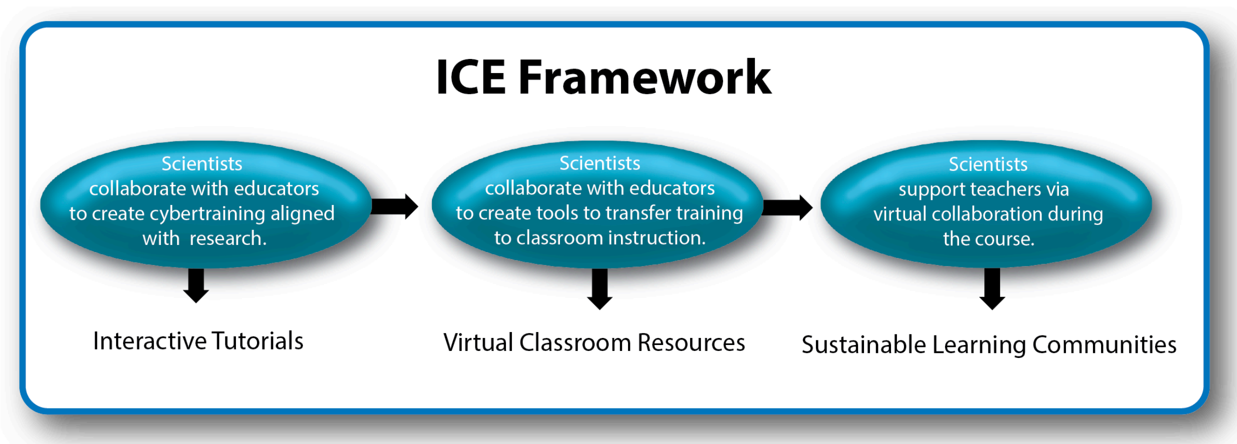
Investigations in Cyber-enabled Education Project Findings

The goal of the Investigations in Cyber-enabled Education (ICE) project was to clarify the constructs of a framework for online professional development and virtual scientist-teacher collaboration that enhances educator ability to provide science, technology, and math (STM) instruction in a way that is sustainable, affordable, replicable, and broadly accessible to teachers in all parts of the United States, including rural and disadvantaged areas far from research centers. The ICE research question was: *Under what circumstances can cyber-enabled collaboration between STM scientists and educators enhance teacher ability to provide STM secondary education?*

This report describes the ICE project and findings. Summative research was conducted using experimental methods that involved random assignment of teachers to two different treatments. The ICE project clarified the constructs of the framework and resulted in:

- Instruments that can be used to measure climate change knowledge and efficacy.
- Interactive web-based technology tutorials, multimedia activities and online lectures that can be used to educate students and teachers about snow and climate.
- A software program for automatically tracking and responding to posts within multiple simultaneously active discussion forums.
- A prototype online course (on snow and climate) that improved teacher STM content knowledge, skills and teaching self-efficacy.

Figure 1: ICE Framework

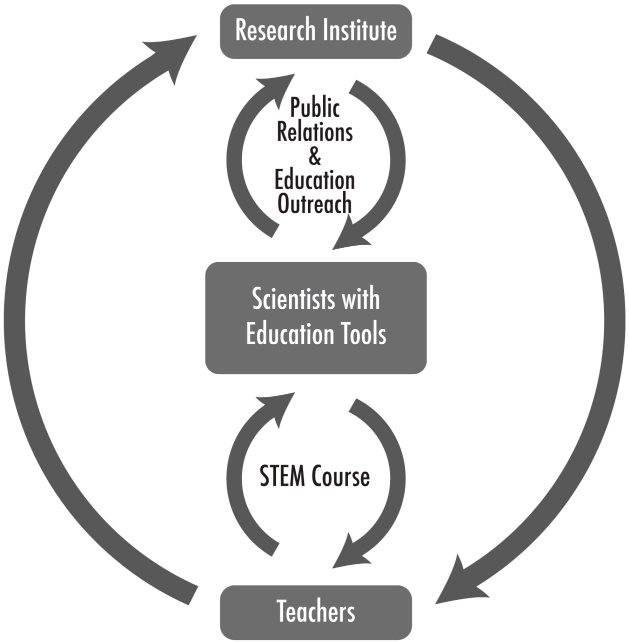


The ICE framework involved STM scientists in a continuum of K-12 teacher professional development in three areas (see Figure 1: Proposed ICE Framework):

1. Scientists helped education specialists develop materials for an online course;
2. Scientists helped education specialists create tools to facilitate transfer of cyber-training to classroom instruction;
3. Scientists communicated with teachers within an online Sustainable Learning Community (SLC) that was active during the course.

The ICE framework is part of a reciprocal model connecting research institutes with teachers, providing scientists with educational outreach opportunities and teachers with cutting edge STM resources, information and training (see Figure 2: ICE Reciprocal Model).

Figure 2: ICE Reciprocal Model



Objectives and Methods

The ICE exploratory project includes three objectives designed to help clarify the constructs of the ICE framework for professional development. The objectives include gathering empirical evidence to determine if, how, why and to what extent the ICE framework results in courses that: (1) enhance teacher ability to provide STM secondary education; (2) support scientist-educator collaboration; and (3) are sustainable, affordable, replicable, and broadly accessible to teachers in all parts of the U.S. including rural and disadvantaged areas far from research centers.

Objective 1: Gather evidence to determine if, how, why and to what extent the ICE framework results in courses that enhance teacher ability to provide STM education.

a) *Did teachers gain STM content knowledge?* This was measured by determining if teachers showed significant improvement between pre- and post-test scores on climate content knowledge assessments. The data from pre- and post-tests were corroborated with survey data indicating teacher perceptions of their content knowledge related to climate.
b) *Did teachers learn process skills used by scientists to study STM topics?* Teacher scores from web-based technology tutorials were compiled. These tutorials were performance-based and required teachers to implement STM process skills. In addition, pre- and post-surveys measured teacher perceptions of improvement in their ability to use skills used by scientists to study STM topics related to snow and global climate.
c) *Were teachers able to incorporate their STM training into their classrooms?* Teachers had to complete a classroom project that involved developing, implementing and sharing results of lessons that make use of online resources teachers learned about during the ICE course. A content analysis of selected lesson plans was conducted to determine the extent to which teachers included methods that supported higher order thinking.

Objective 2: Gather evidence to determine if, how, why and to what extent the ICE framework results in courses that support online scientist-teacher collaboration.

a) *Was an online STM learning community formed?* An tracking system was established to determine how frequently teachers and the scientist network communicated.
b) *Did the Sustainable Learning Community prompt STM information discourse?* Qualitative data regarding the depth of STM discussions was gleaned via content analysis of one group discussion for each unit to determine the extent to which discourse moved beyond the exchange of factual STM information to promote higher order thinking skills.

Objective 3: Gather evidence to determine if, how, why and to what extent the ICE framework results in courses that are sustainable, affordable, replicable, and broadly accessible to teachers in all parts of the U.S. including rural and disadvantaged areas far from research centers.

a) *Are the products and the online learning community established in the prototype sustainable?* A review of the online course delivery system, project website, and prototype course resources was conducted to answer this question.
b) *How much did it cost for teachers to participate in the ICE framework course compared to other professional development courses related to climate?* The cost of the ICE prototype course was compared to other similar online courses related to climate.
c) *What components of the ICE framework proved essential and necessary for replication?* Educator performance data and reflections of the research staff answered this question.
d) *Was the ICE prototype course broadly accessible to teachers in rural and urban Alaska and in other snowy regions of the United States?* Enrollment data and a demographic survey provide evidence for accessibility.

Summative research results indicate that both versions of the prototype course (with and without scientist communication) enhance teacher ability to provide STM education. Results also indicate that the Treatment B version of the course was successful in establishing an online learning community to support scientist-teacher communication, but that the additional component of including scientists in the online learning community did not significantly impact teacher ability to provide STM education in any of the areas measured. Further research is recommended to enhance the impact of scientist-teacher communication, if this aspect of the framework is included in future courses. The ICE external evaluator recommended that additional objectives related to student engagement and performance in STM be included and addressed in future research.

Milestones and Timeline

(1) Website and course interface created (8/2009) Website: CyberEnabledEducation.org.
(2) Prototype course developed and informed by rapid testing (8/2009-2/2010)
(3) Formative full course & diverse classroom testing (Mar-May & Aug-Dec 2010)
(4) Research instruments developed and finalized (July 2010)

Summative instruments include: (1) Moodle *automatic tracking system* for assessing online collaboration; (2) *tutorial worksheets and rubric* to assess STM skills; (3) *teacher pre-/post-test assessment and rubric* for quantifying STM knowledge before and after course; (4) *discussion forum collaboration and timeliness rubrics* to assess the extent and timeliness of online collaboration; (5) *classroom implementation project scoring rubrics* to score final projects, which involved transferring training to the classroom and sharing results; (6) a *demographic survey* to compare the environmental, educational and experiential backgrounds of participating teachers; and (7) *teacher pre-/post surveys* to reveal changes in STM teaching self-efficacy, perceptions of STM skills and content knowledge, and plans to teach climate-related STM concepts in the classroom. (8) *Content analysis* of selected group discussions and teachers' final project lesson plans was conducted to describe the communication that occurred within the SLC.

(5) *Prototype course finalized for summative research (June 2011)*
(6) *Random assignment to treatment groups (July 2011)* (two trials with 80 educators each)
(7) *Teachers participate in summative research on the prototype course (Aug–Dec 2011, Jan-May 2012)*
(8) *Summative research data analyzed (May-June 2012).*

Significant Results

The intellectual merit of ICE lies in establishing a reciprocal model involving scientists in a continuum of educator professional development that results in enhanced educator ability to teach science, technology and math (STM).

Demographic survey results indicate that treatment groups had similar qualifications, teaching assignments, geographic and gender representation (Figure 3).

Figure 3: Demographic Characteristics

Demographic Characteristics of ICE Prototype Course Participants				
	Trial 1 (Fall 2011)		*Trial 2 (Spring 2012)*	
	Treatment A (Sample = 39)	Treatment B (Sample = 40)	Treatment A (Sample = 40)	Treatment B (Sample = 40)
Gender	F=23, M=16	F=25, M=14	F=22, M=18	F=21, M=19
Currently teaching each grade level K-6	54%	60%	33%	48%
Currently teaching each grade level 7-8	51%	33%	60%	55%
Currently teaching each grade level 9-12	33%	43%	65%	58%
Trained to teach grades K-6	51%	53%	28%	45%
Trained to teach grades 7-8	72%	60%	85%	85%
Trained to teach grades 9-12	54%	55%	80%	70%
Years teaching experience (average)	14.19	13.38	10.53	11.32
Bachelor's highest degree earned	44%	38%	53%	43%
Master's highest degree earned	54%	55%	48%	55%
Specialist is highest degree earned	3%	0%	0%	3%
Doctorate is highest degree earned	0%	8%	0%	0%
10 or more college science courses	46%	63%	68%	63%
9 or fewer college science courses	41%	30%	30%	33%
Currently teaching in Alaska	95%	90%	60%	65%
Currently teaching in the contiguous U.S.	8%	10%	40%	35%
Currently teaching in an urban school	33%	45%	18%	30%
Currently teaching in a rural school	62%	50%	80%	68%
Currently teaching in a public school	100%	90%	98%	95%
Highly qualified to teach science	67%	53%	78%	68%
Average class size of 1-10 students	13%	18%	15%	10%
Average class size of 11-20 students	28%	25%	45%	33%
Average class size of 21-30 students	51%	40%	30%	48%
Average class size of 31-40 students	8%	15%	10%	8%
Average class size of > 40 students	0%	3%	0%	3%

The research design produced a study with very low power to detect differences in treatments on Pre-/Post-Assessments and both Pre-/Post-Survey subscales for both trials. Low power makes detecting a difference where none exists unlikely but increases the probability of failing to detect a difference that may exist. Post hoc power analyses were conducted and ranged from 6-41% with 10 of the analyses having power under 9%, one analysis at 15% and one analysis at 41%. Data from both trials indicate no statistically significant difference between the performances of the two groups. Although neither intervention was more effective than the other, both treatments increased teachers' knowledge and skills to teach snow and climate topics.

<u>Objective 1: Evidence of enhanced teacher ability to provide STM instruction</u>.

Educator content knowledge improved: Educators in both treatments showed statistically significant increases in STM climate knowledge between Pre- and Post-assessment scores using a paired-sample two-tailed t-test, (all p-values < 0.05). Post-scores for groups in both trials range between 89.1% and 90.4% indicating that educators ended the course with a good grasp of content knowledge (Figure 4). Primary activities were discussion questions that each group investigated and discussed: Treatment A with peers and Treatment B with peers and the scientist network. Pre-/Post-assessments included nearly 60 multiple-choice questions focused on each unit.

Figure 4: Pre-/Post-Assessment of Climate-related STM Content Knowledge

Pre-/Post Assessment of Climate-related STM Content Knowledge				
	Trial 1: Fall 2011		*Trial 2: Spring 2012*	
	Treatment A	Treatment B	Treatment A	Treatment B
Pre-test Assessment	M: 69.5% SD: 12.67% N: 33	M: 68.1% SD: 14.05% N: 32	M: 67.0% SD: 9.52% N: 35	M: 65.9% SD: 13.23% N: 36
Post-test Assessment*	M: 90.4% SD: 7.95% N: 33	M: 89.9% SD: 9.72% N: 32	M: 89.1% SD: 9.14% N: 34	M: 90.0% SD: 7.96% N: 36
**TOTAL Score calculated by combining scores from each unit post-assessment*				

Educators acquire online STM workforce skills: Educators in both treatments showed significant improvement in their perceived success and efficacy applying online STM workforce skills to teach snow and global climate as measured by a six-item Pre- and Post-survey subscale (Figure 5). A paired-sample two-tailed t-test (all p-values < 0.05) found a statistically significant difference between Pre- and Post-survey scores from both trials.

Figure 5: Pre-/Post-Survey Ratings of Online STM Workforce Skills Subscale

Pre-/Post-Survey Ratings of Online STM Workforce Skills Subscale (Mean ratings on a 9 point scale) by Treatment Group				
	Trial 1: Fall 2011		Trial 2: Spring 2012	
	Treatment A	Treatment B	Treatment A	Treatment B
Pre-survey Ratings	M: 3.96 SD: 1.544 N: 39	M: 4.16 SD: 1.550 N: 40	M: 4.53 SD: 1.372 N: 40	M: 4.12 SD: 1.452 N: 40
Post-survey Ratings	M: 7.42 SD: 0.862 N: 32	M: 7.18 SD: 1.161 N: 32	M: 7.61 SD: 0.781 N: 35	M: 7.24 SD: 1.092 N: 36

Both groups in both trials demonstrated proficiency in online STM workforce skills, as measured by average group scores between 4.39 and 4.97 on a 5-point rubric for each skill-based tutorial worksheet (Figure 6).

Figure 6: Web-based STM Workforce Skill Tutorial Scores

Web-based STM Workforce Skill Tutorial Scores (Mean scores out of 5 possible points) by Treatment Group				
	Trial 1: Fall 2011		Trial 2: Spring 2012	
	Treatment A	Treatment B	Treatment A	Treatment B
Unit 2 Tutorial	M: 4.39 SD: 0.933 N: 33	M: 4.53 SD: 0.761 N: 32	M: 4.56 SD: 0.877 N: 36	M: 4.59 SD: 0.832 N: 37
Unit 3 Tutorial A	M: 4.94 SD: 0.242 N: 33	M: 4.84 SD: 0.574 N: 32	M: 4.91 SD: 0.284 N: 35	M: 4.92 SD: 0.280 N: 36
Unit 3 Tutorial B	M: 4.85 SD: 0.566 N: 33	M: 4.86 SD: 0.554 N: 32	M: 4.89 SD: 0.404 N: 35	M: 4.81 SD: 0.577 N: 36
Unit 4 Tutorial	M: 4.88 SD: 0.415 N: 33	M: 4.69 SD: 0.535 N: 32	M: 4.83 SD: 0.568 N: 35	M: 4.69 SD: 0.624 N: 36
Unit 5 Tutorial	M: 4.73 SD: 0.876 N: 33	M: 4.72 SD: 0.581 N: 32	M: 4.77 SD: 0.490 N: 35	M: 4.69 SD: 0.524 N: 36
Unit 6 Tutorial	M: 4.94 SD: 0.242 N: 33	M: 4.97 SD: 0.177 N: 32	M: 4.91 SD: 0.373 N: 35	M: 4.92 SD: 0.280 N: 36

Training is transferable to the classroom: A 10-point scoring rubric guided assessment of final projects. During the fall trial, participants in Treatments A and B earned average scores of 8.61 and 8.94 respectively, rising to averages of 9.57 and 9.78 points respectively in the spring trial.

Qualitative content analysis of selected teacher lesson plans from the Final further explored the impact of the treatments, assigning lesson plans a code based on the following rubric: (1) no plans to implement; (2) building, refining, or implementing lessons to engage students in factual STM content; or (3) implementing lessons to promote students' higher-order thinking connecting STM content to broader studies/experiences (Figure 7).

Figure 7: Lesson Plan Content Analysis Results

Lesson Plan Content Analysis Results					
Code	Content Description	Trial 1: Fall 2011 Percent of posts in each category for selected discussion		Trial 2 Spring 2012 Percent of posts in each category for selected discussion	
		Treatment A	Treatment B	Treatment A	Treatment B
1	No plans to implement	0%	0%	0%	0%
2	Building lessons to promote acquisition of STEM factual content	27%	55%	29%	50%
3	Higher student engagement in the lesson plans to promote STEM higher order thinking	73%	45%	71%	50%

Educators report significantly enhanced STM teaching self-efficacy on a Pre- and Post-survey subscale analyzed using a paired-sample two-tailed t-test (all p-values < 0.05). These questions asked educators to rate their own efficacy and preparation to teach science in general and snow and global climate in particular. All groups reported average Pre-survey ratings between 3.95 and 4.38 and average Post-survey ratings between 5.77 and 5.95 on the subscale, where the average maximum possible rating was 7.67 (Figure 8).

Figure 8: Pre-/Post-Survey Ratings of STM Teaching Self-Efficacy Subscale

Pre-/Post-Survey Ratings of STM Teaching Self-Efficacy Subscale (Mean ratings out of a maximum possible rating of 7.67) by Treatment Group

	Trial 1: Fall 2011		Trial 2: Spring 2012	
	Treatment A	Treatment B	Treatment A	Treatment B
Pre-survey Ratings	M: 4.38 SD: 1.055 N: 39	M: 4.23 SD: 1.341 N: 40	M: 4.35 SD: 1.135 N: 40	M: 3.95 SD: 0.895 N: 40
Post-survey Ratings	M: 5.95 SD: 0.709 N: 32	M: 5.95 SD: 0.944 N: 32	M: 5.77 SD: 0.749 N: 35	M: 5.84 SD: 0.645 N: 36

In addition to viewing themselves as more effective, educators showed significant improvement between Pre- and Post-surveys on three of four questions targeting teacher intentions to use knowledge and skills gained from the course. A statistically significant difference (using a paired-samples two-tailed t-test, all p-values < 0.05) between Pre- and Post-scores exists on survey questions related to implementing lessons. The fall trial showed significant improvement on the fourth question related to the frequency with which teachers anticipate using geographic data tools such as ImageJ in the classroom (p-values < 0.05); the spring trial did not (p=0.077).

Objective 2: Evidence related to supporting scientist-educator collaboration

An online STM learning community was formed: Automatic tracking system data indicate that teachers in both treatments communicated in all discussion forums within the STM learning community (Figure 9).

Figure 9: Discussion Forum Posts

Discussion Forum Posts

Discussion Forum	Trial 1: Fall 2011						Trial 2: Spring 2012					
	Number of Discussions		Educator Posts		Scientist Network Posts		Number of Discussions		Educator Posts		Scientist Network Posts	
Treatment:	A	B	A	B	A	B	A	B	A	B	A	B
Unit 1	36	57	238	234	N/A	47	52	48	202	159	N/A	54
Unit 2	45	66	246	230	N/A	63	56	44	205	121	N/A	43
Unit 3	43	45	186	171	N/A	51	40	40	210	86	N/A	45
Unit 4	43	44	209	174	N/A	52	37	39	180	105	N/A	44
Unit 5	34	44	157	172	N/A	52	39	39	178	75	N/A	37
Unit 6	36	48	154	157	N/A	31	40	42	174	62	N/A	37
Classroom Implementation	32	37	216	207	N/A	1	36	38	243	170	N/A	4

The average number of posts per educator exceeded requirements for all units in every treatment group (Figure 10). Teachers did not request optional live chats when offered, indicating that asynchronous discussion was the accepted method of communication.

Figure 10: Average Posts Per Educator

Average Posts Per Educator					
Discussion Forum	Posts Required	Trial 1: Fall 2011 Average Number of Posts Per Educator		Trial 2 Spring 2012 Average Number of Posts Per Educator	
		Treatment A	Treatment B	Treatment A	Treatment B
Unit 1	4	7.21	6.69	6.51	6.33
Unit 2	4	7.24	6.57	6.87	5.16
Unit 3	4	5.64	5.34	7.14	4.81
Unit 4	4	6.33	5.12	6.20	4.78
Unit 5	4	4.76	5.38	6.03	4.31
Unit 6	4	4.81	5.06	6.48	4.31
Classroom Implementation	5	6.97	6.47	7.97	7.11

The Sustainable Learning Community (SLC) supported STM information discourse: Qualitative data regarding the depth of STM discussions were gleaned via content analysis of one group discussion for each unit. Teacher responses were coded based on the following rubric: (1) non-STM content, or a reposting of the assigned question; (2) STM content in response to the assigned question, and/or posting a link to additional resources; or (3) STM higher-order thinking, such as posting non-assigned questions or advancing hypotheses to connect course content to broader STM or educational issues. For both treatments the most common teacher response fell into code 2; the least common response fell into code 3. This was true for both treatment groups during both trials (Figure 11).

Figure 11: Discussion Forum Content Analysis

Discussion Forum Post Content					
Code	Content Description	Trial 1: Fall 2011 Percent of posts in each category for selected discussion		Trial 2 Spring 2012 Percent of posts in each category for selected discussion	
		Treatment A	Treatment B	Treatment A	Treatment B
1	Re-posting of assigned STEM question to the forum OR Non-STEM content	39.7%	31.5%	22.6%	30.4%
2	STEM content, such as in the descriptive answer to an assigned question or providing a resource; or content that pertains to course material	55.7%	59.5%	71.6%	65.0%
3	STEM higher-order thinking, such as posing non-assigned questions or advancing a hypothesis	4.5%	9.0%	5.7%	4.6%

Key Outcomes and Achievements

The ICE framework resulted in a course that improves teacher STM content knowledge, skills and teaching self-efficacy and this training is transferable to the classroom. The products that scientists helped to produce worked as intended. The discussion questions prompted STM discussion and guided teachers to learn STM content knowledge both with and without a scientist network. Including scientists in forums increased the number of online resources shared. However, scientist network involvement in the SLC does not appear to have impacted STM content knowledge or skills. The broader impacts of ICE lie in advancing understanding of cyber infrastructure that can provide affordable opportunities for STM professional development for educators and scientist-educator collaboration that can be sustained in any area of the U.S.

The framework resulted in prototype products and an online learning community that are sustainable. Sustainable products include 7 online interactive web-based technology tutorials, 3 databases of weather and climate data for classroom use, more than 30 multimedia activities and 8 digital lectures. All resources are designed for transfer to the K-12 classroom, with an emphasis on classrooms containing indigenous learners. All products are freely available on the ICE website at CyberEnabledEducation.org.

The SLC included asynchronous unit discussion forums, an asynchronous classroom implementation forum, an asynchronous messaging system for communicating privately with the course instructor, and optional live chats for both treatment groups. Teachers in both treatments chose to use the asynchronous venues and did not request live chats. Some reported that work schedules and after-school commitments during the school year made it difficult to participate in live chats. This problem was not encountered during formative full course testing during the summer. Therefore, it is surmised that the live chat portion of the SLC might be more successful during summer, when teacher schedules are more flexible. For Treatment A, the community was limited to teachers and the instructor. For Treatment B participants, the community also included a scientist network. Results indicate that treatments A & B were equally effective, indicating that authentic materials created with scientists may be sufficient to replace direct interactions between scientists and teachers, while minimizing interruptions to scientists' research. Further research is required to determine how this portion of the framework can be revised to maximize its benefits to teachers.

The project also developed a scientist-teacher question and answer database featuring more than 700 educator questions with scientist answers, all related to snow and climate. Though not originally intended for public use, the ICE team intends to seek additional funding to make this online resource publicly accessible and mobile-friendly.

The framework resulted in a prototype course that was affordable for participants. The prototype course was offered entirely online as a special topics professional development course for educators through the University of Alaska Fairbanks. Online courses eliminate travel expenses that rural teachers otherwise accrue when enrolling in professional development. Participants who wished to earn 3 university credits for participating in the prototype course paid $80. All participants who completed the course earned an $800 stipend for participating in the research project. Even in the absence of this stipend, the course is affordable when compared to other online climate courses for educators. For example, the American Museum of Natural History offers a climate change course for educators. It is entirely online and costs $495 to participate in the course and an additional $270 to earn credits for participation. Online climate courses offered by various universities in cooperation with the National Science Teachers Association are similarly expensive, ranging in cost from $300 to more than $900.

Prototype course results clarify essential and non-essential portions of the ICE framework for creating professional development courses that enhance teacher ability to provide STM instruction. ICE research found that scientist involvement in the creation of professional development resources for educators using the ICE framework resulted in a prototype course that was effective in increasing teachers' knowledge and skills related to snow and climate information for teaching purposes. However, equivalent performance of both treatment groups indicates that the ICE framework model for online communication between scientists and teachers did not significantly impact teacher STM content knowledge or STM skills. This indicates that this goal was not met and this portion of the framework should be revised and tested further or eliminated.

Additional factors that the research team found essential to framework success follow:

1) Select a topic of current interest to scientists and relevance to the teacher and student population served.
2) Include quantitative and qualitative data and observations from multiple perspectives in the course content.
3) Ensure that materials developed for educators are transferable to their classrooms.
4) Involve many scientists, including experienced researchers and graduate students for a range of perspectives and to reduce individual responsibility for outreach.
5) Ensure that the course instructor responds regularly to teacher posts within the discussion forums.

The prototype course was broadly accessible to teachers in rural and urban Alaska and in other snowy regions of the United States. During the Fall course 92.5% of the educators participating in Treatment A and 90.0% of the educators in Treatment B were from Alaska. During the Spring course, 60.0% of the educators in Treatment A and 65.0% of the educators in Treatment B were from Alaska. Contiguous U.S. recruitment was increased for the spring course to ensure that it was full. One hundred and three of the educators enrolled in summative research were teaching in rural areas and 50 were teaching in urban areas, indicating that the course is accessible in areas far from and near research centers.

Conclusion

Findings indicate that scientist involvement in the creation of ICE framework professional development resources for educators resulted in a prototype course that was effective for increasing teachers' STM knowledge and skills for teaching purposes. It appears that the framework may be useful for producing effective courses on other STM topics. The research clarified essential and non-essential portions of the ICE framework to aid others in replicating its success. The course materials that scientists helped to create, such as interactive web-based technology tutorials, related databases that serve as virtual classroom resources, and discussion questions to guide teacher discovery of relevant STM content knowledge are among the essential portions of the framework. An online learning community to house discussion about course topics also appears to be essential; however, equivalent performance of treatment groups with and without scientists in their online learning communities indicates that the ICE Framework model for online communication between scientists and teachers did not significantly impact teacher STM content knowledge or STM skills. The role of the scientist in developing online learning courses needs further investigation. This portion of the framework may need to be revised and tested further or eliminated. Scientist network inclusion in the online learning community made a difference in only two areas:

1) It increased the number of online resources shared within the discussion forums. This is to be expected because the ICE framework for scientist involvement in the online learning community includes sharing scientist-developed online multimedia and lectures.

2) Case study evidence indicates that it decreased the likelihood that educators would include higher-order thinking skills in the lesson plans that they developed for their students. This was not expected but may indicate that teachers who had to find and formulate answers to the discussion forum questions without the help of a scientist network (Treatment A) engaged in more complex thought during content research than did teachers who had the assistance of a scientist network (Treatment B). The teachers who conducted all of their own research were therefore more prepared to incorporate higher-level thinking in their lesson plans.

The ICE prototype course focuses on a specific geoscience topic, but the ICE framework is designed for broader application. It requires that the selected research topic be popular among scientists, relevant to students and their communities, and not commonly available in STM professional development. The popularity of the research topic helps ensure that a pool of scientists will be available to participate in the continuum of STM professional development for educators. The relevance of the topic and lack of other professional development opportunities helps ensure high teacher interest in the course and student engagement when training is transferred to the K-12 classroom.

In addition to being replicable, the framework successfully addressed key goals targeting sustainability, affordability, and broad accessibility. Sustainable prototype products developed using the framework include online interactive web-based technology tutorials, associated databases of weather and climate data and observations for classroom use, multimedia activities and digital scientist lectures. The ICE prototype course was offered entirely online at one-third to one-tenth of the cost to participants of online courses on similar topics. The ICE Framework offers an affordable, broadly accessible option for STM professional development for teachers.

ICE exploratory research findings have been presented at relevant educational conferences and published in conference proceedings and on the ICE website. Throughout the project, the ICE Framework, research methodology, and/or findings were presented and shared informally at 12 state and national conferences and meetings. These presentations and publications help to ensure that other developers of STM professional development programs are aware of and can make use of the ICE project findings.

Recommendations for further research on the ICE framework include exploring the following questions:

- How does teacher involvement in ICE framework professional development impact student mastery of STM content, skills, and inclination to pursue STM careers?
- How can the portion of the ICE framework devoted to online collaboration between scientists and educators be enhanced or revised to positively impact educator ability to provide STM instruction? The ICE exploratory project indicated that it may not be necessary to have scientists interact with teachers.
- How do scientists benefit from participating in the development of ICE framework courses?