Engineering a Dynamic Science Learning Environment for K-12 Teachers

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Teachers are eager learners and participants when professional development opportunities are relevant to their personal interests, classroom needs, or both (Basista & Mathews, 2002; Gordon, 2004). However, it is often difficult for teachers to translate professional development concepts to the classroom in a way that meets their students' needs (Duffy, 2004; Gordon, 2004). In-depth research on teachers' professional experiences is essential to identify the features that most effectively promote outcomes that address both student and teacher needs (Westerlund, Garcia, Koke, Taylor, & Mason, 2002). Such research can contribute to a clearer understanding of how learning environments interact with individual and group differences to optimize design of existing and future opportunities (Duke, 2004; Westerlund, et al, 2002).

The present study follows a cohort of 17 K-12 teachers through a six-week resident learning experience in science and engineering, and on into the planning and implementation of applications for their classrooms. This Research Experiences for Teachers (RET) program was examined using the strategic approach of design-based research, with its fluid, adaptive management of the complexity of authentic learning *in situ* and its attentive documentation of expected and unexpected events, in process and products, to capture the richness of teachers' and mentors' experiences.

Background

The design-based research approach used in this study considered multiple elements of teacher learning and transfer in order to obtain a rich and complex data set. Research on effective teacher professional development, adult learning, situated cognition, and learning transfer were utilized to inform the evaluation design. Teachers' and mentors' perceptions of their experience were essential in this study and the data collection was structured to meaningfully include these factors.

Teacher Professional Learning

Effective teacher professional development should: (1) include well-defined theory in teaching and learning; (2) build in-depth knowledge and skills; (3) model strategies; (4) build learning community; (5) support teachers' leadership; (6) link to larger educational communities; and (7) be continually reassessed for improvements (Bell & Gilbert, 1996; Bransford, Brown, & Cocking, 1999; Wilson & Berne, 1999). In order to promote substantive changes in teaching practice, educators need opportunities to study both content and pedagogy (Berliner, 1991; Branscomb, 1993; Wilson & Berne, 1999) and to engage actively in situations merging content with meaningful learning contexts (Bybee & Loucks-Horsley, 2000; Garet, Porter, Desimone, Birman, & Yoon, 2001). However, few teacher professional development opportunities integrate these important design features (Westerlund et al., 2002; Wilson & Berne, 1999). The RET program is designed to address many of these requirements by offering teachers an opportunity to participate in authentic research experiences and then translate them into classroom practice.

During the six-week RET summer experience, teachers work in small groups of four to six with a university research mentor to answer testable questions related to specific engineering disciplines. They are asked to turn what they learn into classroom activities that will increase their students' understanding of concepts they regularly teach. The teachers are offered an opportunity to write proposals to receive funding for classroom materials related to the activities they create in order to encourage full participation.

Teacher professional development couched in authentic field experience can promote knowledge and skill development for teachers, especially when collegiality and communication between scientists and teachers are high (Dresner, 2002; Dresner & Worley, 2006; Westerlund et al., 2002). Summer institutes such as the RET, outside of teachers' daily professional contexts, offer in-depth learning opportunities and promote collegial sharing (Basista & Mathews 2002; Keyser,1997). Participation in this type of professional community facilitates development of expertise and enculturation that supports innovation (Hardré, Ge, & Thomas, 2005; Gordon, 2002). Collegial relationships also enable ongoing development and application of skills, improve success expectations, and support teacher follow-through (Dresner & Worley, 2006; Hausman & Goldring, 2001). The intent of the RET structure is to encourage ongoing teacher-teacher and teacher-mentor communication and collaboration to promote and sustain innovative teacher practices.

Effective professional learning addresses teachers' individual differences, beliefs, knowledge, and attitudes (van Driel, Beijaard, & Verloop, 2001; Wilson & Berne, 1999) and considers that learners' investment of effort in learning depends on their perceptions (Salomon, 1984; Bransford, et al., 1999). Teachers are motivated by incentives, but also by interactions with like-minded colleagues, sharing their passion, experiences, and insights (Barnes, Hodge, Parker, & Koroly, 2006; Dresner, 2002; van Driel, et al., 2001). As adult learners, teachers are motivated to engage in professional development based on relevance (Barnes et al., 2006; Gilmer, 1997), and the opportunity to share ideas with professional peers (Hausman & Goldring, 2001; Lieberman & Miller, 1999). These elements of teacher learning were considered in the RET evaluation design, and data was collected to assess teachers' perceptions of the experience in these terms.

Transfer of Skills and Authentic Experience

The development and transfer of usable skills requires authentic experience (Brown, Collins, & Duguid 1989; Hutchings, 1991). Too often, however, school experiences fail to link to the authentic practices of professional cultures (Bransford et al., 1999; Putnam & Borko 2000). Teachers tend to select and integrate new tools and strategies piecemeal into their existing teaching practice (van Driel, Beijaard, & Verloop, 2001). Integrated, holistic, conceptual change requires extensive time, resources, and support (Posner, Strike, Hewson, & Hertzog, 1982), and is facilitated in authentic, professional communities of practice (Dresner & Worley, 2006; Fish, 1980; Little, 1993; Zellermayer & Tabak, 2007) such as those created by RETs. The cognitive dissonance generated in this type of transformative learning experience forces teachers to seek ways to modify their current practice (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003).

The ultimate measure of success in a program like RET is the extent to which teachers assimilate knowledge in a meaningful way and subsequently teach their students what they learned. In examining the issue of authentic transfer for the present study, we distinguished two phases/types of teacher outcomes: (1) the authenticity of the on-site teacher learning experience, and (2) the teachers' translation and eventual transfer of the authentic experience to the classroom. Teachers need scaffolding and support to successfully accomplish a transition-and-transfer task from their own learning experience to that of their students (Garet et al, 2001; Lieberman, 1995).

Without support in the transition, they may experience frustration and helplessness and may even abandon their project implementation (Granger, 2002; Putnam & Borko, 2006). However, those who feel supported through the transition should retain their efficacy from the on-site experience and sustain their commitment to the transfer-to-practice task. Few studies of teacher research experiences have fully examined effects and implications through the implementation phase (Beighley, 1998; Gonzales, 1998).

Design-Based Research

Design-based research (Brown, 1992; Collins, 1992) is the systematic design and subsequent implementation and study of instructional tools and strategies in authentic practice (Design Based Research Collective, 2003). Using empirical methods and theory-driven design of learning environments, its goal is to understand how, when, and why educational innovations work (or do not) in complex, authentic learning and performance contexts (Design Based Research Collective, 2003; Hardré, 2003; Tessmer & Richey, 1997). The field of education needs new research approaches that address implementation in practice (National Research Council, 2002; Ponte & Smit, 2007) and lead to useful knowledge that informs practice (Lagemann, 2002; Shavelson & Towne, 2002). Design-based research ensures rigor and adherence to solid theoretical underpinnings with attention to the culture of context (Design Based Research Collective, 2003; Thornkildsen, 2005), while documenting processes and products of adaptation (Wang & Hannafin, 2005; Yates, 2004).

Research Questions

The research questions for this study focus on teacher learning, engagement, and classroom implementation with respect to the program design. The intent is to examine factors that contribute to or diminish the effectiveness of the program and its desired outcomes in order to inform practice.

1. What personal, interpersonal, and environmental factors contributed to teachers' engagement and other motivational characteristics, as well as their science knowledge and skill development?

2. What factors contributed to the development and support of the educational learning community in the on-site experience and afterward?

3. What factors contributed to teachers' transfer and implementation of the science teaching strategies from their on-site mentoring to their own classroom teaching?

4. What by-group differences existed that might illuminate findings related to these key outcomes?

Methods

Participants

Teacher-learners. Program participants were 17 K-12 teachers, from the following subject areas: seven in math, nine in science, and one in special education. There were eight male and nine female; nine with bachelor's degrees only, seven with master's, and one with a Ph.D. Ten of the teachers had 1-5 years of teaching experience, three had 6-10 years, and four had more than 10 years. The 16 schools from which the teachers came had the following characteristics: levels—11 high schools, five middle schools, one elementary school; locations—three rural, 14 from two metropolitan areas.

Faculty mentors. Three primary faculty mentors (all Ph.D.s), and their staffs (one junior faculty member, plus four undergraduate lab assistants) worked within three labs. The labs were in three different engineering departments (Industrial Engineering, Computer Engineering, and Environmental Engineering) on two campuses of a research university in the Southwestern United States.

Program Scope

The scope of the present program included teacher recruitment and orientation, a six-week on-site (resident) university experience with mentor and peer learning communities, and support for transition and transfer of the learning experience to classroom application. Teachers were volunteer participants recruited from schools around the state. Teachers were asked to identify research issues and interests for classroom research and instructional innovation, and were selected for the program based on match of their personal project goals with the program's goals and resources. Teachers were then placed in cohort-based mentoring groups for the on-site group experiences, based on alignment of their project goals with mentor expertise. Groups consisted of 5-6 teachers in each of the three mentoring groups in the three engineering labs: group 1, industrial engineering (IE); group 2, computer engineering (CE); and group 3, environmental engineering (EE).

Following the early summer (May-June) on-site experience, teachers returned to their home communities for the remainder of the summer and fall. Each teacher wrote a proposal for classroom application of the skills and concepts learned and practiced in the cohort. Proposals included requests for funding for necessary equipment and supplies required for implementation. Proposals were reviewed and evaluated by the mentors, and feedback given. When proposals were approved (and funded), the required materials were provided by the RET team. Teachers implemented their proposed projects, wrote up the results, and submitted those reports to the RET team, receiving feedback from their mentors. Teachers had ongoing access to the online discussions and communication tools and to their peers in the learning community throughout the 12-month program lifecycle. The online access was developed as a secure site in Moodle®, an open-source information management system (IMS) software.

Data Scope and Collection

Data for the study included multilevel indicators, collected from multiple sources over the full year of the program cycle, in forms both qualitative and quantitative. Data were collected via various methods and media, in person and online, to maximize access, authenticity, and clarity, and to promote salience and proximity to experience. This approach also served to streamline analysis and promote data security.

A shared, secure, virtual data collection and communication system was created in Moodle® to provide a central access point for the multievent, year-long program (including links to questionnaires, discussion tools for community sharing, and product submission upload capabilities). Links to surveys, discussion prompts and document submission instructions were posted to the online site, and email reminders sent to participants. In addition to the online collection of questionnaire and product data, observational and interview evidence was collected, via face-to-face interactions, to ensure that the voices of participants were clearly heard and understood, and to enable conversation and dialog with and among participants.

Instrumentation

Evaluations of process and product indicators were made using a combination of standardized quantitative scoring rubrics and supplemental qualitative descriptors as evidence, to promote objectivity and comparability of judgments. Both the mentors (as active participants in the experience) and two evaluators (as objective others) scored and commented on the materials. Assessments included both well-

Table 1
Timeline of Data Collection Events

Week	Events	
Wk 1	Orientation to D2L; Demographics survey; Begin reflective writing (Teacher and Mentor)	During RET
Wk 2	Continue reflective writing	During RET
Wk 3	Teacher Perceptions-Intent Survey – Time 1; Mentor Eval of Teachers – Time 1	During RET
Wk 4-5	Continue reflective writing; Discussion tool for project proposals utilized	During RET
Wk 6	Teacher Perceptions-Intent Survey – Time 2; Mentor Eval of Teachers – Time 2; Proposal rough drafts submitted & reviewed	During RET
Wk 7-11	Teachers complete and submit proposals	Post RET
Wk 12-18	Mentors provide proposal feedback; Proposal revisions submitted by teachers; Proposals accepted and funded	Post RET
Wk 19-26	Materials delivered to teachers; Support for Implementation Survey – Time 1	Post RET
Wk 27-39	Teacher Focus Group; Mentor Interviews; Support for Implementation Survey – Time 2	Post RET
Wk 40-48	Teacher Interviews; Teachers submit project report	Post RET
Wk 48-50	Complete reflective writing	Post RET

validated instruments used previously with similar groups, and new instruments contextualized for this project using assessment design best practices (e.g., Chatterji, 2003; Reynolds, Livingson, & Willson, 2006; Thornkildsen, 2005). The researchers sought this range as an appropriate balance of instrumentation for an applied, mixed-method project (e.g., Creswell, 2003; Creswell & Plano Clark, 2007; Fraenkel & Wallen, 2006). Instruments are described below, and additional technical details are included in a separate publication (Hardré, Slater, & Nanny, 2009).

Individual and background characteristics (demographics). Background questionnaires on age, gender, race/ethnicity, years of teaching experience, years in current school, subject(s) taught, grade level(s), educational level, and licensure type were administered on day one of the on-site experience. Data were collected in digital form, also serving as an orientation to, and practice in, the online system.

Evaluation of teacher participation and engagement. Mentor evaluations of teachers' participation and engagement during the on-site research experience included a combination of measures. Mentors used a standardized observation scoring rubric (7-item, Likert-type, 5-point scale, "Not at all true" to "Very Much true"), rating teachers' demonstrations of participation and engaged behaviors, verbal and nonverbal, at two administrations (weeks 3 and 6). To supplement the numeric evaluations, mentors provided *illustrative descriptive evidence* on a page appended to each of the rubrics, plus independent *interim notes and observations* of student participation. Mentors also reported individual and group participation and engagement in their *interviews*, near the end of the program period (weeks 27-30).

Evaluation of teacher products. Mentors and evaluators completed a set of rubrics and observation notes on products that teachers generated during the on-site experience (7-item, Likert-type, 5-point scale, "Not at all true" to "Very Much true"). Though the specific activities and projects in groups varied by context, the rubrics featured generalizable characteristics of teacher quality of engagement that were recognizable in research products across contexts. The same scoring model, with *illustrative descriptive evidence* and *interim notes and observations,* was used as for participation.

Teacher perceptions surveys. Multiscale questionnaires were used to assess a range of present- and future-oriented teacher perceptions and intentions related to their learning experience and of the embedded skills and concepts they were learning. The 40 survey items were selected *a priori* to assess seven different constructs: *perceived value, relevance/utility* and *benefit of the current skills*; and *future plans to use, efficacy in transfer of, feasibility,* and *perceived fit* for their K-12 classrooms. The constructs were selected based on their demonstrated importance in supporting transfer from teacher professional development. The 4-5 items for each subscale were presented with Likert-type, 7-point scales (subscale Cronbach's *alphas* .90-.94). Questionnaires were administered twice (weeks 3 and 5).

Online implementation planning and discussion. To bridge from the on-site resident experience to implementation and integration of the content, teachers engaged in online implementation planning and collaborative discussion. Eight prompts elicited teachers' thinking through conceptual and procedural aspects of the transfer and integration of the science and engineering content into their classrooms.

Proposal documents. Teachers wrote a plan for an action research project, taking their summer research experience into their classrooms. Proposal documents consisted of two parts: (1) the research plan, and (2) the intervention/lesson plans. The two parts focused on two key elements of teacher transfer: (1) *designing the research project* to generate meaningful information on student learning (transferring the scientific process); and (2) *designing the science lesson* to pass on principles of scientific knowledge and exploration to students (translating the teaching of science). Proposals were scored by mentors and evaluators using a standardized rubric (0-3 numeric scale). Criteria were aligned with the performance goals for the two outcomes, operationalized in the task specifications. The required score for proposal approval (and funding) was at least 20 (of 30 possible) by at least two raters on *both* components. Teachers whose proposals did not meet this criterion were given feedback and invited to resubmit.

Project implementation reports. After implementing the classroom research project, teachers wrote up their results and findings in a research implementation report and submitted it. Reports were evaluated using a rubric parallel to that used to evaluate the project proposals (0-3 numeric scale) and descriptive criteria aligned with the report specifications (30 points possible).

Periodic teacher reflective writing prompts. Over the course of the project period, teachers were given periodic sets of online writing prompts timed appropriately for the phase of the project in which they were currently engaged (or had just completed). Prompts addressed teachers' perceptions of their own progress and conditions in their school environments relevant to project implementation and integration. Generative, open-ended items required narratives or analysis as responses.

Email conversations. Though these were an informal, non-systematic source of data, the wealth of email that flowed among mentors, teachers and program staff provided critical insights about what was occurring in the program, particularly after teachers left the on-site resident experience. We collected a total of 147 emails for analysis.

Focus groups and interviews. Semi-structured individual and group conversations were conducted with participants at various points in the program lifecycle through intervention and implementation phases. Questions addressed perceptions of learning in the RET experience, implementation, and school and community support.

Analysis

Data were analyzed in multiple ways for: (1) whole-group patterns, such as teachers' needs and perceptions of their experiences, indicators of their development, and functional program implementation; and (2) by-mentor-group differences that shed light on design of experiences, support effectiveness, and overall program effects. Mentor group differences were not viewed as right or wrong, but examined through the lens of best fit with program goals and outcomes.

Analysis included a variety of methods, matched to the questions and data types. For the quantitative data we generated overall and by-group means in Excel. As the sample size (N=17) was inadequate to expect any statistical power or to meaningfully demonstrate significance, scores were simply compared for differences by individuals and groups, and for patterns of change over time. For the qualitative data, multiple external evaluators independently coded the text of responses, and then the researchers compared them for patterns of meaning, change, and perceptual differences. Toward the synthesis of findings, both types of data sources were used to address the research questions. They were analyzed by both mixed-method and multimethod approaches as appropriate to the questions, with multisource data triangulated to ensure validity and identify differences in stakeholder perspectives (see Creswell, 2003; Denzin & Lincoln, 2003; Huberman & Miles, 2002). The findings reported below emerged as consistent across data sources and types, as relevant to each research question.

Results

Question 1: Personal, Interpersonal, and Environmental Factors

Our first research question was: “What personal, interpersonal and environmental factors contributed to teachers’ engagement and other motivational characteristics, as well as science knowledge and skill development?” To address this question, we examined teacher perceptions questionnaires, reflective writing (of teachers and mentors), mentor evaluations (of participation and products), focus groups, and interviews.

Learner engagement is important because engaged learners encode more knowledge, develop more expert skills, and are better prepared to transfer to application contexts (Druckman & Bjork, 1994; Hardré & Miller, 2006; Kytle, 2004). Engagement was a primary goal of the program specifications (National Science Foundation, 2007) and a key predictor of learning and professional skill development (Latham, 2007; Taylor, Marienau, & Fiddler, 2000).

Overall, both teachers and mentors reported that teachers were engaged in the RET experience and that they experienced an opportunity to increase their learning. The majority of teachers tied their engagement to connections between their current learning and their future teaching needs. Most expressed some conflict between the authenticity of the university research experience and the utility of what they were learning for classroom transfer. Consistent with the theoretical linkages, teachers who found the most value and utility in what they were learning also reported the highest engagement; and those who were most engaged had the strongest intentions to transfer and use the content in their classrooms. There were differences in teachers' degrees and types of engagement, vestedness in the process, and the extent to which valued outcomes were tied to engagement, as reflected in the comments on perception surveys and in interviews.

Teachers identified diverse factors as influencing engagement. They acknowledged the influences of their past experiences and future needs and expectations on their current perceptions and processing of the on-site research experience (e.g., "I feel that the entire project is designed to promote group learning, and the engineering push also goes with my math and the group issues that I have had in the past."). They identified specific elements of the experience that promoted intellectual skills and linked them to research tasks (e.g., "I am encouraged by the thinking skills I am practicing. The on-site research experience is teaching me to be more confident in my thoughts or ideas on the research topic").

Some teachers defined engagement in terms of utility of the content they were exposed to (e.g., "[I am] mostly trying to focus on how I can use this experience."). Others experienced personal engagement in the research but felt a sense of conflict with their reason for coming (e.g., "[I got] so engaged [in the research] that I forgot that I was here for my kids"); and one mentor confirmed that "some teachers got so involved in the research that they did not make the transfer to teaching." Some defined their engagement around the community and collaboration:

> I am definitely staying engaged because I find goals and objectives for our group to work on. I am a proactive individual and try to make sure I am contributing to my group's project and see how I might use the project in my own classroom.

Others identified the research opportunity itself as engaging, including the collaborative dynamic and spirit of inquiry:

> The research itself keeps me engaged. I enjoy discussing our progress and results with the lab techs and other teacher participants. I know we are the experiment and what we are doing is someone else's research. It seems like one big circle, where everything and everyone involves inquiry.

Others cited the collaboration and peer-support features, along with the tools (e.g., "Our group has been very supportive. The sensors we have been using have also brought more ideas for other projects."). Most teachers found the collaboration and community experience particularly satisfying (e.g., "I have learned a lot especially about collaboration. The best part is being able to work with other teachers").

A few teachers expressed the feeling that the work they were assigned to do was not personally meaningful and that they lacked ownership of the project tasks, that they "felt like lab aides". Some participants wanted more time to achieve their goals, while others thought that tasks took more time than they should; but both groups said they had learned much (e.g., "It has been a real pleasure working [and learning here]. I feel like I will go back to the classroom and encourage my students to problem solve on a higher level").

Challenge is important because it is related to goal achievement, motivation, learning, and perceptions of the value of instructional and developmental events. All of the teachers reported that they felt challenged in their learning experience, but described different levels and types of challenge, and related perceptions. Challenge was often linked to the teachers' perceptions of difficulty in translating content and skills from the research experience to classroom practice. Several teachers welcomed the *personal* challenge of lab science, but were concerned about the *professional* challenge of classroom transfer. Thus, they distinguished between personal and teaching goals regarding perceptions of challenge (e.g., "I am definitely challenged [but] It is going to be hard to implement it in my classroom."). Similar perception with a different strategy emerged in this teacher's comment: "I am challenged with the [university] research and I in turn challenge myself to see how I will apply what I have learned back into the classroom." Another perspective was distinguishing between the content and context as sources of intellectual and personal or social challenge (e.g., "I do feel challenged in more than one way. The research topic is challenging my brain, and working with three other people creates another set of challenges but good ones").

Teachers enthusiastically said that they were learning, but generally tied their learning more to thinking about classroom use than to being engaged in the current (more pure, traditional, or laboratory) research. This distinction indicates that the teachers are divided between focusing on the utility versus the authenticity of their on-site research experience. They appear to regard research skills as discrete vs. integrated (both in current experience and in their classroom instruction). Teachers' conceptualizations of authenticity and challenge result in different perceptions of the transfer of their current learning to classroom research, with those differences ranging from proximal (near and similar) to distal (far and different). Some saw transfer to their classrooms as easy, based on interpreting their own experience as aligned with and closely translatable to the experience they wanted to create for their students (e.g., "Yes, I feel like doing science is a great way of learning science. The on-site research experience gives teachers a true science experience that they can then take back and work into their classrooms"). While some found the experience mostly focused on the lab research and further removed from learning to teach science (e.g., "The experience continually focused me towards learning research techniques. I had to keep reminding myself of my students."), others found the opposite true and sought more "real" research (e.g., " I feel like what we have accomplished can transfer to our classrooms easily. I do not feel like we have done 'real research' though").

On changes that indicated their learning, the teachers said they shifted from thinking about the "steps with lab" to the "problem-solving steps" (from the primarily technical, mechanical, or procedural to more substantive and deeper elements of tasks). Mentors also independently reported the same shift, saying said that they saw learners' questions shift from "questions on technical and mechanical issues" to "real inquiry, self-questioning, and scientific skepticism."

Expectations provide a framework for organizing and responding to new experiences, and goals that arise from expectations are a lens through which learners view educational opportunities. How teachers link the research experience to their expectations of the RET experience form a critical mass that emerges as influential on their engagement, learning, and satisfaction with the program. These links are also related to their perceptual responses to all of the opportunities they are afforded. The teachers' perceptions of their learning and engagement are tied directly to their expectations of the program, from a range of tangible and intangible tools to more esoteric goals of traditional academic research.

Overall, on Question 1, teachers' motivation and subsequent engagement were supported by their perceived relevance, value, and transfer utility of the content. These perceptions were based on their past experience and future needs, which influenced how they processed their mentor's activities, style, and communication. They were also influenced by level of intellectual and personal challenge provided, and how they defined transfer goals and expectations.

Question 2: Development and Support of Learning Communikty

Our second research question was: "What factors contributed to the development and support of the educational learning community in the on-site experience and afterward?" To address this question, we examined teacher perceptions questionnaires, reflective writing (of teachers and mentors), mentor evaluations (of participation and products), focus groups and interviews, proposals and reports. Teacher-mentor support, trust, and availability are no less important for adult teacher-learners than for their own K-12 students (Brookfield, 2006; Merriam, Caffarella, & Baumgartner, 2007). Consistent with findings from previous studies (e.g., Barnes et al., 2006; Brown & Melear, 2007; Dresner & Worley, 2006; Westerlund et al, 2002), teachers identified a number of factors that influenced their development of community.

Teachers developed community based on both similarities and differences. Their shared interest in science learning and teaching created "common interests" and "common ground" for communication and collaboration. The immersive nature of the on-site experience including the residency component ("living, eating, sleeping together") promoted "knowing each other well," building "closeness," and community. Facing the demands of challenging tasks caused groups to "learn and depend on each other's strengths" and develop mutual respect, as members of cohorts took leadership on various (e.g., mathematical, mechanical or technological) components of complex projects.

A particularly interesting difference emerged between the teachers' and mentors' perceptions of the scope of the program, and the attention mentors gave teachers after they left the on-site phase. In the teachers' view, the program continued into the school year as they sought to implement their proposals, while the mentors saw their role as minimal beyond the summer experience. Teachers felt less connected and supported in the off-site phase than when on site (e.g., "felt alone" and "had trouble reconnecting with mentors and peers"). The reduction in contact intensity and focus for the faculty mentors seemed to create a critical disconnect for teachers in the adequacy of the support they felt they were receiving, in the integration and networking phases. They "expected more connection" after going home (back to school) and "felt less successful" because they lacked support that they needed and wanted. The most challenging goals of the program were after the teachers left, integrating RET into their classrooms and building networks, for the teachers to continue integration and implementation in their schools. This is when teachers need their mentor and peer community of practice most profoundly, to extend and apply the knowledge they had built together.

Mentor availability and support were sensitive and influential. Consistent with previous research (e.g., Barnes et al, 2006), more than one teacher said that the mentor was very expert and credible but seemed "too busy." Teachers with this perception reported less enthusiasm for the program overall, in perceived learning during the on-site experience, and in expectations of success afterward; and these teachers were less successful in implementation than those who perceived their mentors as accessible and involved. This critical perception underscores the importance of mentor attention as an aspect of teacher immersion experiences, with the perceived support, access, and availability of mentors to their teacher-learners emerging as critical elements in teachers' overall program success. Ongoing communication among mentors and teachers was essential to building and sustaining networks for implementation.

Overall, on Question 2, teachers' ongoing learning community was developed and supported primarily by their interactions during the on-site experience and the ease of communication and interactions (with mentors and peers) afterward. Initial and continued mentor support and communication were critical to community development, so it was essential to explicitly provide user-friendly, accessible communication tools for teachers to sustain community interaction.

Question 3: Transfer and Implementation of Teaching Strategies

Our third research question was: "What factors contributed to teachers' transfer and implementation of the science teaching strategies from their on-site mentoring to their own classroom teaching?" To address this question, we examined periodic questionnaires, reflective writing, email conversations, interviews and focus groups, proposals and reports, and evaluations of proposals and reports.

In data from teachers and mentors, linkages to classroom integration differed widely. Perceptions linked to implementation in classrooms also differed both in strength and stability by group (see details in by-group differences). However, overall, teachers demonstrated good strength and consistency in their responses to the professional development activities, with the following means for subscales (out of 7): value 5.45; utility 5.3; benefits 5.25; feasibility 5.4; fit 5.15; confidence in implementing 5.25; and plan to use 5.5. These perceptual scores reflect on motivational issues (e.g., perceived value, utility and benefit), and on potential transfer to the classroom (via the future-focused characteristics of confidence, feasibility, fit, and plan to use). The items in this questionnaire target how they perceived the content and skills they learned, as useful, feasible, and beneficial *for transfer to their own K-12 teaching*. Teachers who used the online support system and support staff made a smoother transition to implementation and integration. Those whose mentors communicated the value of the system were more likely to adopt and use it, give feedback, and engage in collegial community as well.

Most of the teachers reported that they were successful in transferring principles and strategies from RET to their classrooms. They were able to identify specific ways that they transferred learning from the on-site experience and implemented these in their K-12 classes. Only about half of the teachers (8 of 17) completed their full, planned classroom research projects (implemented the planned lessons; measured, analyzed and reported results). These were the most successful RET participants. Most others implemented key features from RET and were able to discuss the perceived effects and benefits generally, so we considered them also to a degree successful in transferring the content and skills to their classrooms.

As to influences on success in integration, several points are clear. Teachers emphasized the goal of integration from the first days of the on-site RET, through their proposal writing and implementation reports. Specific elements of the RET experience that they integrated most fully were consistent with what they valued and enjoyed *when they were learners in RET* and what they identified as having highest perceived utility for their own teaching. Some teachers identified elements of the *general* research experience, such as inquiry, discussion and problem-solving analysis, that they are more attentively and consciously integrating into their classrooms after RET than they did prior to it (e.g., "I use the research process and inquiry based teaching more"). Other teachers identified very specific changes in their *design of daily activities* that they attributed to RET, such as using collaboration in the research process:

> Each section taught contains daily demonstration explaining the object of the period, toward the end of the sections students are required to break into small groups, 3 or 4 student groups, develop a research question, determine a hypothesis, laboratory testing, write an evaluation of their results.

Many teachers shared that they integrated strategies from RET into their general teaching practice, not just into the implementation of their planned projects (e.g., "I do more of the real life problem solving. We also talk more about applying our math"). Some teachers shared other features that they planned to implement in their classes, based on what they found useful during the laboratory research experience (e.g., "…the importance of randomizing the experiment so that results were not biased to a learning curve. The reason this helped me so much was to receive valid results from my experiment"). These were examples of direct strategy transfer (proximal transfer of what they learned in RET). Beyond the science, RET mentors modeled important interpersonal qualities that the teachers adopted and attribute to their mentors' examples, from modeling rather than telling (e.g., "The main thing that my mentor passed along to me was the need to develop closer relationships with my students so that they will approach me with questions/ideas").

Overall, on Question 3, the community development and continued communication were important supports for implementation and integration in classrooms. Mentor relatedness and modeling also proved critical, as teachers tended to take back and transfer what they saw modeled by their mentors in both content-related and more general teaching strategies.

Question 4: By-Group Differences

Our fourth research question was, "What by-group differences exist that may illuminate findings related to these key outcomes?" To address this question, we examined all of the data sources, from teachers and mentors, divided into clusters by mentoring groups.

By-Group Differences. Marked differences in overall design of the learning opportunity by mentoring group emerged in the descriptions from both mentors and teachers. By-group differences in the patterns of the teacher outcomes data (both quantitative and qualitative) underscore the importance of examining these features. Table 2 compares features of the three mentoring groups in their overall

Table 2
Group Design Features

	Group 1	Group 2	Group 3
Research Area	Industrial Engineering	Computer Engineering	Environmental Engineering
Mentor Contact	• Junior faculty member - first contact • Moderate presence - high availability • Active collaboration – projects & class activities • Provided structured face-time • Direct contact time · 4 hours/week	• Mentor – first contact • High presence - daily engagement • Active collaboration - projects & class activities • Provided structured face-time • Direct contact time · 20 hours/week	• Graduate research students - first contact • Moderate presence – low availability • High engagement on core projects and class activities • Low structure • Mentors · 4 hours/week (GAs 20/wk)
Group Collaborations	• Whole group collaboration • Mentor and within group leadership • Collaboration on project work • Groups mixed across tasks and projects	• Collaborative group tasks not assigned • Mentor leadership • Integrated structure and questioning • Focused on individual core projects	• Two self-selected groups • Group leadership with mentor support • Individual groups independent research • Groups had own research projects
Task Autonomy	• Low independence and low autonomy	• Low independence and low autonomy	• High independence and high autonomy
Scaffolding of tasks	• High scaffolding of pre-planned research tasks provided by mentor • Some tasks related to mentor's current research	• Structured learning with multiple problem-solving activities by mentor • Tasks not specifically related to mentor's current research	• Emphasized low structure of learning tasks and high independent learning • Research directly related to mentor's current research
Authenticity	• Low traditional authenticity • Authentic practice linked to classroom applications and examples	• Low traditional authenticity • Authentic practice linked to classroom applications including tools	• High traditional authenticity • Traditional academic/scientific research environment
Transfer	• Explicit scaffolding of transfer using activities with direct classroom application • Involved hands-on tools and activities appropriate to the K-12 classroom	• Used focused questions designed to implicitly scaffold transfer of learning • Utilized tools appropriate to the K-12 classroom	• Low scaffolding of transfer – little explicit support for transfer • K-12 classroom tools not used – provided "cutting edge" research tools for teacher learning
Integration	• Explicit support of integration	• Explicit support of integration	• Implicit support of integration

learning environment design, mentor style and interactions, and differences in learner perceptions and behaviors. The mentoring groups are described in terms of autonomy (the amount of direct mentor supervision on research tasks), scaffolding (the extent to which the mentor determined what the research tasks would be), traditional authenticity (the extent to which the research questions and tasks were related to the mentor's current research), and support (the amount of direct assistance the teachers were given for transfer and integration).

Perceptual and Effects Differences. Teachers in the different groups reported very different perceptions of their learning experiences overall, their mentors as teacher-facilitators, the perceived linkages to classroom teaching, and the perceived utility, feasibility, and fit with classroom teaching. These differences in perceived patterns parallel the group divisions and other program-relevant outcomes. What emerged, not by explicit design but by the mentors' choice, was *an exceptionally rich intervention-comparison design-based experiment* across the three groups, on degree of: (1) structure and direction vs. fluidity and independence; (2) explicit support of transfer to classroom; and (3) degree and nature of collaboration. These features are summarized in Table 3.

Overall, for Question 4, by-group differences in goals, structure, mentor presence, and explicit scaffolding of transfer and integration apparently exerted profound effects on learner outcomes. The on-site learning experience and mentor-teacher interactions within it and beyond need to be closely examined and strategically designed to align with program goals. It *can not be assumed* that all mentors and

Table 3
Perceptual and Effects Differences

	Group 1	Group 2	Group 3
Group Profile Characteristics	• 3 M, 2 F; avg age 34; avg 3 yrs tchng exper; subjects- 3 math, 1 science, 1 special ed.; 3 Masters, 2 BS degrees	• 3 M, 3 F; avg age 47; avg 9 yrs tchng exper; subjects - 3 math, 3 science; 3 Masters degrees, 2 BS degrees, 1 PhD	• 2 M 4 F; avg age 33; avg 6 yrs tchng exper; subjects - 1 math, 5 science; 1 Masters degree, 5 BS degrees
Teachers' perceptual and effects differences			
Overall Learning Experiences	• Good classroom transfer, but desired more authenticity ("real science") • Owned research and collaborative work • High level learning useful skills	• Good classroom transfer , but desired more authentic research experience • Owned research and collaborative work • High level learning teaching strategies	• Less successful transfer, but traditional research experience • Learned interesting research & lab skills • Less ownership but "authentic" research
Mentors as teacher-facilitators	• High interpersonal skills and high support	• High interpersonal skills and high credibility	• High interpersonal skills but less-than-optimal support
Links to teaching	• Linkages apparent and feasible	• Linkages apparent, required time	• Linkages less certain & accessible
Utility, feasibility and fit with classroom teaching	• High perceived utility, feasibility, fit • Modest confidence for transfer	• High perceived utility, feasibility, fit • Highest confidence for transfer	• Lower perceived utility, feasibility, fit • Lower confidence for transfer
Mentors' perceptual and effects differences			
	Group 1	**Group 2**	**Group 3**
Definition of "authentic" & strategy	• "When teachers experience the critical components for themselves [so] we will not spend time on the research hypothesis development phase, which is where they bogged down last year."	• When "teachers see its utility for their classrooms, based on their needs and goals [so] I brought tools in to help them see how they could…give their students a more authentic experience."	• " if they experience what we do in the university lab when we do research [so] I brought them into my world and showed them how we do research … how to think like scientists."
Reciprocal learning and Adaptation	• Translated & transferred strategies learned from teachers to undergraduate engineering teaching	• Observed teachers using equipment, developed understanding of their methods, drew on their examples	• Listened as teachers shared ideas & stories, adapted ways of illustrating concepts for them

teachers will interpret program outcomes similarly. Such interpretations should be examined at the outset of such programs, to support consistent learning, development and satisfaction.

Discussion

Teachers overall enjoyed the RET experience; they appreciated the faculty expertise and insights, and admired their mentors. The teachers used desirable terms (terms that match program vision) for targets of research, including terms like "proper science," "real world," and "true science." Some perceived the science as "over my head" but acknowledged that it was a good way to be challenged, "to stretch myself." They recognized that there were multiple levels of learning occurring: "The real lesson [was not] lab process but the process of discovery."

Every participant reported gaining something of value from the program. Collaboration with mentors and peers was a unifying theme across all target outcomes and stood out as a key benefit for the participants in the program. Communication and support were key factors in promoting program outcomes overall, all differences considered. Those teachers who felt communicated with and supported in the RET experience were the most successful in learning and applying concepts and skills in the on-site context. Teachers made changes in both formal scientific process and daily classroom strategies, which they attributed directly to their RET mentoring. Those teachers who felt supported and enabled in their schools felt the most confident about following through to implementation and integration. Those teachers who saw relevance between their mentored activities and their own class content and goals selected applicable tools from the on-site context and transferred those tools and principles to their classrooms through implementation most readily. The implementation of web-accessible technology for communication served an important purpose in bridging the distance gap, particularly through the transition to implementation in the schools. These findings underscore the importance and utility of mentoring with communication and support for learning and teaching as a model for effective teacher professional development.

Teachers came expecting very different things from the program, and strong relationships were evident between teacher expectations and value gained, tied to the teachers' expectations of what the program was *supposed to* provide them. Most participants struggled to arrive at a clear idea of the expectations of the program in order to construct personal meaning for themselves. An important difference in expectations was the question of whose responsibility it was to support strategic transfer to the classroom (mentors or teachers). It is clear that program-level goals, design of the research experience, and mentoring style interacted with teachers' expectations and individual differences. These findings underscore the critical role that perceptions and expectations play in effectiveness of teacher education and professional development opportunities.

The question of defining authenticity is an important one, and not easily answered; nor is there one best way to bridge between the two "worlds" of K-12 teachers and research scientists. Both teachers and mentors independently defined authenticity at various places along a continuum, from authenticity being "more like real, university lab science" (bringing the teachers into "our world") to it being "more like what teachers will do in their own classrooms" (taking our ideas and principles into "their world"). Some teachers wanted "pure research" but got praxis; others wanted praxis or explicit transfer, but got "pure research" ("cutting edge research", "authentic research experience"). What was "authentic" to teachers did not always match what was authentic to mentors, and such differences in definitions implicitly influenced the strategy use of mentors and the responses of teachers in this program. We could (consistent with much of the research literature and with National Science Foundation guidelines) define authentic research as research done the way it is done in the university, in a cutting edge, fully-equipped laboratory, supported by RAs and mentored by a research scientist.

If we accept that it is authentic research when the experience simulates the way university scientists do research in the lab, then these teachers perceived authentic research as difficult, unfamiliar or foreign, and disconnected from their transfer needs. Alternately, if we define "authentic" as science the way teachers will use the ideas, processes and principles in their own classes, the teachers perceived it as clear communication and applicable to their needs (but some lamented the lack of "real research"). To distinguish between these two interpretations of authenticity, we might reframe the latter as *authentic transfer,* as K-12 teachers taking principles from the university laboratory to their own classrooms and successfully doing an appropriately-contextualized version of lab or field science, utilizing the mentored principles and concepts, so their own students learn what they did.

Translating from authentic research to authentic transfer is difficult for teachers on their own, and arguably they need access to both to be able to carry out both the on-site and off-site components of a program of this kind. However, if the mentors spoon-fed teachers their classroom strategies, if they scaffolded them too much, would they be being robbed of the opportunity and challenge to create, to discover, even to have an authentic research experience at all? These questions bear further examination, with implications across teacher professional development programs. The contrasts in by-group design parameters and effects raise a host of questions about the relationships among teacher differences, expectations, perceptions, learning and transfer, questions with implications for ongoing research in teacher professional development experiences.

In this study we see three parts of teacher professional development. The first is knowledge and skills, the intangible tools, cognitive and psychomotor, to do the research tasks. The teachers were given these in the on-site experience. The second is equipment, the physical resources and tangible tools with which to do the work. These were provided through the funding proposals. The third is empowerment—in self-perceptions, motivations, and drive necessary to carry out the plans, provided through initial and ongoing support and communication.

Members of two separate but related communities of practice were joined in one shared discourse community. Their different perceptions, understandings, and vocabulary were critical to the success of their learning, development and transfer. A subtext of the teachers' learning was the integration of the two communities in one discourse, not only one group teaching the other, but a blending and integration of their ways of knowing. Teacher-learners, expert in K-12 science education, learned from university mentors, expert in engineering. Engineer-mentors learned about K-12 science education and the demands of effective teacher development. The result was a change in the practice of both groups of teachers, in K-12 education, in undergraduate engineering (reported by the mentors), and in the adaptive revision of the professional development program itself. The dynamic interaction framed on design-based research supported examination of internal processes that underlie success in authentic educational experiences for teachers. These findings can richly inform research and teacher professional development, open doors for inquiry, and illuminate strategic design.

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