Perspectives on Deepening Teachers' Science Content Knowledge: The Case of the Life Sciences for a Global Community Teacher Institute

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Abstract:
The Life Sciences for a Global Community (LSGC) Teacher Institute is a collaboration among Washington University in St. Louis, Missouri Botanical Gardens, the Donald Danforth Plant Science Center, and St. Louis Public Schools to establish an advanced degree program and leadership training for teams of high school biology teachers. The three-year degree program includes a total of nine week-long summer courses focused on disciplinary content. Academic year coursework focused on pedagogical strategies for incorporating new content into teachers' classrooms. As an example, the Evolutionary Ecology summer course addressed major ecological theories through investigations that focused on a research question, data collection and analysis related to the question, and interpretation of the analytic results. The Program Capstone 1 course was taught by science educators as a distance-learning course during the academic year; participating teachers engaged in action research around their implementation of curricular pieces they developed based on content and pedagogical strategies they encountered at the Institute.

The Life Sciences for a Global Community Teacher Institute was based on a belief that an effective partnership between biologists in a research institution and high school life science teachers could impact not only the next generation of scientists, but also the workforce and citizens of the future. A citizenry that can make educated decisions about personal, public and global issues must be scientifically literate and able to draw conclusions from a set of facts as scientists do. They must be able to see the implications of emerging technologies or global disasters beyond the immediate concerns of local economies. The last opportunity to teach large numbers of the general public scientific reasoning and the critical importance of life sciences at a personal, local, national, and global level is high school.

The Institute design team was aware of the low rate at which students complete upper level courses in biology and that the curriculum of even the best teachers is often constrained by the available instructional materials, which often reduce the essentials of science to an endless list of facts. Therefore, the participants targeted by the Institute would be teachers of beginning courses as well as advanced.

The Institute vision was enacted with the combined resources of Washington University's biological research labs, the Missouri Botanical Gardens and the Danforth Plant Sciences research programs, as well as partnerships with Washington University's Science Outreach program and K-12 district liaisons. The tight connections between research institutions and science education institutions formed the foundation of the working Institute. The partners were committed to assisting teachers to both improve their students' biological content knowledge, and to sustain improvement in teaching practice at their schools and districts. The focus of project leaders was on a rigorous interdisciplinary approach, combining content knowledge and the broad implications for human impact. The stated goals of the project were:

1. Develop a national cadre of master teachers of high school biology who demonstrate intellectual engagement with, and mastery of, global issues in life science, and who use related research-based pedagogy and challenging content in their courses.

2. Improve interest, engagement and achievement of students in secondary biology.

3. Promote Institute partners' and participants' development as local and national educational leaders.

The Institute is comprised of two major parts, a MS in Biology and a post-degree leadership institute. The focus of this report is on the design of the professional development comprising the degree program. Seventy teachers, grades 9-12, from 32 school districts in 21 states were selected from a national pool of applicants, and an additional 30 teachers were drawn from local high needs schools, for participation in this program. Criteria for selection included certified teachers with at least three years teaching experience, some leadership experience and/or leadership potential. Teachers were selected as part of district teams and assigned to one of three cohorts. Cohort I began in summer 2007 and graduated with a master's degree in spring 2009. Cohort II began in summer 2008 and will graduate spring 2010. Cohort III, the final cohort, began in summer 2009 and will graduate in 2011. The typical teacher spent more that 500 hours, including time interacting with the scientists and educators over the course of the LSGC Institute.

The LSGC Institute was designed to incorporate findings from science education research (Borko, 2004). For example, effective professional development programs for science teachers often involved sustained inquiry over time (Supovitz & Turner, 2000; Banilower, Boyd, Pasley, & Weiss, 2005), strengthen science content and contextualize the activities around the needs of the teachers in their classrooms (Garet et al., 2001; Cohen & Hill 2001), and provide opportunities for teachers to engage in scientific research processes (Silverstein et al., 2009). These findings from research were triangulated by practitioner knowledge of teachers and science educators/professional development specialists (Loucks-Horsley, et al., 2003; Macias et al., 2009). The program implementation was guided by a mastery learning philosophy, with structures in place to assist all teacher participants in the attainment of the degree program's content expectations. There were structures that facilitated 1) research scientists' ability to discern and deliver content relevant to the high school curriculum, 2) teachers' ability to transfer new knowledge in relevant ways to their students, and 3) teachers' ability to assess the impact of changes they made to their own practice.

The Institute design team was made up of scientists, science educators, teacher educators and teachers. The scientists were responsible for selecting the content, sequencing main concepts for effective instruction and selecting the lab activities that illustrated current research and methodologies important to advancing their field of study. The science educators and teacher educators were responsible for designing program elements that would result in transfer to the classroom. The teacher participants were responsible for ensuring that the transfer to their classrooms was done in ways that supported their curricular goals and impacted their students.

One of the most engaging aspects of this Institute is the participation of research scientists in the role of primary instructors of secondary biology teachers. Communicating the importance of their research to the general public was a top motivator for our research scientists to step out of their comfort zone and expend the energy to design and teach the one-week courses. The process of curriculum development was collaborative and led to multiple ways that high school biology teachers, of varying backgrounds, could access the advanced knowledge of a research laboratory. During the academic year prior to the course, the research scientists met with the project P.I., a research scientist skilled in communicating science to the public, and the project's leading science educators. Conversations were about the nature of the audience, the importance of connecting with their prior knowledge, and ways to design lab and field experiences that could provide the teachers with resources they could transfer back to their classrooms and use with their students. This strategy resulted in some courses in which the scientists and their doctoral students conducted both presentations and inquiry experiences, and more commonly, courses in which lab/inquiry experiences were designed and taught by both doctoral students and science educators.

The summer coursework could be best described as focused on disciplinary content with pedagogy in the background, while the academic year coursework focus was on pedagogical approaches and teaching strategies to implement new content into teachers' classrooms. This shift in the positioning of content relative to pedagogy was a design element based on the assumption that both are important but better taught where each can be applied. Therefore, as defined by the LSGC, 1) relevant content for teaching high school biology is knowledge established by scientific research and knowledge of the scientific research process, and 2) relevant pedagogy provides vehicles for translating content into knowledge aligned with the high school biology curriculum and the capacity of their students.

During the first summer of the program, teachers attended three courses, "Plants and People", "Evolutionary Ecology", and "Biological Evolution". These were followed by three distance learning courses during the academic year, "Chemistry for Biology Teachers", "Application of Case Studies to Teaching Biology", and "Program Capstone I", in which teachers applied content from the courses to their classroom instruction. During the second summer, teachers attended "Neuroscience and Behavior", "The Molecular Basis of Heredity", and "Matter and Energy Transformations". These were followed by academic year courses, "Laboratory Investigations with Model Organisms", "Applications of Biology to World Health Issues", and "Program Capstone II", in which teachers extended learning from the Institute by establishing professional learning communities in their districts and states.

Biological Content Courses: Evolutionary Ecology

To describe the Institute and illustrate the lessons learned we have chosen two courses, the *Evolutionary Ecology* course, taught during the first summer that teachers are in residence and the *Program Capstone I* course, taught during the first academic year using a distance-learning format. The summer course was taught by two professors of ecology, one a community ecologist and the Director of the Tyson Ecological Field Station and another a population ecologist who researches the impact and control of invasive plant species on natural populations. The course was taught at the field station, a 2000-acre, mixed forest ecosystem located approximately 25 miles from Washington University. Both ecologists were interested in dispelling myths they believe are held by the general public and their undergraduates, about how research is conducted in ecology. As they described it, conducting field research in ecology is not a nature walk, rather an application of scientific methods in the most challenging of settings. Their course reflects this underlying desire to show teachers how existing ecological theories are tested and new knowledge is acquired in the field.

The course instructors chose to highlight four major concepts: Individual Behavioral Ecology, Population Ecology, Community Ecology, and Research in Ecology (Appendix I, Ecology Concept Map-2009). They supported the direct instruction of major ecological theories with field experiences, each of which involved focused observations on a research question, data collection, statistical analysis, and interpretation. For example, day one consisted of a pollination study designed to instruct teachers in both the principles of behavioral ecology and the research methods used to derive those principles. Teachers observed pollinators visiting two different kinds of flowers, in several different locations, counting the numbers and types of insects visiting specified flowers in the stand. In the field station, the data were summarized and a t-test was run to see if there were significant differences in the types and abundances of insects visiting two different types of flowers.

On day two, teachers conducted a study to see if there were differences in herbivore activity between two species of plants, one native and one introduced and considered to be invasive. The percent area of the parts of leaves missing due to herbivory were compared between different plant species and t-tests were used to determine if differences were significant. The results showed that herbivores were much more likely to feed on native rather than introduced species of plants. Accompanying this investigation was a lecture demonstrating the use of population life cycles and elasticity matrices as tools to track dynamic processes in populations and guide the management of invasive species.

Days three and four were devoted to community ecology. Teachers sampled and counted the animals and plants in two ponds separated by a road. One pond is shaded more than the other. The results of data collection and a comparison between the two ponds resulted in findings that could be interpreted using trophic cascade hypotheses which have persistent explanatory power in community ecology research and inform food chain/web lessons in K-12 instruction. As one teacher stated, “Trophic cascades are something I teach frequently in general biology. It was interesting to actually be able to see the real life effects of top down control. There was an overwhelming difference between the diversity in the pond without fish and a lack of diversity in the pond with fish.” This study was followed by a comparison of plant diversity in the understory of two different parts of a forested area, one on a hilltop and the other on a hillside. Results were interpreted with the construction of species-area curves and explained within the framework of island biogeography equilibrium theory. The last investigation on the 4th day was a study of the effect of distance from the forest edge on tick populations. To illustrate methods to study the spread of tick borne disease, tick collection devices (coolers with dry ice on the inside and double edged tape on the outside) were set up in grassy areas near the forest edge and in areas interior to forest. Traps were collected, ticks counted, t-tests run on the data, and interpretations asserted. All field experiences were placed in the context of current ecological theories with observations and data collection derived from research hypotheses.

The various investigations in the field and in labs did not always lead to clear interpretations of data; rather, similar to the work of a practicing field ecologist, the week included some that demonstrated clear decisions about results and others that did not. Scientists, who led the investigations in ecology, periodically discussed the science process teachers were experiencing. In addition, science educators lead end-of-day discussions with teachers about applications of what they were learning to their instruction.

These experiences culminated with a project on the last day of the week which was reserved for teachers to work in groups with field researchers, post-docs, doctoral students, and others who were working on projects at Tyson. Together they designed, conducted, analyzed, interpreted, and presented their data from their own research. The day was intense, the time too short, but the outcome, an experience most teachers appreciated.

Transfer to the Classroom: Program Capstone I

Research on teacher professional development has been more successful documenting changes in teacher learning than in documenting the connections between teacher learning, teacher practice, and student learning. Through the design and instruction of the distance learning courses, the project team assisted teachers in moving past barriers encountered when adapting the learning from summer courses to academic year classrooms.

For example, the ecology course is taught as one of three that teachers take while in residence during the first summer of the program. During this time, the teachers are given an assignment to design a curricular piece that might be incorporated into their teaching during the following academic year. This piece can reflect content or investigatory strategies that they encountered as part of the Institute coursework, or other pedagogical strategies inspired by the Institute, focused on any of the three content areas. This flexibility allowed all teachers to choose and design curricular projects that fit with their district mandated curriculum. The implementation of the design was supported by a distance-learning course, Program Capstone I, taught by science educators, requiring that teachers articulate some way they are taking new knowledge and skills from the Institute to their classrooms and conduct action research on the effectiveness of their implementation.[1]

Fundamental to the design of this course assignment is the adult learning principle of choice. The types of content and teaching strategies chosen by the teachers are ones they deem important to the advancement of some aspect of their own curriculum and instruction. Additionally, teacher choices provide feedback to the Institute about which aspects are most likely to transfer.

To illustrate this process of the transition from teacher as learner to teacher as practitioner, we highlight the action research projects of three teachers on a team from a school district in northern Illinois who chose to add the use of elasticity matrices from the ecology course to their unit on biodiversity and global threats encountered by invasive species. Two of the teachers had classrooms with students who could understand the algebraic algorithms used in the matrices and one did not. These differences in student ability resulted in different teaching strategies, in two cases students would develop the matrices, while in the case where student algebra backgrounds were limiting, the teacher would develop matrices and demonstrate their use. In all three cases,

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[1] Action research (Appendix II) provides a methodology for teachers to identify new teaching strategies, illustrate the impact they intend for the strategies to have on student learning, connect impact to specific qualitative and quantitative data sources, collect and analyze the data, and assess their teaching of the concepts in light of the findings. The methodology allows teachers to change strategies once revealed as ineffective while they are teaching and to treat entire classes without denying some (a control group) the opportunity for optimal learning.

the learning goal was to deepen student understanding that the management of invasive species, garlic mustard in this instance, was dependent on population characteristics of various parts of the life cycle. The elasticity matrices were developed prior to the traditional annual field trip during which they pulled garlic mustard from a nearby field, but without understanding of the impact this might have on eradicating the invasive plant.

The following lesson, as it was taught and studied, is presented as a high level implementation of the Institute content through one teacher's approach to a unit. The students in this class had adequate background in algebra and biology to support the level of instruction. These steps were abstracted from the teacher's report, with the parts that the Institute appeared to influence, in italics:

1. The unit was introduced with a biodiversity discussion connected to a prior unit on evolution. The major conceptual theme was the impact that overexploitation has on genetic diversity of a population and consequently the biodiversity of an ecosystem.

2. Students watched video, "Planet in Peril", followed by a reading on invasive species.

3. The "threats to biodiversity" lesson was followed by direct instruction on mechanisms that increase biodiversity, and in the words of the teacher, "*from this point I incorporated the Island Biogeography activity from our Ecology and Environmental Science summer course, to show students the rate of organism colonization to an island and the effect that the area of the island has on biodiversity.*

4. Students took a quiz on biodiversity.

5. The "populations and life cycles" powerpoint was presented. *This year due to our summer course, I integrated the exponential growth model formula which allowed the introduction of another new piece of the curriculum, life cycle graphs and population matrices.* I modeled this with the life cycle graph for humans.

6. I gave students a practice life cycle graph so they could check their understanding.

7. *I had the students use the life cycle graph and matrix for garlic mustard to track each life stage of the population over time. Once they noticed that the population was growing exponentially, I had them brainstorm ideas of how to eradicate garlic mustard from Fullersburg woods.*

8. *Students used their life cycle graphs and matrices to hypothesize the best ways to eradicate, followed by my population graphs of the effects of only managing the rosette life stage versus the adult life stage. From this students realized that they should only focus on eradicating the adults during the field trip to Fullersburg woods.*

9. Students watched a video about identification and eradication of garlic mustard followed by a field trip to Fullersburg woods to pull garlic mustard and take vegetative surveys of previous years' efforts.

The teacher's analysis of data from this action research project was based on two quizzes, field notes/journal notes of teacher, analysis of video taken during two of the matrix classes, and a student attitude/opinion survey.

The teacher's assessment of the new components to the curriculum can be summarized in the following excerpts:

1. The "Planet in Peril" video gets students highly engaged in the effects of human impact on the planet.

2. Student average on quizzes was 83%, demonstrating a proficient understanding of biodiversity.

3. *Although I felt that many students would not understand the exponential growth model, most of them seemed to grasp how to complete these types of problems after going over one in class (video analysis). After my explanation of the example problem I received a couple of questions regarding the growth rate percentage, which showed me that the students were thinking about the material and trying to understand it (journal). This understanding of the exponential growth model was further validated through the students averaging an 80% on the "Population Ecology and Matrix Quiz".*

4. Many students related to the life cycle graph for humans, sparking their interest (video analysis).

5. Many questions about life cycles were generated by a worksheet on life cycle graphs relating to plants (video analysis).

6. Students seemed to grasp the garlic mustard life cycle graph (video analysis).

7. *In response to my question, "which life cycle stage should we target to eradicate garlic mustard?" students had a variety of responses but seemed to understand the importance of life cycles to answering this question (journal notes; video analysis).*

8. Student understanding of how to apply life cycles to management required the use of the mathematical matrices. To my surprise, many had been exposed to matrices in middle school math class, so implementing the matrices was quite easy (journal; quiz).

9. When applying life cycle graphs to the garlic mustard, students brainstormed possible eradication methods and rationale, discussing the implications of eradicating only the rosettes, or only the adults. *In comparison with previous years, in which we introduced the field trip with "garlic mustard is an invasive species" I hoped that giving students a way to make decisions about the management approach would increase their ownership. It seems that I was successful in this, compared to previous years students were much more enthusiastic about wanting to get rid of the garlic mustard.*

10. *In the opinion survey, students connected the life cycle-matrix lesson with the effective management of garlic mustard; additionally they stated that they liked 'seeing everything they learned'.*

This implementation exemplar shows that tracking the impact of the Institute on teaching behavior in classrooms is more complex than surveying which activities teachers used from summer courses and/or analyzing student gain scores on pre-post tests. Teams from at least four additional schools taught and researched the use of statistical analyses of plant populations and/or the use of growth stage matrices, to teach a better way of making decisions about controlling invasive species. Analysis of reports of these projects allows us to gather more detail about how teachers were using their Institute knowledge and how they had to modify it before teaching it to their students.

Teachers did not transfer aspects of the institute equally. Some abstracted or modified activities from the labs and field experiences in order to construct a more inquiry-based curriculum for their students. For example, one teacher used measures of herbivory from the Institute ecology course to design environmental impact lessons for her students. Another teacher reproduced the plant diversity/community ecology lesson, but without the theoretical frame of island biogeography. Although the level of content integration varied, by the end of the action research project, all teachers were using evidence to analyze the effectiveness of their teaching and to make decisions about improving the lessons.

Measuring Impact

Content knowledge gains are an important outcome of the summer residential program, and the LSGC has implemented an extensive assessment program for Institute participants (teachers). Two assessments were developed that were keyed to the content delivered during each summer institute (Summer I and Summer II). In year 1, each teacher took the Summer I pre-test and post-test. In year 2, teachers took the Summer II pre-test and post-test. In addition, they also took the Summer I post-test as a measure of knowledge retention. This strategy has been repeated for each teacher cohort. This staggered approach allowed us to use later teacher cohorts as a comparison group for earlier cohorts.

The items for each assessment were selected, written and compiled by a team consisting of the project director, the lead scientist for each content area, and a statistician/educational psychologist. Each year the teacher assessments were subjected to validity/reliability testing with standard psychometric software. The first year assessment contained more items than subsequent years so the most effective items could be retained. Initial modifications to the tests were made with the advice of the external evaluation team after item analysis.

During years 2-3, the test items were submitted to psychometric testing each year, with minor changes in item wording and distracters. As advised by the project’s external evaluator, all changes were recorded on an item blueprint to inform decisions during analysis or interpretation of results. Each subsequent year resulted in fewer changes in items, while no changes were made to 30% of the items on each test so that longitudinal analyses and interpretations could be made with identical questions from year 1 to year 5. This process resulted in content tests that were flexible enough to assess learning as teaching goals change from year to year; and stable enough to be used in a longitudinal analysis.

Results from the quantitative analyses indicate that teachers gained significantly in content after the summer courses.

Lessons Learned

The lessons learned thus far from the Life Sciences for a Global Community Institute relates the design, instruction, and research aspects of the initiative. The strength of each of the Institute's components is visible in most of the research and evaluation reports. Not so visible, yet we believed essential to its success, was the attention that the Institute's leadership paid to the links among the components. It is through these connections that the usual barriers between institutions and roles within institutions were circumvented. Embedded in each of the following "lessons learned" is a solution to a problem and a person or persons who were willing to trust that changing a norm, expectation, or rule, might result in a stronger program. Among those who played important connector roles were the P.I., a prominent evolutionary plant biologist (who had the respect of the senior research biologists); a co-P.I. and assistant dean and director of science outreach (who had the respect of the university administration), science educators and K-12 teachers and administrators; and the program director, a science teacher educator (who had the respect of the teachers, curriculum designers, and professional development providers). All of these individuals, and others, assisted teachers and scientists in understanding their complementary roles in the larger goal of a biologically literate citizenry.

Design Element: Bridging university and K-12 cultures
The decision to have a program for teachers from across the country raised a number of concerns from the biology department and graduate school curriculum committees. Their concerns presented the design team with an essential challenge, how to organize content courses rigorous enough to satisfy requirements for a masters degree into a schedule that would work for practicing high school teachers. The required number of contact hours for two graduate credits could be achieved in a week-long course, but the committee thought that it would take a longer time period for teachers to synthesize new knowledge. Therefore, it was decided that the master's degree content courses, one per week, could be delivered through a 3-week residential program over two consecutive summers **if** the distance-learning program conducted during the two subsequent academic years included a capstone course that extended content learning from the summer into the academic year. The decision to confine the residential program to three weeks, full days, was based on information about local teachers' summer schedules and the amount of time out-of-town teachers were willing to be away from their families.

Engaging full time teachers in a graduate program that requires time and attention during the academic year can be difficult, especially when teachers are participating from a distance. The high rate at which teachers completed the degree program was facilitated by the university's willingness to allow the Institute to lengthen the end-of-semester deadlines to include K-12 school breaks. The fall semester was extended from the second week in December until the first week in January and the spring semester extended from the first week in May until the second week in June. This scheduling created record-keeping challenges for the graduate school but allowed teachers time to attend to graduate coursework when school was not in session.

Design Element: Establishing a multi-faceted instructional team
Having prominent research scientists and their lab personnel design and implement the week-long courses engaged the teachers in content more deeply and broadly than any of us predicted. All of the teachers were willing to think hard about biology beyond what they were likely to use in their teaching. Some teachers were reconnected with their love of biology; others were surprised and excited to have time to interact with scientists whose work they knew and respected; nearly all felt treated as if they were intellectually capable and performed important work in their role as teachers.

In addition to the scientists' willingness to respond to feedback and questions from teachers about information in their courses, the science educators' ability to focus on the prior knowledge of the teachers and provide ways to scaffold their learning of new knowledge was critical to the success of the Institute. Some scientists' views of teacher knowledge and the enterprise of teaching are often quite different from the teachers' experience. The process of translating advanced scientific knowledge and current scientific research to a general audience is challenging enough, but translating it to a non-research audience whose particular goal is to translate it to their high school students is even more challenging. On the one hand, teachers understand the biology more easily than the general population; on the other hand, they must be able to take it apart and put it together again, using their curricular and instructional tools. The mental process that teachers engage in while learning graduate level biology is difficult and often the complexity is invisible to the scientist-instructors. Having science educators involved in the design and instruction of the courses, along with scientists, was highly beneficial.

Design Element: Teacher learning
Teachers were recruited into the Institute in school or district-based teams. This plan was meant to increase the support for teachers when they return to their districts to disseminate new knowledge and teaching skills throughout the district and state. However, it resulted in cohorts comprised of teachers highly diverse in their backgrounds in both content and teaching experience. For example, in the ecology course, overall, the teachers responded positively to the rigor of the fieldwork. However, the first time the course was taught, teachers with less experience with data management and statistics found that component impenetrable. Providing teachers with prior instruction in data manipulation the Sunday evening before the course began solved this problem for subsequent cohorts. The lesson learned by the instructional team was, before compromising a challenging curriculum, implement more instructional supports. The teachers were more than willing to give up their Sunday evening in order to feel more confident and competent during the week.

The focus of the ecology course on teaching all content through the entire scientific research process satisfied the professors' goal of showing the rigor of ecological research. Additionally, it provided teachers, some for the first time, with an experience of scientific research. This process also dispelled the myth that it takes weeks or months to model scientific research.

Design Element: Ensure transfer to the classroom
In our experience, and evidenced by some professional development research, expert instruction and intelligent, highly motivated teachers are not enough to ensure the integration of new knowledge and pedagogies from professional development into classrooms. Over the years, the educators in Science Outreach have addressed this challenge by searching for scientists who

excel in direct instruction, teaming scientists with master teachers, designing teaching teams made up of a scientist and science educator, assigning teachers lab activities to try out in their classrooms, and including extensive discussion time for teachers to process with each other ways they might integrate new knowledge into the classroom. Each of these resulted in more effective teacher learning and some enhancement of teacher practice, but changes to teachers' instructional approaches and the depth of biological knowledge available to their students were not well-documented. To address this problem the Institute made teachers' change in practice central to the successful completion of on-line, academic year courses.

In addition to the *Program Capstone I* course, each academic year course required teachers to try out new approaches to teaching in their classroom whether they were chemistry activities for biology classrooms, laboratory investigations with model organisms, or uses of biology case studies to teach content. Connecting the distance learning to the transfer of new knowledge to the classroom was the primary way the Institute supported the transfer of research knowledge to the classroom. The key factor contributing to successful transfer was the inclusion of one or more assignments in every course that required teachers to reflect on, collect data, and analyze the success of the new unit, citing supporting evidence. This model worked better than predicted and sustained the engagement of teachers in the Institute while their attention was called to their primary role as teachers.

The decision to allow the teachers to determine the content and method of transfer, rather than prescribe a uniform pre-designed curriculum for all teachers to implement, was highly effective and perhaps the only way that a uniform professional development experience could be relevant to a wide array of state, district, and school situations. This design component resulted in more highly relevant courses able to hold the attention of a widely dispersed national audience.

Additionally, preliminary research data show that teachers who integrate programmatic components into an existing, well-structured curricular unit, are having a greater impact on student learning than teachers who are only weakly utilizing Institute resources. If this interpretation is accurate, then professional development to assist teachers in the integration of new learning into their teaching might be as essential as deepening content.

Design Element: Balancing research and content instruction

The tension between the project leadership's focus on implementation for learning and the restrictions of the research design provided a persistent challenge. The first lesson learned was to be very open, honest, and transparent with teachers about the content tests, how test items were derived and how they would be used. Due to the research need to develop and validate the items before the Institute began, the test items did not always align to the Institute content. In addition to being transparent about this misalignment, we implemented additional test items so the teachers could demonstrate what they learned. These questions were used for purposes of assigning grades, not research. Additionally, subsets of "good" questions were taken from the research tests and used for grades. It was also awkward to give a test and not be able to report scores by item, as would be expected if modeling the use of assessments in providing formative feedback to learners. This pattern was only moderately remedied by providing a score by concept within a subject area, rather than by item. So, for ecology, teachers were told how many correct items there were in the area of population ecology, community ecology, and research design.

Correlating changes in teacher learning to changes in student learning is difficult. It was important to have both qualitative and quantitative measures of teacher content knowledge, transfer to classroom, and student learning. In addition to adding validity to the research design, this plan served to enlist the confidence in teachers that their performance was being assessed through multiple indicators, something rarely experienced in their district evaluations.

Design Element: Planning for sustainability of instructional changes in teachers' classrooms

Three sustainability strategies were included as a design element of the LSGC Project; recruiting the teachers by teams, using the distance learning courses to encourage teachers to embed and study the integration of new knowledge into their curriculum, and developing networks to broaden support for future teacher initiatives. These strategies were intended to provide the conditions needed to have the innovations sustained in a school.

We believed that giving teachers the power to choose the aspects of the content institute they thought would have an impact on their instruction, and the means with which to assess the impact using qualitative methods, increased the probability that the change would be sustained in their teaching and biology curriculum. The teachers featured in this report provide an illustration of this. The results of their integration of elasticity matrices into their curriculum on invasive species was a way to improve their management of garlic mustard and extend the lesson to another prominent invasive plant. Additionally, a non-Institute veteran teacher in the department became interested in using the elasticity matrix and integrated it into his classroom biology instruction. In the Capstone I story highlighted in this paper, the invasive species matrix and management of garlic mustard were extended to teachers beyond the Institute and applied to another invasive species.

Design Element: Sustainability of the Master's Degree program

Work with the biology department and with the graduate school to sustain the new MS degree program for teachers is currently in progress. Initially, more scientists would need to be recruited to teach during the summer. The project, as implemented presented a burden on scientists' schedules during a time (summer) when they are most busy with research and international travel. Therefore, additional faculty need to be recruited and the course offerings expanded so that any one scientist's teaching rotation would be every few years. Currently, the lead scientists served at the request of the P.I., and Biology Department Chair, and received no monetary or in-kind compensation for their efforts. The sustainability model would have to include compensation for service rendered in either the form of summer pay or release time from other course instruction. Both of these possibilities are under consideration by the P.I. and other senior faculty and administrators.

The important first step has been accomplished. The major stakeholders, the university graduate school leadership within the biology department, and teachers and administrators at local school districts are interested in sustaining the masters degree program. After reflecting on evaluation and research reports from the first 3.5 years of the Institute, the sustainability committee has decided to focus the degree on both a national and local audience of teachers, using the hybrid, in person/distance learning, model with the essential design elements discussed above as central to the continuation of the program.

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