Perspectives on Deepening Teachers' Science Content Knowledge: The Case of the North Cascades and Olympic Science Partnership

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Abstract
The North Cascades and Olympic Science Partnership (NCOSP) project served teacher leaders of grades 3-10 and disciplinary science faculty. NCOSP created and conducted a sequential series of three 80-hour residential Summer Academies. A central feature of the academies is the use of content immersions to help participants develop a more scientifically-accurate understanding of relevant big ideas in science. For example, the Life Sciences Academy included a focus on the function of food for animals, and the Earth Science Academy contained several chapters about plate tectonics. In addition to deepening teacher understanding of fundamental scientific content ideas, NCOSP devoted substantial time to pedagogical knowledge goals based on the application of principles from *How People Learn* (National Research Council, 1999) to science education. Facilitators modeled instructional strategies as they addressed scientific content goals, and some Academy assignments directly addressed the pedagogical knowledge goals. For example, participants revised selected lessons using resource materials that provided information about scientific content, instructional strategies, and common student misconceptions. Attention to scientific content, learning theory, and instructional strategies was cyclic, and work on instructional strategies incorporated scientific knowledge acquisition. The roles of evidence and questioning as scientific ways of building knowledge were modeled through the professional development activities.

Introduction

Central to the work of the North Cascades and Olympic Science Partnership is the belief that to make science accessible to all learners, K–12 teachers need a strong understanding of the subject matter, an appreciation for how students learn, and a repertoire of appropriate instructional strategies to engage students' prior ideas and build more accurate understanding of science. NCOSP created a sequential series of three 80-hour residential Summer Academies to improve content knowledge and reinforce conceptual, constructivist science teaching strategies among participating teachers. Each Academy included an approximately 40-hour Content Immersion experience that explored a small number of scientific topics to achieve a deep level of conceptual understanding. The topics in the immersion were based on national science standards and benchmarks; they were relevant to content that teachers teach, but they were not the actual topics taught, nor were they tied directly to existing instructional materials. The content of the immersion was at a level beyond what students were expected to know and beyond what most teachers knew prior to the experiences.

In addition to engaging the K–12 teachers with subject-specific content, the Summer Academy sessions introduced "*How People Learn*" (NRC, 1999) as a unifying framework for learning and modeled this framework in the context of the immersions. Focused discussions of pedagogical strategies consistent with that framework were conducted periodically, sometimes supplemented with video recordings of naïve student conceptions of the content under consideration. Additional experiences incorporated into the Summer Academies provided support for implementing the instructional approaches modeled and discussed in the Academy in the context of the K–12 classroom. These experiences tied to learning theory and content-specific pedagogy combined to fill approximately 25-30 hours of each two-week program. Coupled with the immersions, these sessions focused on developing the knowledge and skills important for effective instruction, while also addressing values and beliefs about teaching and learning that create the will to change. (The remaining 10–15 hours of the Academy focused on leadership development which is outside the scope of this discussion.)

From 2004–2006, approximately 150 teachers from 27 different school districts, and 25 disciplinary science faculty from five institutions of higher education, participated in the three–year NCOSP Summer Academy sequence. In 2008, a new cohort of nearly 200 teachers from the same partner districts began a modified Summer Academy sequence, including all of the previously described components except leadership development. Evaluation data were collected over five years to assess changes in participating teachers' content knowledge, pedagogical content knowledge, and instructional practice, and in their students' learning.

Making the Case for Instructional Change

Facilitating changes in instructional practices is not just about developing teacher knowledge and skills, but also includes addressing fundamental beliefs about teachers and teaching, and learners and learning. Moreover, the NCOSP program fully embraces the notion of partnership and therefore working to ensure that all members have a shared understanding of effective instruction was important to long-term, collaborative work. So, the first NCOSP Summer Academy began by asking both faculty and teachers to question the effectiveness of current science teaching practices. These initial experiences were designed to reveal the limitations of commonly-used teaching practices and to suggest alternatives based on research on learning.

A typical session to "Make the Case" for instructional change opens with all participants - teachers across all grade levels and participating higher education faculty seated together in table groups in a large room. They are asked to think about a well-documented scientific process: "Where does the mass of a tree come from"? After allowing time for individual reflection, table groups are asked to discuss their thoughts to surface the ideas present. Drawing upon the expertise in the room and using carefully constructed prompts, table groups are patiently guided to an accurate, though simplified, portrayal of the process by which plants use carbon dioxide from the air along with sunlight and water to create the carbon-based molecules that form the mass of the tree. Then a video clip of Harvard and MIT graduates ("Private Universe/Minds of our Own") responding to the same question is played for all to see and hear. The video segments demonstrate that graduates from these two highly-regarded universities are largely unable to offer a complete and correct answer. The irony of the overconfident graduates publically revealing their limited knowledge is not lost on the crowd and even generates some laughter.

A second video clip of the "star pupil" in a middle school classroom is then played. The clip includes an interview with the student before instruction and an excerpt of a hands-on lesson on photosynthesis. The final scene is a second interview with the student following two weeks of instruction. The participants gasp as they listen to this bright young boy when he details the exact same misconceptions he had prior to instruction. Despite participating in a series of seemingly "inquiry-based" lessons, he still is unable to link carbon dioxide in the air to the carbon-based molecules in the tree. His original ideas about photosynthesis were essentially unchanged; he has not learned the important scientific ideas intended by the unit.

The combination of these two clips quickly demonstrates that neither the middle school student nor the Harvard/MIT graduates have a conceptual understanding of the process of photosynthesis. Additional data are shared from other studies done across the country to show that photosynthesis is not the only topic students are struggling to understand – the problem is widespread across many topics. What could account for this lack of understanding? The opening videos and complementary research studies make the case that the current education system is failing to help students develop an accurate understanding of fundamental scientific concepts.

The dissonance raised by these opening experiences creates a window of opportunity to suggest an alternative to current approaches that may lead to improvements in student learning. Here, participants are introduced to the book "*How People Learn*" (NRC, 1999) and are invited to read and discuss the three key findings:

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.
2. To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.
3. A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

Participants read the relevant pages of the book, discussing sections of the text in pairs, then table groups. A subsequent debriefing brings the whole group together to ensure that all emerge with a shared, albeit preliminary, understanding of the reading. Additional data from selected research studies are then presented to support the claim that when the recommendations outlined in "*How People Learn*" are put into practice, students do in fact learn.

The focus of discussion then shifts to the "Science Classroom Observation Guide" created by NCOSP (See Appendix A). The guide articulates observable behaviors and actions on the part of teachers or students in a classroom setting that are consistent with the recommendations in "*How People Learn.*" The guide is organized around four elements of effective instruction and includes representative indicators for each of those elements. The "Science Classroom Observation Guide" paints a concrete picture of the How People Learn theory of learning in action.

As these opening activities come to a close, facilitators prepare teachers to transition to the Content Immersion in which they will learn science through curriculum and instruction that reflects these key findings. Over time, the findings from "*How People Learn*" and the "Science Classroom Observation Guide," go on to become the foundation for all of the Summer Academies, and the overarching framework for considering effective instruction. As the Academy unfolds, participants will have the opportunity to consider the significance of that instructional framework in supporting their own learning of science and what is required of them to enact those research findings in their own classroom practice.

Modeling "*How People Learn*" through Content Immersion Experiences

Having teachers experience science learning through immersion in content is central to the NCOSP program. A Content Immersion guides participating teachers through a purposefully structured sequence of writing prompts, experiments, data analyses, and discussions to help them develop a more scientifically-accurate understanding of relevant big ideas in science. By working through curriculum designed with a well-constructed learning cycle, participating teachers develop their understanding of science content with increasing sophistication over time. Facilitators continuously conduct formative assessments embedded in both written and oral exercises to monitor content understanding. New ideas are introduced as teachers demonstrate the prerequisite knowledge needed to proceed.

Previously published inquiry-based Physical Science materials were used as the curriculum for the Content Immersion in the first summer (Goldberg, et al, 2008). Life Science and Earth Science curricula developed by NCOSP faculty based on the same pedagogical model were used for the immersions offered in the second and third years. Together, these immersion curricula provided teachers with authentic learning experiences in the scientific disciplines commonly included in the K–12 curriculum. Because each immersion focused in-depth on a few topic areas in the selected discipline, the set of sessions does not provide content preparation in all the topics teachers teach. But, when coupled with the other components of the Academy (See below) the immersions help teachers come to recognize the importance of content knowledge for teaching, to identify limitations in their existing content knowledge, and to understand how to develop their knowledge in other topics.

With that description in mind, let's take a "look" at the immersion experiences as they unfold over the course of an NCOSP Summer Academy. An observer in the Content Immersion would see a room of roughly 30 teachers seated together in groups of three or four. The teachers span the K–12 grades, come from a range of school districts, and use a variety of different instructional materials in their classrooms. The facilitators typically include 1-2 higher education disciplinary science faculty and a K–12 teacher on special assignment (TOSA) who is on leave from the classroom for one year to work with NCOSP project leadership on professional development activities. At least one faculty member is an expert in the discipline; and at least one has prior experience and training in the intended pedagogy. The TOSA brings content experience as well, but also brings a strong sense of the culture and climate of K–12 schools and of working with children as learners. This facilitation team works together to support the learning needs of each participant each day, and to learn from the facilitation styles and strengths of others in improving their practice.

The opening session of a Content Immersion begins with introductions and the development of norms for working and learning together. The norms ensure that (1) all participants are clear on their respective roles in the immersion; and (2) a learning environment is established that is consistent with NCOSP norms and beliefs for collaboration as well as the specific needs of the participating teachers. These norms are posted and serve as touchstones for reflection and assessment throughout the immersion. Facilitators invite the teachers to actively monitor their own actions and behaviors – as well as those of others in the group – to ensure that everyone adheres to the norms. Revisions and additions to the norms are also welcome based on needs that emerge from the group over time. In this way, the facilitators establish the list of norms as a relevant and living document and encourage the group to take ownership of these ideas in order to create the best possible learning environment for themselves and their colleagues.

With introductions complete and norms established, a short pre-assessment is typically administered. The idea of giving a "test" at the start of a session may seem problematic, but with thoughtful facilitation it can be used as a first step towards establishing a culture that values evidence to justify claims. Facilitators prepare participants for taking the assessment by disclosing the reason for it and how the findings will be used. In NCOSP, a partnership-wide norm is that "everyone is a learner," including the faculty and TOSAs who are serving as facilitators. The assessment data provide a means for them to learn more about their facilitation skills and the NCOSP immersion instructional materials by generating data about what the teachers learn. These results are used to inform revisions to the materials and to identify professional development needs for facilitators. Disclosing these purposes encourages participants to take the assessments seriously and to continue to share their observations and reflections about the immersion experience for program improvement purposes.

Now the real work of learning science begins. At this point the teachers are invited to open the NCOSP immersion instructional materials. At the start of each chapter, the facilitators outline the specific learning targets that will be developed. For example, the first chapter in the Earth Science Content Immersion instructional materials focuses on the distinction between observation and inference as a way to consider how scientists can come to "know something" even if they can't see it, feel it, or hear it. The next chapter considers how scientists take measurements and make observations to understand Earth systems and processes whether at an atomic or global scale. These opening ideas are important for many subsequent activities that help participants develop their understanding of both the nature of science and specific Earth science concepts.

The Life Science Content Immersion instructional materials also unpack fundamental scientific concepts in the opening chapters that pave the way for exploring and understanding the concepts that follow. Chapter two, for example looks at the function of food for animals. This seemingly simple idea includes understanding the basic composition of food; the chemical nature of carbohydrates, proteins, and fats; and the processes by which organisms use these chemicals to grow and produce energy. Through each activity, individual learning targets are developed to build up to the larger ideas related to how animals use food for both growth and energy.

With the learning targets for a given chapter or series of activities defined, it is time to elicit the prior ideas of the participating teachers. The Content Immersion proceeds with a writing exercise where individual teachers record their initial ideas related to the chapter focus. For example, the initial ideas prompt from Chapter Two of the Life Science immersion related to the function of food, begins with a prompt to first explore ideas related to the composition of food: "Do you think that all food is basically composed of the same 'stuff' or is it composed of all kinds of different materials?" The prompt goes further by following up with a second question, "If you think that food is made of the same stuff, what do you think that 'stuff' is? If you think that food is made up of different types of materials, what general kinds of materials do you think food is made of?"

The Earth Science immersion offers a similar approach. Mid-way into the immersion instructional materials the curriculum establishes that the Earth's surface is composed of "plates" and that these plates can and do move. Later chapters work to establish how energy transfers are involved in those plate movements. As these ideas related to energy are introduced, teachers are prompted to write down their initial ideas, e.g., "What ideas do you have about energy inside the Earth?" and "How might this energy contribute to plate motion?"

Following these individual writing exercises, teachers discuss and share their initial ideas with their table partners. A summary of the ideas from the table discussion is then recorded on a small whiteboard to share with the whole group. The discussion of initial ideas is facilitated by the faculty and TOSA to surface the way teachers are thinking about the topic, not to build consensus or establish a "right" answer. Surfacing these ideas publically gives all participants access to the ideas present within the room to add to their own thinking. It initiates the process of having them question their own ideas and the basis for them. These opening discussions are also a critical formative assessment for the facilitation team to take note of the participants' prior knowledge. The insights gained here are used to inform instruction in the activities that follow, and to ensure that the evidence generated in the subsequent experiences can be used to support the correct ideas and refute the incorrect ideas discussed in the opening elicitation.

Once the initial ideas have been surfaced, the Content Immersion moves ahead with a series of activities to allow teachers to systematically collect and analyze data related to those ideas. Each experiment included in the content immersion instructional materials targets one or more common preconceptions that may prevent learners from developing a full and accurate understanding of the intended learning target. To return to the earlier example in the Life Science Content Immersion, the second chapter is working toward understanding how organisms use food for both growth and energy. Research has shown that many learners do not recognize that the molecules that make up food for animals are the same as those that make up the organisms themselves. Learners think of food as an "energy source," but do not realize that molecules in food are also broken down, rearranged and used to form the cells, tissues, and organs of the living organism.

The Content Immersion then must provide opportunities for the participants to collect or examine data that directly challenge this incomplete understanding of the relationship between food and growth. A series of activities enables teachers to look carefully at the molecular composition of food and to compare it to the molecular composition of the human body and other organisms. These experiences are followed by a simulation that depicts what happens to the molecules in food when they enter the mouth of an organism and proceed through the digestive system. Each activity provides another discrete piece of evidence to support a scientifically-accurate understanding of how food is used to support growth.

The results from these experiments, simulations, and other activities serve as evidence to support group discussions. Whiteboard discussions of results are strategically facilitated to ensure that participants confront their previously-held ideas in light of new evidence. The facilitation team guides participants toward scientifically-accepted responses through careful examination of their data. This cycle of data analysis and discussion continues with each activity purposefully addressing yet another commonly held idea or supporting previously accurate but unsupported claims. The facilitators ask teachers for explanations for their claims, prodding them to use their data as supporting evidence. Facilitators initially model questioning that challenges ideas or assertions that group members make, particularly when not supported by evidence. Over time, teachers themselves begin to question one another during white board sessions.

This process of using evidence to support conclusions, using discussion to raise questions and challenge ideas, and changing ideas based on new evidence establishes a scientific culture within the Academy. Over time, this process itself is brought to the foreground and made explicit for teachers to discuss. In this way, participants are helped to develop both an understanding of the scientific concepts intended in the curriculum and an appreciation for the scientific process that allowed those ideas to form. Linking scientific content, process, and communication in this manner provides a more authentic depiction of the often misrepresented "scientific method."

Activities and analyses for each topic continue until the teachers amass enough evidence to draw sound conclusions and develop a scientifically-accurate understanding of the intended learning target. The findings generated by the series of activities within a chapter of the content immersion instructional materials is then synthesized with a closing discussion to ensure that all participants are able to link their experiences with the intended learning targets. Readings from "Scientists' Ideas" follow these discussions to introduce terminology for the findings revealed through the activities in the curriculum and provide additional data that are not possible or practical to collect in the confines of the Academy curriculum itself. These discussions provide teachers a chance to make sense of their own data sets and conclusions in light of the larger body of scientific knowledge. This process of comparing emerging ideas with prevailing ones is used to model yet another aspect of scientific culture.

The conclusion of a chapter is marked by one more important discussion. The activities and data analyses are important for teachers to develop their understanding of the science content. But the Content Immersion takes this one step further to make sure teachers have a chance to reflect on the design of the learning experiences within the Academy curriculum and to identify how those experiences supported their learning. Both the findings from "*How People Learn*" and the indicators in the Science Classroom Observation Guide introduced earlier in the Academy are revisited to focus these reflections. Facilitators invite teachers to examine a specific segment of the immersion curriculum selected to illustrate a particular element of effective instruction as described in the Science Classroom Observation Guide. Teachers are asked to look back on that segment and see how the materials, or the actions of the facilitators or the learners, provide evidence of that element of effective instruction.

For example, one element of the observation guide articulates how "instruction fosters and monitors emerging student understanding." A reflection prompt related to this aspect of instruction is used to drive discussion.

Consider the strategies your Content Immersion facilitators have used this week:

- Questioning, but not "telling"
- White-boarding
- Checking in with groups
- Whole class discussions
- Redirecting when groups are going astray from intended learning target

Select one strategy from the list, and discuss how that strategy fostered and monitored your understanding.

This prompt encourages teachers to identify specific examples within the Academy curriculum where these instructional practices supported their learning. From here, the conversation turns to exploring how to incorporate that facet of instruction into their own classroom practice given the teaching materials they use. The teachers continue with a discussion of modifications they might make in their instructional practice to help ensure that instruction is "fostering and monitoring student understanding". The intent of these discussions is to help teachers recognize the selected facet of effective instruction and its potential impact on learners. This process also allows participating teachers to become more familiar with the "Science Classroom Observation Guide" to help ensure that they are able to use it effectively outside the confines of the Academy.

As a set, these experiences are intended to help teachers confront their personal beliefs and assumptions about effective instruction and consider an alternative, research-based approach. The Content Immersion provides them with an authentic experience as learners engaged in a curriculum that applies that same research-based instructional model. Reflections on their experiences in light of that model enable teachers to develop a deeper understanding of the intended science content, how the Academy instructional materials and facilitation supported their learning, and of potential ways to modify the implementation of their own instructional materials to improve their effectiveness.

Putting Knowledge into Practice

The Content Immersions are supported with time and structure for teachers to prepare to connect their new content and pedagogical content knowledge to their classroom practice. Given the time, resources, and expertise needed to develop and test effective science instructional materials, NCOSP does not ask teachers to create new lessons. Rather, teachers are encouraged to think deeply about how to incorporate the recommendations from "*How People Learn*" into their instructional practice by developing a plan for how to make small but significant modifications to the way they implement their existing classroom instructional materials.

The process by which the Academy engages teachers in examining their classroom instructional materials requires a variety of resources. Time is the first resource. The Academy provides designated time for teachers to examine their instructional materials and create a plan to implement new practices, rather than assuming they will do this "on their own" when they return to the classroom.

Human resources are also critical. In the context of the Academy, teachers access colleagues both within and beyond their district, as well as higher education disciplinary science faculty with expertise in each of the content areas. For the planning sessions, teachers are grouped with others teaching the same topic, perhaps using the same instructional materials, with faculty pre-assigned to these groups based on their content expertise. These pairings are done to forge collaborations where they are likely to be most successful and lasting.

Material resources provide another connection to additional expertise. Planning sessions provide teachers with purposeful and practical strategies for using a range of research-based resources that can be used to support both short and long term improvement efforts. The integration of these resources underscores the NCOSP message that research can be used to inform and support practice; it is intended to equip teachers with the ability to use these resources independently to address questions that arise in their practice outside the confines of the Academy.

The Curriculum Topic Study process (CTS) serves as the primary means for teachers to examine their classroom instructional materials. The book "*Science Curriculum Topic Study*" (Keeley, 2005) provides an index that links 147 science topics to research-based resources to help teachers learn to use their instructional materials effectively. For each science topic, there is a "study guide" that directs the user to selected readings specific to that topic in one of several resource books. Each of the readings in the set addresses one of the following purposes: (1) identify adult content knowledge; (2) consider instructional implications; (3) identify concepts and specific ideas; (4) examine research on student learning; or (5) Examine coherency and articulation. The individual readings can be used independently, or all can be used collectively, depending upon the needs of the teachers.

Initial CTS sessions introduce teachers to the idea of topic study and the CTS resource books referenced in the study guides. As their experiences in the Content Immersions accumulate, the teachers soon come to recognize how the CTS process can assist them in applying the recommendations from "*How People Learn*" to their classroom instructional materials and classroom practice. Teachers begin the CTS process by identifying a small section of a unit they will teach when they return to the classroom in the Fall and clarifying the scientific content of that portion of the unit. The collaboration among teachers, and the presence of supporting faculty, helps teachers with weak content backgrounds identify the core content ideas amid the myriad of activities described in typical instructional materials. The CTS study guides then provide the teachers access to resources related to their identified science topic. During the planning sessions, a group of elementary teachers who teach the FOSS "Variables" unit might be seen using the "Controlling Variables" CTS guide. A group of middle school teachers seated at the next table might be using the "Heat and Temperature" and "States of Matter" CTS guides as they prepare to teach an early chapter from "Interactions in Physical Science".

With the teachers now working in small groups based on common topics/instructional materials/grade bands, they engage in readings from the CTS guides. The first step is to clarify their understanding of the science content in the selected unit. The CTS study guide directs them to readings in "*Science for All Americans*" (AAAS, 1989) or "*Science Matters*" (Hazen, 1991) as an initial avenue to develop their adult content knowledge. Fellow teachers and partner faculty are also on hand to extend discussions on issues these readings might surface. With their own content knowledge strengthened, the teachers turn to other readings recommended by the CTS guides to help them consider instructional issues. These readings describe grade level appropriate learning targets as defined by state and national standards (AAAS, 1993; NRC, 1989); common student preconceptions revealed by research (e.g., Driver, 1994); articulation among related ideas at previous and future grade levels (AAAS, 2001); and content-specific instructional considerations. Teachers collaboratively study the information in these resources and record their findings to create a CTS summary as a reference document. Examples of CTS Summary Documents are provided in Appendix B (for grade five) and C (for grade ten).

Armed with their CTS summary, teachers now have a rich repository of resources to draw upon to inform modifications to their instruction that can greatly improve the learning outcomes for students. The teachers are now directed back to the Science Classroom Observation Guide, which serves as a framework to describe core elements of effective science instruction. Individual teachers are then invited to select two or three elements that they wish to target in their efforts to improve their practice. Using the guide to define their goals helps provide focus and keeps their goals both doable and measureable. Rather than a broad goal like "increase the use of inquiry in my classroom," which would be difficult to measure, the CTS planning sessions target the implementation of a specific element of instructional effectiveness for a particular lesson within a particular unit.

As an example, NCOSP elementary school teachers preparing to teach "FOSS Variables" looked at "Science content is accurate and worthwhile" as the first element in the Science Classroom Observation Guide to focus their goals. They chose to further focus on one indicator related to this element, "Science content is explicit and apparent to the students." With the goal of making content apparent and explicit to students, they looked carefully at opportunities within the FOSS "Variables" unit where it could be appropriately addressed. Drawing upon their experiences in the Content Immersion sessions, the teachers began to brainstorm instructional strategies they could use to support their efforts. In this way, the teachers have identified a very clear target for improvement and defined specific instances within their curriculum to address that target. Using this same approach, the group selected two other specific areas of improvement based on the elements and indicators described in the Science Classroom Observation Guide.

Note that the teachers are not asked to write a new lesson or unit, but rather to think carefully and intentionally about how to use their existing classroom instructional materials in ways that support effective instruction as described by the key findings in "*How People Learn.*" In this way, the theoretical research findings are made relevant and meaningful as teachers translate them to their everyday classroom actions and decisions. Using the framework from the Science Classroom Observation Guide further helps ensure that the initial goals set by the teachers are manageable, and that teachers can successfully focus their efforts on a discrete aspect of instruction that they can improve. It helps them communicate their goals clearly and effectively to others to seek support or to share success. And, it helps them define evidence that they can look for to know if their change led to improvements. Over time, teachers see that the changes they are making in their practice are resulting in observable and measureable changes in their students' learning. We have found that this evidence of impact on students drives real change in teachers' beliefs about teaching and learning, and we believe those changes will ultimately drive long term, sustainable instructional improvement.

Evidence of Impact

A comprehensive, long term evaluation plan was incorporated into the NCOSP program to gather data on the impact on teacher knowledge. Multiple-choice assessments were used as objective measures of teacher content knowledge. Surveys, interviews, and observations provided multiple measures of teacher pedagogical content knowledge and values and beliefs about teaching and learning.[1] Teacher content knowledge was assessed using instruments associated with the immersion curricula. Teachers who attended the series of Summer Academy experiences showed significant increases from pretest to posttest, as well as retention as measured by delayed post-tests one year later (See Table 1). Teachers also reported increases in their understanding of inquiry-based teaching and of their own learning process. In open-ended responses teacher commented that the inquiry-based approach in the curricula helped them develop a deep understanding of the science concepts in the curricula since they had to re-examine their thinking in light of data they had generated. In surveys, nearly all teachers reported having a clear or very clear understanding of the science content, of their own learning processes, and of how students learn science.

Course/Schools	**Pre-test mean %correct**	**Post-test mean %correct (effect size)**	**1-year delayed-post %correct (effect size)**	**Number of teachers** w/matched pre/post
Physics (2004)	36%	84%* (.79)	55%** (.29)	116
Biology (2005)	67%	84%* (.54)	78%** (.36)	144
Geology (2006)	65%	85%* (.56)	83%** (.41)	133

* Denotes statistically significant increase from pre-test to post-test at $p < 0.05$
** Denotes statistically significant increase from pre-test to one-year follow-up at $p <0.05$

Lessons Learned

A look across the five-year NCOSP program offers insights that we believe are both important and generalizable to others engaged in providing content-focused professional development experiences for teachers.

Maintain science content as a priority
Many teachers have limited preparation in the science disciplines they teach. Even those with relatively strong content backgrounds have had few opportunities to learn science in a context that models research-based pedagogy. The very act of learning, and learning deeply, is an all too uncommon experience for most. The Content Immersions are of critical importance to help teachers develop the content background they need to understand science themselves, to diagnose student thinking, and to facilitate student learning. Experiencing the discomfort of not understanding something, followed by systematically working through the difficult task of learning, gives teachers powerful insight into what learning looks and feels like, and greater empathy for their students' daily experience. Learning science content in a setting that models

[1] The evaluation included assessments of changes in instructional practice based on classroom observations, and changes in student outcomes on the state science assessments were used as a measure of instructional effectiveness.

effective instruction gives teachers a vision of what is not only possible, but necessary, to develop student learning. Further, learning science content in a collaborative context with both K–12 and higher education peers opens the doors for ongoing relationships that can help teachers continue to build knowledge and expertise over time.

Evaluation data collected in the initial days of a Content Immersion revealed quite a bit of "dissatisfaction" among participating teachers, with some noting that the experience was "too hard," and others demanding experiences that were "relevant to K–12 teaching." In the face of comments such as these, it is easy as a facilitator to feel you have gone astray and are not meeting the needs of the participants. However, within a couple of days of the beginning of a Content Immersion, teacher views take a dramatic turn. As they come to recognize the shortcomings in their prior content understanding coupled with an appreciation for their ability to overcome those shortcomings, teachers express a profound appreciation for the immersion and its "relevance" to teaching. Indeed, by the conclusion of the Academy, teachers view the immersion experiences as the most valuable aspect of the Academy, describing them as "transformational". In studies conducted annually, teachers consistently listed the immersion experience as having the most profound impact on their practice. Program leaders need to pay careful attention to formative data to distinguish participant "dissatisfaction" from the short term frustration inherent to the challenge of learning something new. The message here is to remember to stay grounded in the science content. Resist the temptation to explore too many concepts or tools, regardless of how good or important they are. Remaining firmly rooted in the idea that "less is more" will reap far greater benefits for teachers. Expect teachers to be intellectual partners, actively engaged in thinking to learn. Be patient and trust the process.

Ground actions in theory

All too often in professional development, teachers are presented the strategy du jour. A silver bullet is introduced each year as the ticket to improved student learning. The basis for this new strategy is rarely revealed and sufficient time for teachers to learn, practice, and reflect on that strategy is almost never provided. Often, professional development provides little more than a mechanical set of procedures or scripts that provide oversimplified, solutions that teachers are expected to follow regardless of their context or expertise. Teachers will continue to dismiss these well-intended scripts until their fundamental values and beliefs about teaching and learning are surfaced and challenged in the context of a rich learning environment that engages them in thinking deeply about their profession.

"*How People Learn*" was introduced to NCOSP teachers in the first year, and was the focus of their work for five consecutive years. Over the course of those five years teachers learned science content from the Physical, Earth and Life Sciences. They learned instructional strategies for eliciting knowledge, developing a conceptual framework, and making sense of new ideas. They learned collaborative strategies for working and learning together. The strategies and content changed, but the basic theory in which those strategies were grounded remained unchanged.

Teachers also had time to consider the applications of what they were learning to their own teaching, and to practice these new strategies in their classroom. Afterwards they were provided opportunities to reflect on their efforts and set new targets for learning and improving. Evaluation data collected longitudinally over the five years of the project show teachers reporting a high level of confidence in aspects of pedagogy related to "*How People Learn*" at the conclusion of each Summer Academy. At the start of the next summer, when asked to respond to those same questions, there was always a decline from their responses the previous year. In their attempt to put their knowledge into practice, it seems confidence in their knowledge waned. By the close of the summer, their responses peaked again, higher than the previous year. The next summer, when they were surveyed yet again, the numbers showed a similar, but smaller drop in the preassessment, but an even larger gain by the close of the program. Teachers also expressed their appreciation for staying the course and allowing them the time to fully develop their understanding before moving on to something new.

The importance of having multiple experiences to learn complex ideas, followed by time to practice and reflect, should not be underestimated. This consistency came to be a defining aspect of teachers' experiences and helped shaped their expectations for NCOSP programs. Choosing to focus on this core set of ideas came at the expense of introducing other ideas, so there are indeed trade-offs to this practice of consistency. However, in NCOSP, learning a few ideas well is valued above short exposures to many ideas.

Think to learn

Professional development for many elementary and secondary science teachers is often limited to an introduction to the student instructional materials, typically walking them through the activities that comprise a unit. These introductory experiences do not challenge their basic beliefs about teaching and learning, nor do they equip teachers with the content knowledge to fully appreciate the learning targets the activities are intended to address. And, they do not help the teachers develop a larger picture of how to recognize the strengths and limitations of the instructional materials themselves to support them in the decisions they make in real-time every day in the classroom.

The Summer Academy experiences provided by NCOSP fall far short of providing teachers all the content and pedagogical content knowledge needed to be effective in every science topic addressed, every day, for every child. However, the experiences do develop the teachers' ability to understand a widely accepted theory of learning; to recognize observable behaviors and actions consistent with that theory; and to begin to modify their instructional practice to incorporate those behaviors and actions given the student materials available to them. The program expects and requires teachers to think deeply to learn, rather than being given a template or script to follow. With their newly-developed knowledge and appreciation for their ability to learn, teachers leave equipped to recognize limitations in their knowledge and avenues to pursue to overcome them. They also leave with a deeper sense of professionalism rooted in their enhanced appreciation for research and commitment to a scholarly approach to the teaching profession. In the end, NCOSP teachers abandon a quest for the "silver bullet" or "quick fix" and embrace the perseverance needed to change their classroom practice in ways that will slowly but systematically improve the educational experience of their students.

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