expertise to an existing mathematics-oriented summer camp for underperforming middle school students, and to work with a high school science teacher to create educational materials for use with his students. However, when the summer camp was discontinued by its organizers, and when integrating BeeWorld-based content into the existing high school curriculum proved impractical, the BeeWorld Project decided to investigate the possibility of developing and presenting weeklong summer workshops in 2007 (with seven middle school-age learners) and 2008 (with fourteen high school-age learners). As I recounted in Chapter Five, research into BSEW08 took the forms of my own observant participation, extensive documentation of planning meetings and the week's workshop curriculum including videotaping of all activities, and pre-workshop and post-workshop interviews with both organizers and learners. Analysis of this data led to identification of seven design features that figured prominently in developer and learner accounts of BSEW08: *coherence of experience*, *scientific authenticity*, *characteristics of setting*, *necessary simplifications*, *connecting worlds*, *learning trajectories*, and *importance of set of learners*. In Chapter Six, I drew on published research involving episodic memory (Tulving, 1972) to propose that the design features of BSEW08 may have contributed to learners' being able four months after the workshop both to recall many of its particulars, and to integrate information learned at the workshop into their knowledge of bees and biology. In Chapter Seven, I drew from conceptual literature related to science learning to consider ways that the seven design features I identified with BSEW08 might contribute to meaningful learning of science more generally. These speculations led me to suggest that the design features drawn from BSEW08 show promise as potential design principles for informing design of curricula for meaningful learning of science whether the pedagogy is primarily receptive as in the case of Inreach or primarily discovery-oriented as in the case of HOPSI-oriented RSMSS designs.

Policy Implications

Among the reforms called for by the National Research Council (1996) in its *National Science Education Standards* publication is the recommendation that “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” (p. 221). Numerous education-centric initiatives have experienced success in achieving this aim through RSMSS outreach that is described in literature as primarily involving curricula of problem-solving inquiry. What is less well studied and demonstrated is the appropriateness of this pedagogical model for research endeavors that are organized and funded primarily to engage in scientific discovery, and that are tasked with offering educational outreach as a secondary aim. This is the case, for instance, with the bulk of the \$5.73 billion in research funded annually (FY2010 figure) through the National Science Foundation that is administered through NSF directorates and offices concerned with programs involving “Research and Related Activities” (R&RA). NSF has since 1997 directed all candidates for its funding to attend in their proposals not only to the intellectual merit of their activities, but also to broader impacts that are typically intended to involve education of the general public. In most instances, educational outreach conducted for this purpose is not considered a research endeavor in its own right, but rather a supplementary service provided with project funding. On the few occasions when educational outreach of this type has been subjected to evaluation, the results have been unimpressive. In the words of a 2007 report, even following substantial recruitment of education and outreach professionals to help STEM researchers learn how to use outreach methods or partner with outreach professionals, “confusion and resistance on the part of some members of the STEM community concerning BIC remains strong” (Holbrook & Frodeman, 2007).

The research I describe in this dissertation can contribute to resolution of this recognized dilemma in at least two ways. First, merely addressing education for broader impacts as a research initiative in its own right, within the larger funded projects, is a step in a positive direction. As participants in a 2002 workshop on the topic of broader educational impacts recommended (Avila, 2003), the goal should be to “integrate education and research” in a manner that “builds on the efforts of others, explores unknown territory, and risks failures”; “provides opportunities for personal growth for all who are actively involved”; “provide[s] opportunities for collaboration and cooperation,” and is “communicated and available to an audience beyond those immediately involved

in the research activity.” At the same time, some attention needs to be paid to whether the “confusion and resistance” remarked upon in the 2007 report might be in part be ameliorated through educational activities that are designed to be especially sensitive to the primary research goals of the supporting project, while utilizing its resources and opportunities as a uniquely valuable window upon the world of emerging science. It may well be the case that curricula grounded in the pedagogy of hands-on, problem-solving inquiry, effective as they have been shown to be in circumstances that are conducive to them, are not the best fit for laboratories in which complex, high-stakes, and potentially hazardous research is being conducted. In the course of educational design for the BeeWorld Project, experience with earlier outreach-oriented prototypes led to development of a BSEW08 workshop exhibiting principles that comprise a novel Inreach model. To be sure, the design and conduct of this workshop satisfied only in part the set of criteria identified by NSF as socially valuable forms of outreach, while at the same time leaving unanswered questions about the potential for the design to lead to worthwhile educational activities for a broadly representative range of students. In particular, the decision to offer the BSEW08 workshop specifically to students from a highly selective secondary school acted to constrain the learner population in ways that raise cautions about generalizability of this study’s results.

Given those caveats, however, the research described in this study supports the conclusion that an Inreach-oriented curriculum can be a proper match for the constraints and affordances of scientific research projects that, like BeeWorld, are given the ancillary task of designing and delivering education to young and non-specialist learners as a means of meeting broader-impacts goals. Projects in this position should consider the Inreach model as a potential means of designing educational opportunities that meaningfully connect young learners with the emerging science being explored by their projects. They might do so, for instance, by “cloning” the curricular design of BSEW08: working closely for multiple years with a school teacher much like Daniel Stern, whose interests and areas of expertise overlap with their own; collaborating with that individual to create standalone educational resources to be distributed electronically, and involving the individual in school-wide recruiting of student volunteers to participate in one or more weeklong summer workshops during the project lifespan. Equally important, the

project leadership and participating teacher could work collaboratively to recruit and bring into participation a project-funded graduate student who like Ned Nelson was already involved with the project's scientific research, to serve as lead presenter and "tour guide" for the workshop; following the BSEW08 design, additional project researchers would be tapped as guest presenters. Throughout, the emphasis would be on utilizing principles of Inreach to craft educational opportunities with maximal potential for bringing young learners meaningfully into the world of emerging science as currently being explored by the project as a whole. As occurred with BSEW08, workshops organized along these lines could be used both to improve the quality of standalone learning materials created with the teacher's assistance and to serve as the basis for video-based curricula made available online by the project.

However, to fully realize the potential for Inreach, it might also be useful to consider developing an enduring support structure with a reach beyond that of any individual project. Science educator Eric Jolly (Jolly, Campbell, & Perlman, 2004) has suggested that for educational initiatives to be of real worth, they must deal successfully with "ECC" issues of *engagement*, *capacity*, and *continuity*. BSEW08, as a prototype effort by a single project, can be claimed on the basis of my research to have *engaged* the limited group of learners involved in the workshop in a successful manner. Its *capacity* as a venue for first-hand learning was severely limited, both in terms of duration and numbers: a one-week workshop, with fifteen contact hours, provided to fourteen school-age learners on a one-time basis, can do no more than illustrate potential. With regard to *continuity*, the video-based "Electronic BeeWorld" curriculum that emerged from the workshop week has enduring existence as an online resource linked from the project's website and has begun to attract attention from external audiences; for instance, in August 2008 the Entomological Society of America selected eBeeWorld as its "buzz of the week" educational resource, and opportunities for exposure will continue to emerge as scholarly publications describing the curriculum are prepared and published. Even so, the resources of a single time-limited project position BSEW08 and Electronic BeeWorld as small and piecemeal sorts of initiatives on their own. Their value consists primarily of their being proofs-of-concept.

One way, admittedly ambitious, through which the promise of BSEW08 and the Inreach model might be extended, could involve university-level resources having greater potential for engagement, capacity, and continuity than one-off projects are able to manage. For instance, the university at which BeeWorld was based launched in mid-2009 a campus-wide science education initiative involving multiple academic departments and research units. An organization with similar reach and resources would be well placed to encourage numerous funded scientific research projects to consider, adopt and/or adapt the Inreach model to their own educational outreach missions. The campus-wide organization could provide ongoing assistance throughout the life cycles of individual projects, from advising on proposals, to suggesting partnering of schoolteachers and projects, to investigating the project-specific educational designs as they emerge, to operating as a clearinghouse for educational materials that result from BSEW08-style workshops. All the while, the campus-wide unit would be in position to engage in high-level educational design research, drawing from each project's successes, failures, and lessons learned to inform improvements and disseminate findings on an ongoing basis. Similarly but less ambitiously, research units and academic departments whose faculty and staff are involved with multiple projects could elect to manage and research the projects' educational aspects as a loose portfolio, again with the aims of increasing efficiencies while creating outcomes with broad and enduring worth.

The Thorny Issue of Trust

The research described in this dissertation was carried out in what Kelly (2008) 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 I as a researcher was solely or primarily a visitor, 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 BeeWorld 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 BeeWorld 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 BeeWorld 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, 2010, 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 BeeWorld did. Moreover, my own decision to explore the story of BeeWorld educational development for this dissertation, and my intention to author and co-author additional works building upon this research, contribute 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 (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.” Within the research reported upon in this dissertation, two major barriers emerged against the developers’ initial aspirations to target scientifically rich, project-relevant educational opportunities to groups of learners coming from diverse and traditionally underrepresented populations. The first challenge stemmed from difficulties I and other members of the project education team faced in coming to recognize and appreciate just what sorts of learning activities would truly amount to unique and valuable educational opportunities that the project was in position to make available. The answer to this challenge has taken the form of this dissertation research itself. In essence, these pages tell a story of how the BeeWorld Project, and I as an individual contributor to it, developed an educational agenda and an associated

research methodology that utilized iterative cycles of development, enactment, and analysis, and culminated in an approach to broader impacts for NSF R&RA projects that I describe here as the Inreach model. As described in this research, the Inreach approach 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." If the Inreach model approach had not yielded the positive results that it did with the admittedly elite group of learners we involved in our prototype efforts, it would be difficult to justify using the approach with learners who have more to lose from their efforts. Up to that point, it was sensible to explore and develop the approach first with teachers and learners who were particularly accessible to us, and who were likely to have the least distance to travel in crossing borders into the world of emerging science. Now that the results described in this research have been found, 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*. Daniel Stern, 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.

Likewise, the middle school teacher who together with her students participated in the school year outreach in 2005-2006 was someone with whom several of the project researchers were previously acquainted in professional and personal capacities. Moreover, some of the students who took part in various workshops, although none of the research participants in the summer 2008 study, had additional connections with project members. The research took place, after all, in a fairly small community with an economic and social life dominated by a large university campus, and both the private middle school and public high school that were involved in the project were located very close to the campus and had numerous formal and informal connections with it. 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 BeeWorld 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 as a matter of “intellectual merit” in its own right, with program goals and funding levels in place to support broadening of the investigations begun here.

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 initiatives.

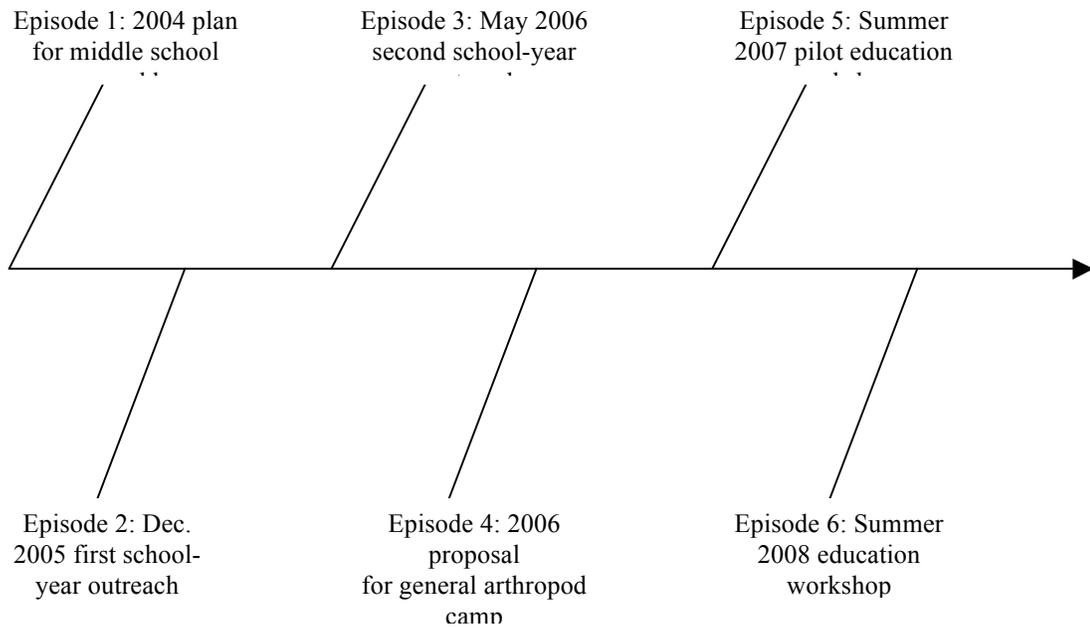
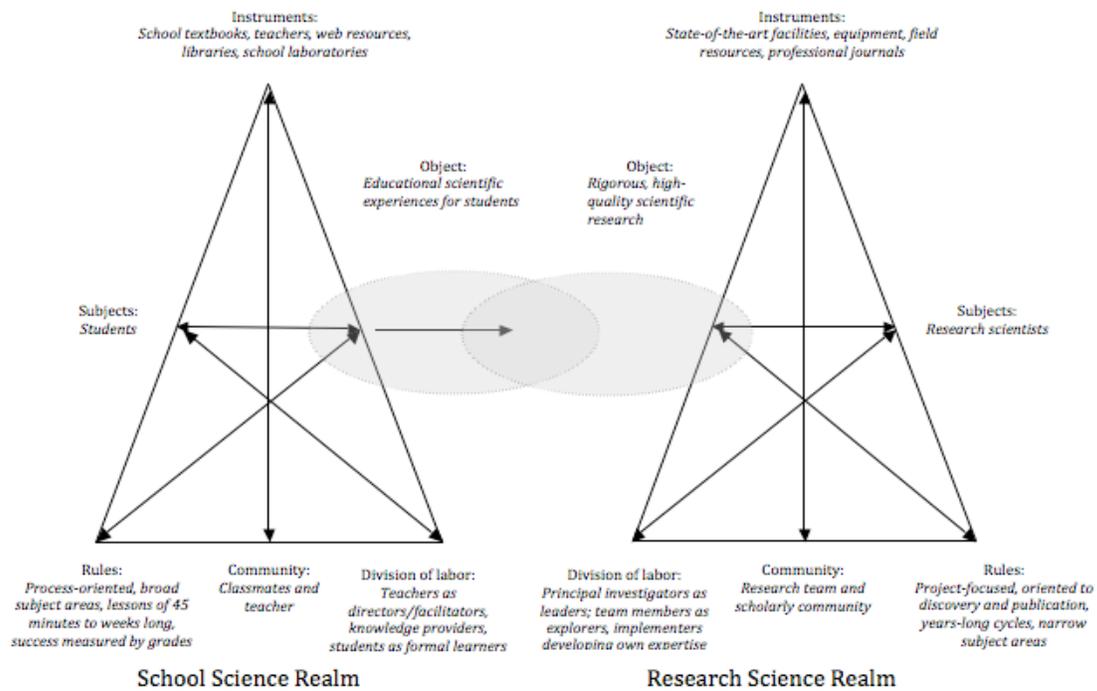


Figure 1. Six episodes of BeeWorld educational design.



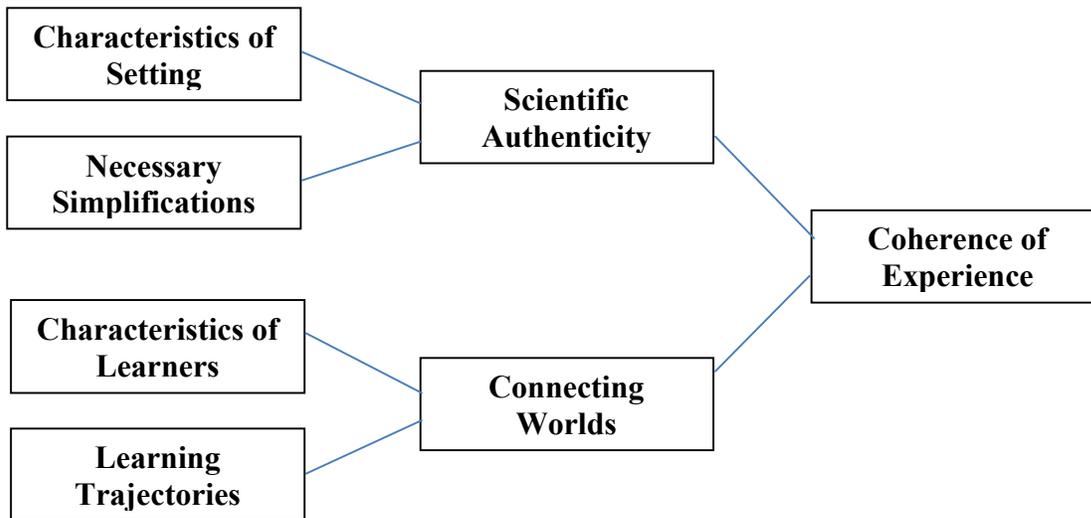


Figure 3. Seven design features of the 2008 BeeWorld Summer Education Week (BSEW08) curriculum.

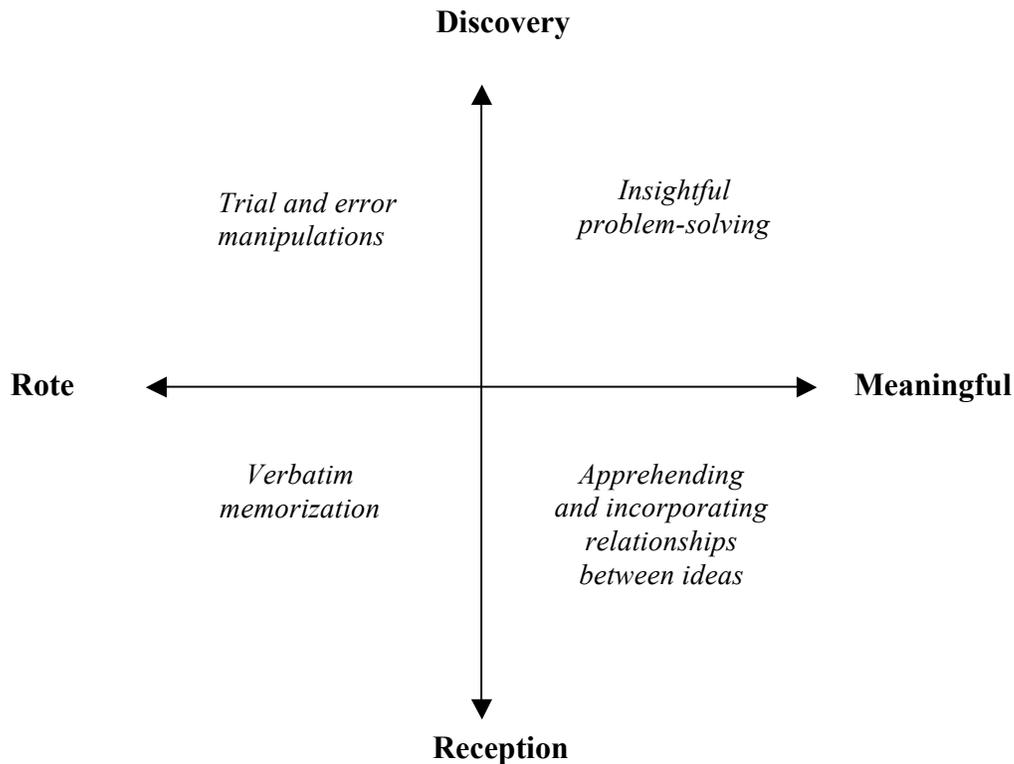


Figure 4. Illustration of four quadrants of learning defined by poles of rote-meaningful and discovery-reception (derived from Ausubel, 1965).

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Appendix A

Description of Activities for Summer 2007 Pilot Workshop

- *Bee Dissection Laboratory* (Monday). In this activity, the learners dissected honey bees under a microscope, to learn about bee anatomy and parasites of bees and to better understand what scientists were reporting about the condition of bees in hives afflicted with CCD.
- *Colony Collapse online search* (Monday). Learners were introduced to the problem of Colony Collapse Disorder and to a variety of online search tools, including the BeeWorld Navigator software then in development, in order to explore what scientists know about CCD.
- *Learning About Pollinators* (Tuesday). The students met the head of the university's Department of Entomology, who spoke with them about pollinating insects and Colony Collapse Disorder. The professor spoke about the importance of bees as crop pollinators, the poor state of knowledge regarding pollinator health nationally, threats to bees and other pollinators including CCD, and the challenge of separating good science from "junk" in popular press accounts.
- *BeeLand Game* (Tuesday). The students played and evaluated BeeLand, a board game created by the North Carolina college students.
- *Honey Tasting* (Tuesday). The students conducted a "blind" taste test of honeys made from the nectars of various flowers.
- *Visit to a Bee Research Laboratory* (Wednesday). BeeWorld's lead biology investigator hosted a visit to his laboratory's Bee Research Facility, site of leading-edge research into bee genomics and social behaviors. There, he led a wide-ranging discussion about the conduct of scientific research related to bee behavior. Plans had called for the students to don beekeeping suits for an up-close look at an open beehive during the visit, but strong thunderstorms forced cancellation of this activity.
- *Learning About Genome Bioinformatics* (Wednesday). A post-doctoral researcher hosted a computer laboratory session in which she showed the

- students how bioinformatics enables exploration of links between evolution, genomics, and behavior across species.
- *Observing Pollinators at Work* (Thursday). The university's greenhouse manager guided the students in observing pollination activity by honey bees, bumble bees, carpenter bees, butterflies, and other insects in outdoor gardens.
 - *Getting to Know Leafcutter Ants* (Thursday). A professor from the university's Department of Entomology introduced the learners to his leafcutter ant colony. Ants are another highly social insect with a colony structure similar to that of honey bees.
 - *Creation of Summary Posters* (Friday). The students worked in small groups (pairs and a trio) to create posters summarizing what they had learned over the course of the week, then reported on their learning to the whole group.
 - *Nature vs. Nurture Game* (Friday). The students played "Nature vs. Nurture," a Jeopardy-like computer game created by college freshmen in which teams vied to answer questions about bee behaviors.
 - *Capture the Nectar Game* (Friday). The students played "Capture the Nectar," a lively outdoor chase game created by college freshmen that was modeled on the campout standard "Capture the Flag."

Appendix B

Description of Activities for BSEW08 Workshop

- ***Monday Activities.*** The Monday morning session began with introductions by the workshop staff and students, and an overview of the week's curriculum. This was followed by a slide-illustrated informational talk, a little over one hour in length, in which the BeeWorld Project biology investigator discussed honey bee biology. Sections of her talk introduced honey bee taxonomy, bee biology, beekeeping, pollination, pathogens, bee venom, and Africanized "killer" bees. Next, the students engaged for about an hour in a hands-on activity, under staff tutelage, in which they handled day-old live bees -- at the age of one day or less, adult bees' stingers are still too soft to be inflict a sting -- and used visual microscopes to explore the anatomy of bee carcasses. The final activity of the day involved using a scanning electron microscope via the "BugScope" web interface.
- ***Tuesday Activities.*** The Tuesday morning session began with a hands-on introduction to removable-frame beehives and other beekeeping by Mr. Nelson, the graduate student who served as the workshop's lead instructor, which went for about half an hour. Following this introduction, the workshop group traveled by van to the campus honey bee research laboratory, located in the countryside about two miles away from the genomic biology institute. There, the group donned beekeeping protective apparel to join Mr. Nelson in observing an outdoor removable-frame beehive, in an informational session that lasted about 30 minutes. While at the bee research laboratory, the group also went indoors for about 45 minutes to visit a glass-encased observation hive and an experimental indoor flight cage and to learn how bee researchers investigate and manipulate field conditions to conduct behavioral experiments. Afterward, the group returned to the genomic research institute for a slide-illustrated presentation by Mr. Nelson, lasting about 35 minutes. In this talk, Mr.

Nelson offered an introductory overview of the BeeWorld Project's research agenda; his topics included project goals, exploration of contributions of nature and nurture to behavior, the importance of honey bees for behavioral research, key steps in carrying out a bee behavior experiment, and important tools for honey bee research.

- ***Wednesday Activities.*** This day centered around two lengthy slide-illustrated lectures, one by Mr. Nelson and another by the project's lead biology investigator, and concluded with an activity centered on the tasting of numerous varieties of honey. Organizers had wished to avoid back-to-back placement of lectures during the week, but this sequencing was necessitated by limits on the biology investigator's availability. In his 45-minute talk, Mr. Nelson focused on the molecular analysis of bee genetics, describing several state-of-the-art tools of the trade for researchers and the sorts of knowledge they contribute; his topics included an overview of a half-dozen major steps involved in the qualitative real-time polymerase chain reaction (qRT-PCR) procedure, the procedure of *in situ* analysis to explore mRNA expression by particular anatomical structures, and the use of whole-genome microarrays to compare mRNA expression associated with contrasting behaviors. The biology investigator's 80-minute talk focused on the conceptual questions that inspired the BeeWorld Project as a whole; as he discussed, these center on interrelated roles of nature (biological inheritance) and nurture (environment) in shaping animal behaviors, and particularly on how the genome responds to environmental stimuli with production of messenger RNA (mRNA) derived from particular components of the organism's DNA, with the mRNA going on to produce physiological effects. He described how this system is becoming understood with regard to behaviors of honey bees and numerous other organisms, including voles, rats, and humans. Following these talks, students engaged in a tasting activity in which they competed to identify about a dozen different

varieties of honey that were produced from the pollens of different kinds of flowering plant.

- ***Thursday Activities.*** Thursday began with a brief tour, led by Mr. Nelson, of the BeeWorld genetic analysis laboratory facilities in the genomic biology institute; students were shown a PCR machine, heating and cooling equipment, testing kits, a centrifuge, a freeze dryer, and a spectrophotometer. Upon returning to the classroom, the students engaged for about 45 minutes in a hands-on simulation of microarray analysis, using materials adapted by Mr. Nelson from a commercially educational kit (Campbell, no date) that was originally produced in part by another genetic research facility on the university campus. Afterward, the students heard an hour-long, slide-illustrated talk by a doctoral student in entomology who described his and others' ongoing research into symptoms and causes of Colony Collapse Disorder, the mysterious disease affecting honey bee colonies that began making headlines around the world in 2007.
- ***Friday Activities.*** The final morning of the workshop began with an 80-minute slide-based talk by Mr. Nelson in which he described areas of bee behavioral research in which he and fellow BeeWorld biology researchers were engaged. Topics in this talk included use of bees as research organisms, bee learning and memory, and experiments involving bee dance language, navigation, and time sense. This was followed by an outdoor activity in which the students walked across the street to gardens maintained by the university's botany department, to observe bees and other insects active on various flowers there. Afterward, the students returned to the classroom for a final 30-minute talk, presented by BeeWorld's lead investigator, who described how computer software developed by the project might prove beneficial for human health care. During the final 45 minutes of the workshop, the students were divided into two groups. For half the time, one group learned to construct solitary bee houses from blocks of wood and other common materials, while the

other group engaged with me in a brief focus group session so that I could learn about their impressions of the workshop curriculum; after about 20 minutes, the groups switched off, so that all students could participate in both activities.

Appendix C

June 2008 Learner Pre-Interview Protocol

These questions were the basis for individual telephone interviews I conducted during the last week of June 2008, with ten students who had volunteered to participate in the BeeWorld Summer Education Workshop that would be held July 7-11, 2008. Each interview was between about ten and twenty minutes in length.

1. Why are you interested in taking part in this workshop?
2. How would you describe yourself as a science learner?
3. What have your experiences been like as a science learner up to now?
4. What's the best thing about science for you?
5. What's the worst thing about science for you?
6. What do you know about honey bees?
7. What else might you like to know about them?
8. What do you know about genomic research?
9. What else might you like to know about it?
10. What are your feelings about genomic research?
11. How do you think genomic research might affect society in your lifetime?
12. What do you expect to be the most useful aspects of this workshop for you?
13. Do you have any concerns about this workshop?
14. How do you expect you might use the knowledge you gain from the workshop in the future?
15. What are your feelings about science as a field of study?
16. How do you think scientists go about learning new things?

Appendix D

July 2008 Learner Focus Group Interview Protocol

These questions were the basis for two focus group sessions I conducted during the final morning of the BeeWorld Summer Education Workshop, on July 11, 2008. Nine students in all participated in the focus group sessions -- four in one session and five in the other. Each session lasted approximately fifteen minutes.

1. What were some of the best things about this workshop? Why?
2. What things could have been better? Why/how?
3. What sorts of things did you learn that surprised you?
4. What sorts of things did you learn that you'd like to know more about? How do you think you might go about learning more about those things?
5. Overall, what's good about this kind of workshop for people with interests and science knowledge like yours?
6. Overall, how could workshops like this be improved to better match with the interests and science knowledge of people like you?
7. How was taking part in this workshop similar to learning science during the school year?
8. How was taking part in this workshop different from learning science during the school year?
9. What do you think you understand better now than you did when the workshop started?
10. What did the workshop leave you confused or unsure about?
11. Would you recommend a workshop like this to a friend? Why or why not?
12. Would you recommend that more science research projects around campus offer workshops like this one, in their own areas of research? Why or why not?
13. What else do you think the organizers should know about your experiences in this workshop?

Appendix E

November 2008 Learner Post-Interview Protocol

These questions were the basis for individual telephone interviews I conducted during the second week of November 2008, with eleven students who had participated in the BeeWorld Summer Education Workshop the previous July. Each interview was between about fifteen and twenty-five minutes in length.

1. Could you describe for me your understanding of what the BeeWorld Project is all about?
2. What would you say you learned about bees and behavior, during the week?
3. What would you say you learned about genomic research, during the week?
4. Have there been any points in your learning since the workshop, where you might have had occasion to think, “That relates to something I learned in the workshop”?
5. How do you think that what you learned during the week, might relate to your educational and career paths beyond high school?
6. From the vantage point of these several months, what stands out most about the workshop week?
7. Are there still things that came up during the workshop week, that you'd like to learn more about?
8. What advice would you have, for organizing future learner workshops, for leading-edge science projects like BeeWorld?
9. What advice might you have for taking the videos, slide sets and so on from the workshop, and making them useful for additional learners via the web?
10. Is there anything else you'd like to mention, that might help me understand better your experiences with the BeeWorld workshop?
11. Do you have any questions for me before we conclude?