

Evaluating the effectiveness of a laboratory-based professional development program for science educators

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Amolins MW, Ezrailson CM, Pearce DA, Elliott AJ, Vitiello PF. Evaluating the effectiveness of a laboratory-based professional development program for science educators. *Adv Physiol Educ* 39: 341–351, 2015; doi:10.1152/advan.00088.2015.—The process of developing effective science educators has been a long-standing objective of the broader education community. Numerous studies have recommended not only depth in a teacher's subject area but also a breadth of professional development grounded in constructivist principles, allowing for successful student-centered and inquiry-based instruction. Few programs, however, have addressed the integration of the scientific research laboratory into the science classroom as a viable approach to professional development. Additionally, while occasional laboratory training programs have emerged in recent years, many lack a component for translating acquired skills into reformed classroom instruction. Given the rapid development and demand for knowledgeable employees and an informed population from the biotech and medical industries in recent years, it would appear to be particularly advantageous for the physiology and broader science education communities to consider this issue. The goal of this study was to examine the effectiveness of a laboratory-based professional development program focused on the integration of reformed teaching principles into the classrooms of secondary teachers. This was measured through the program's ability to instill in its participants elevated academic success while gaining fulfillment in the classroom. The findings demonstrated a significant improvement in the use of student-centered instruction and other reformed methods by program participants as well as improved self-efficacy, confidence, and job satisfaction. Also revealed was a reluctance to refashion established classroom protocols. The combination of these outcomes allowed for construction of an experiential framework for professional development in applied science education that supports an atmosphere of reformed teaching in the classroom.

science education; professional development; reformed teaching; laboratory training

EMPHASIS on educator implementation of teaching strategies using constructivist principles in science instruction has increased dramatically in recent years (7, 13, 19, 44). Specifically, inquiry-based learning focused on student-led discussion with critical thinking methods has been shown to improve both student efficacy and performance (5, 10, 14, 39). Refinement of constructivist teaching includes methods for promoting development of logical thinking and applied cognitive, affective, and psychomotor skills by implementing student-centered, student-directed learning.

Reformed teaching is defined as an approach to inquiry-based learning that asserts teaching should be “consistent with the nature of scientific inquiry” (4). Teachers who engage in this type of instruction, reflecting “scientific ways of knowing,” aim to address learning anxiety and take the time to optimize learning, extending beyond the textbook, and tapping into relevant applications (42). Studies have found that implementation of such principles in the classroom results in high levels of academic success, including meaningful conversation, critical proposition and analysis of problems, and improved confidence in their students (39, 46). The research in this report expands on proven and effective methods to improve student engagement and performance as well as improve teacher efficacy, morale, and confidence as they pertain to reformed teaching principles in the physiology and broader life-science classrooms (17, 41). This was accomplished by partnering laboratory-based training and pedagogical intervention for seven high school science teachers to promote student-led and student-centered instructional strategies while also fostering the development of physiologically relevant applied life science classroom activities to enhance those strategies. The significance of this approach is that while examples of professional laboratory-based training opportunities that promote experiential tactics for teachers are known, the formal marriage of these concepts to effectively use the acquired skills for personal and classroom advancement and understanding is not a common practice.

Constructivism and reformed teaching. Since the earliest remarks by Jean Piaget regarding the constructivist education movement, inquiry-based learning has been identified as a hallmark of the contemporary science classroom, focusing on the student-led generation of questions sparked from personal experience and human-environmental connections, thereby enhancing student interest and facilitating the development of critical and logical thinking skills, such as the analysis and synthesis of evidence-based research, reflection, conceptualization, and application (2). The teaching of applied science not only requires knowledge of content but also the ability to facilitate student-led dialogue regarding observation, investigation, and discovery. Implementation of inquiry-based techniques that expand on traditional classroom practices, such as showing rather than telling and asking students the big questions and letting them find their way to the answers, has been found to transform the learning environment (28, 56). One goal of constructivism in the science classroom is movement from a behaviorist natured action-reward model, where students simply follow instructions and rephrase lecture notes to meet the criteria for an end-point grade, to a more student-centered,

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engaging, and highly influential learning experience in which the student is expected to develop a skillset not unlike that of a laboratory research scientist. The teacher is expected to facilitate this process through active and student-centered learning.

Reformed teaching, combined with inquiry-based learning, is one possible approach to constructivism in the science classroom. The concept of reformed teaching was introduced in 1995 by the Arizona Collaborative for Excellence in the Preparation of Teachers based on principles introduced by the American Association for the Advancement of Science in 1989: “1. Teaching should be consistent with the nature of scientific inquiry, 2. Teaching should reflect scientific values, 3. Teaching should aim to counteract learning anxieties, 4. Science teaching should extend beyond the school, and 5. Teaching should take its time” (1, 2, 42). This pedagogical concept “presupposes that teachers do not emphasize lecture, but rather stress a problem-solving and active exploration” (25, 42) via student-led interactive conversations, laboratory application, and awareness of current science principles.

The need for such highlighted teaching practices has come to the forefront in recent years, with the National Research Council’s publication of the *Framework for K-12 Science Education* in 2011 and the collective publication of the *Next Generation Science Standards* by the National Academy of Sciences/National Research Council, the American Association for the Advancement of Science, and the National Science Teachers Association in 2013 (31, 32, 33). The National Research Council (32) suggests that the three dimensions from the *K-12 Framework* (practices, crosscutting concepts, and disciplinary core ideas) set up educators using the *Next Generation Science Standards* for successful reformed and inquiry-based instruction through implementation of the following four principles:

Lessons: 1. Have broad importance across multiple sciences or engineering disciplines or are a key organizing principle of a single discipline, 2. Provide key tools for understanding or investigating more complex ideas and solving problems, 3. Relate to the interests and life experiences of students or are connected to societal or personal concerns that require scientific or technological knowledge, and 4. Are teachable and learnable over multiple grades at increasing levels of depth and sophistication. That is, the idea can be made accessible to younger students but is broad enough to sustain continued investigation over years.

Studies have found that educators implementing reformed teaching principles in the classroom reported high levels of meaningful conversation, critical proposition and analysis of problems, and improved confidence in their students resulting in documented academic success (29, 46). In the cited examples, those with the most significantly reformed instruction, as measured by the reformed teaching observation protocol (RTOP), enhanced the characteristics described above and fostered student-centered, inquiry-based discussion and improved student-teacher relationships and overall student growth. Lessons producing the least reform were typically teacher centered, preventing students from structuring the theoretical framework to ask questions, participate in meaningful communication, and ultimately relate to the content, thereby remaining unengaged in the learning process.

The need for instructional training toward reformed teaching. While some researchers fear that reformed teaching does not necessarily translate into inquiry-based instruction due to variables such as teacher and student motivation (23, 51), the studies above have demonstrated that a strong correlation does in fact exist between the two concepts (39, 42, 46). A more recent study by Mattheis and Murray (26) also reported that conceptual changes on the part of participating educators from teacher-centered to student-centered strategies supported motivational benefits. To implement such teaching strategies, it is believed that educators must first be trained on how to efficaciously develop active, student-centered lessons that prompt students to conceptualize new information through the use of inquiry and connection to prior knowledge (3). This was a key foundational component in the development of this study and training program. As a result of general observation, it has often been reported that educators will teach using techniques with which they are familiar and comfortable. These are often approaches that allow educators to learn best in their individual lives, even though it may not be best for students. They may be aware of alternative methodologies that have proven more successful for a broader range of learning styles, but, more often than not, they do not have the training or confidence to venture into such risky endeavors (3). Yet, it has been well documented in multiple studies that significant differences in student success outcomes between active learning and traditional lecture exist and heavily favor the reformed approach (15, 16, 22, 43). By using professional development and instructional coursework to create a learning community focused on reformed teaching, educators are not only encouraged to reflect on teaching practices but are also provided with the tools necessary for such change. For example, teachers actively involved in discussions centered on active learning and student-led conversation become more prepared and intrinsically motivated to implement such practices in the classroom and are sought out more often by colleagues than those known for traditional approaches (20, 21). In developing this professional development program, particular care was taken to ensure that these components were integrated into the teacher development process and that appropriate instrumentation was used to measure their success.

Laboratory-based professional development as a means of promoting high standards in science education. Over the past several decades, a number of development programs that promote active and student-centered learning on the part of teachers in the high school sciences have emerged. In the early 2000s, Schwartz, Lederman, and Crawford conducted a study in which educators served as interns in university laboratory settings. Results indicated that participants gained a philosophical appreciation for the “nature of science” and consequently implemented such philosophies in their own classrooms (55). Similar programs conducted by The University of Tennessee, the National Radio Astronomy Observatory, and the Science For Early Adolescence Teachers organization found that a “viable constructivist model for exposing teachers to science research and transferring that experience to the classroom” was accomplished (8, 29). These “apprenticeship” models in which the science educator gets to participate in a laboratory experience, side by side with an expert scientist, allow for “the novice learner to become an expert through the mechanism of acculturation into the world of the expert” (8).

From its earliest beginnings nearly 25 yr ago, the laboratory apprenticeship model of professional development has been strongly supported by the National Science Foundation (NSF) and has collectively come to be known as the Research Experiences for Teachers (RET) program (40, 41). The RET Program was originally modeled to emulate the NSF Research Experiences of Undergraduates Program, with a goal to promote interactions and professional development between science professionals in the K–12, university, private, and government sectors (37, 40, 41). Nearly all RET programs are now funded through this centralized agency, and their success has been well documented (12, 27, 54). With these programs in mind, it was possible to construct a foundation for the current program being highlighted in this study, focusing primarily on how they might be improved on to provide more pedagogical instruction for successful translation into the classroom.

Research questions. In looking at the two aforementioned aspects of science education, reformed teaching and laboratory-based professional development, it was hypothesized that a novel marriage of the two concepts would result in an optimum facilitation of both pedagogical and practical teacher preparedness for effective classroom teaching. Concepts such as active learning, inquiry, problem solving, investigating complex ideas, and providing application can all be easily attained while working in the laboratory. However, their translation into valuable lessons at a level that is consistent with the middle and high school classroom can often be challenging. On that premise, the purpose of the present study was to examine a laboratory-based professional development program and its ability to facilitate the emergence of reformed teaching principles in those classrooms. This included the participants' ability to integrate advanced laboratory training, research principles, and student-led instruction into their daily lessons and to develop novel activities for classroom implementation. This study also sought to reveal any improvements in teacher performance, job satisfaction, confidence, and self-efficacy resulting from these changes upon return to the classroom. For the purposes of this study, self-efficacy was defined as the extent to which teachers believe they can instruct in a manner that will generate a desired outcome in their students (6). As such, the following research questions were examined:

1. What impact does laboratory-based professional development, which includes advanced training in laboratory techniques, research principles, and reformed, student-centered methods, have on the adoption of reformed teaching practices and student-centered instruction by high school teachers in the science classroom?

2. To what extent does improved teacher efficacy, confidence, and overall job satisfaction result from inquiry-based and reformed teaching methods when they are taught during a laboratory-based professional development program?

MATERIALS AND METHODS

The present study used a mixed methods approach, using multiple qualitative and quantitative resources appropriate for their respective measurements. Because of the small sample size, it was found that any quantitative measurements would require significant qualitative reinforcement to generate an understanding of the overall educational impact. Given both the data-driven nature of scientific research and the humanistic nature of education as a profession, this approach was deemed to be appropriate for the study. After a year-long pilot study

and Institutional Review Board approval in 2012, data were collected over a 1-yr period, from the spring of 2013 through the fall of 2013, as part of a program titled the Science Educator Research Fellowship (SERF).

The SERF Program was created by Sanford Research (Sioux Falls, SD) in response to a national initiative meant to identify new approaches for the improvement of science, technology, engineering, and mathematics (STEM) education and the teaching of 21st century skills (50). SERF participants were engaged with pediatric health research opportunities using basic, translational, and community-based approaches as well as professional development and pedagogical training over a 10-wk summer session within a pediatric research department that housed a diverse number of research projects being conducted by both MD and PdD researchers with medical and basic science training. This method was focused on enhancing innovative learning techniques in the classroom and creating novel approaches to applied and experiential classroom activities while being grounded in the program experience and reformed student-led activity. This process was further highlighted by weekly events, round table discussions, and research and ethics seminars, all presented by scientist-mentors, as well as pedagogical training focused on reformed teaching and inquiry-based instruction, presentations led by participants, and a culminating symposium. The long-term goal of the SERF program was to provide a mechanism for stimulating student cognition and motivation by providing participating educators with a deeper understanding of content, application, discussion, technique, and ethics while improving confidence in both teaching abilities and laboratory techniques. It was felt that the activities described above would not only foster that stimulation, understanding, and confidence but would also provide unique individual experiences that would ultimately motivate participants to instill such changes in both their instructional approaches and classroom environment. An outline of the SERF program as well as a summary of data collected are shown in Fig. 1.

Participants. Data collected for this study came from two male and five female teachers ($n = 7$, age: 25–47 yr) and indirectly through ~300 students. All participants were selected by a committee of independent scientists not specifically involved in the blind handling of data for this research study and were placed in complementary laboratory settings based on an examination of individual interests, experience, and laboratory availability. The criteria used for selection included previous performance in the classroom as well as demonstrated need and scale of potential impacts. To begin this process, an e-mail and application were sent to all science educators in the state of South Dakota, inviting them to apply to be part of the 10-wk program, and participants were selected from this pool. Analysis of demographic data revealed some common factors. All participants taught in public schools within the state of South Dakota, representing an even distribution of rural ($n = 3$) and urban ($n = 4$) designations, with district populations ranging from just a few hundred to over one thousand students. These individuals displayed significant diversity in terms of professional/educational training and years of experience, including participants new to the field of education, those in the middle portion of their careers, and those nearing closer to the end of their careers. Participating educators taught multiple high school and middle school science courses, including Physical Science, Life Science, Biology, Advanced Biology, Anatomy and Physiology, Zoology, Chemistry, Advanced Placement Chemistry, and Physical Education. Although the participants were not selected randomly, it was felt that the demographic described above was representative of the teaching population in the state of South Dakota and therefore could be considered more or less representative of that population. However, it should be noted that it is unclear to what extent these personal characteristics played a role in the outcomes of this project, purely based on the limitations of such a small sample size and the associated caution of overextending the results to represent that population.

Instrumentation. To fully assess the progress of the seven subjects who participated in this study, data from three instruments were

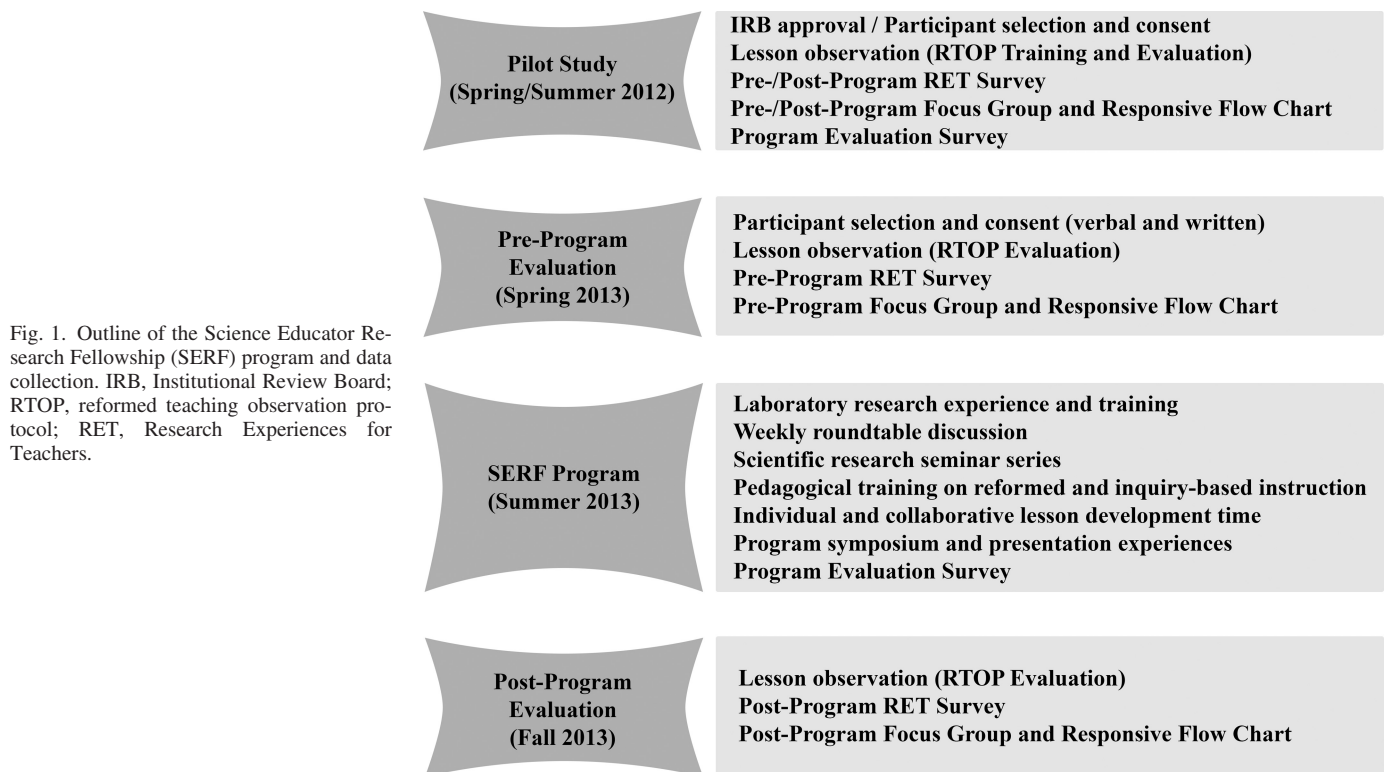


Fig. 1. Outline of the Science Educator Research Fellowship (SERF) program and data collection. IRB, Institutional Review Board; RTOP, reformed teaching observation protocol; RET, Research Experiences for Teachers.

compiled by independent evaluators, contracted by Sanford Research, and then assessed blindly by the authors of the present study. These data encompassed both qualitative and quantitative approaches. While care should be taken not to generalize too liberally from a small sample size, it is nonetheless pertinent to the evaluation of the effect of this program on the participants described in this study. As such, all data collection was assumed to be in the context of a case study in which these experimental data established correlational significance as it pertained to program participants. One data set was made up of pre- and posttreatment scores based on the well-established RTOP. A second data set was collected through pre- and postprogram RET surveys originally developed by SRI for use with the National Science Foundation RET program (34, 40, 41, 45). A supplementary section was included with this survey to collect additional qualitative data from the participants. Finally, a third data set was composed of transcripts and responsive flow charts collected during pre- and postprogram focus groups conducted exclusively for use in this study. For reference, a copy of each of these three instruments has been provided as supplementary information.¹

RTOP. The RTOP was developed by the Evaluation Facilitation Group of the Arizona Collaborative for Excellence in the Preparation of Teachers for the purpose of measuring innovative, student-centered, constructivist teaching in the science classroom (36). The goal is for the RTOP to evaluate and promote the concepts of problem solving, reasoning with proof, communication, connections, and representation, ultimately raising the standards and expectations in the science and mathematics classroom (30). The instrument itself is a 25-item assessment divided into 3 subsets: 5 items used to gauge lesson design and implementation, 10 items evaluating the content, and 10 items assessing the classroom culture. With regard to the first subset of questions, the intent is to determine how well a lesson “recognizes a student’s prior knowledge and preconceptions, engages

each student as a member of the learning community, values variety in the possible solutions to problems being addressed, and allows for student-led discussion and direction” (36). The second subset can be further divided into content quality and the ability of that content to develop inquiry among classroom participants. The third and final subset focuses on the stimulation and climate of the classroom environment itself and is also broken down into two sections: communicative interactions and student-teacher relationships (42). In terms of validity and reliability, the RTOP has been evaluated in a number of classroom settings, including mathematics, physics, chemistry, and biology. Assessments from three independent evaluators trained in proper RTOP assessment were compiled for comparison of interrater reliability and normalized using percent agreement as a standard. The results were estimated at an exceptionally high level for instruments of this nature (36).

Coursework and training using RTOP assessment as an instrument for measuring reformed teaching have served as a platform to facilitate pedagogical change in numerous applications (11, 42). For example, observer notes from an RTOP study in 2001 noted numerous characteristics as a result of professional development, including the catalysis of student-centered teaching and conversation in the classroom, self-reflective change, and improved collegial behavior (24). Explicit communication of such goals during professional training fosters success in the classroom by helping educators to understand and operationally define reformed teaching (24). Individuals successfully trained in RTOP assessment have cited its use as credible, authentic, justifiable, and believable (24). Furthermore, its use has been shown to both empower educators to self-reflect on their practice using the rubric to critique their own performance as well as continue to reconceptualize those approaches while sustaining or even catalyzing similar practices among their colleagues through improved relationships and communication (20, 24).

Pre- and postprogram RET surveys. A 26-item survey, developed by SRI for review of the NSF’s RET programs, was selected and amended to include a second section for questioning of SERF participants on their background, experience, and beliefs regarding

¹ Supplemental Material for this article is available at the *Advances in Physiology Education* website.

their teaching practices in the classroom and their participation in the SERF program (40). Because of many distinct similarities between the NSF's RET program and SERF program as well as the survey's established validity and reliability, it was determined that the questionnaire would suit this study when attempting to determine 1) the importance of professional development in the pedagogical development of the subjects, 2) how the confidence and personal beliefs of these educators will change while participating in the SERF program, and 3) how school demographics, funding, and outside training will influence the teaching practices of program participants. Responses to the RET survey were subcategorized according to their relevance in answering either *research question 1* or 2 and according to their support of either reformed or traditional pedagogical tendencies. A secondary survey created by SRI for the NSF RET program, known as a program evaluation survey, was also administered for program assessment but was not used as data for this study.

Focus groups. To gain a qualitative understanding of how participating teachers perceived their ability to confidently and efficaciously communicate scientific knowledge to their students, a series of two focus groups was constructed for implementation at the beginning and end of the program. Questions were designed to allow for open-ended responses and were used as a general flow chart for discussion. To provide a frame of reference for their responses, each participant was provided with a response sheet containing 5- and 10-point Likert scales that accompanied appropriate questions during each session. Items from the focus group protocol were intended to gauge how participants typically use their time during classroom lessons, how they perceive the satisfaction and challenges of their day-to-day jobs, the ingenuity being used during and frequency of classroom laboratory experiences, and how they perceive their ability to educate students. These responses were subcategorized according to their relevance in answering either *research question 1* or 2. In each case, their opinions about how the SERF program played a role in their successes and failures were also evaluated. Focus group sessions were video recorded, transcribed, and administered by trained employees of Sanford Research not affiliated with this study.

Analysis. Data were organized according to a paired and coded system, allowing for evaluation of each participant across multiple data sets, before and after treatment. Interrater reliability of all evaluative techniques was determined through a percentage of agreement correlation before further analysis (96% agreement). Because of the small sample size and nonrandom selection of participants, all data were assessed on the premise that any and all outcomes could not be generalized but instead provided an intimate picture that illustrated the impact and effectiveness of the SERF program on its participants.

Categorization of data subsets for analysis of *research questions 1* and 2 is shown in Fig. 2. In each paired-samples *t*-test, significance required an α -level of $P < 0.05$. All numeric data were analyzed using the Statistical Package for Social Sciences and Microsoft Excel, whereas all transcribed data were coded and evaluated by researchers involved in the study.

Research question 1 asks about the impact of pedagogical and/or specialized skills training (acquired during a laboratory-based professional development program) on the participants' willingness to adopt reformed teaching practices in the secondary science classroom. Three measures were used to analyze the correlating data. First, a one-tailed paired-samples *t*-test was used to determine if there was any growth in student-centered, inquiry-based instruction as determined by RTOP analysis, both on individual subset scores and overall scores. Similar one-tailed paired-samples *t*-tests were implemented on subset scores of Likert scale responses from the RET survey and were used to assess for specific examples of growth in specific pedagogical techniques, observations, and experiences that lend themselves to student learning. In each case, effect size was determined using Cohen's *d* as a measure of practical (educational) significance (9). Short-answer responses from both the RET survey and focus groups were coded according to similar pedagogical categories for the purpose of citing specific in-class examples.

Research question 2 addresses the extent to which the treatment improved teacher efficacy, confidence, and overall job satisfaction. One-tailed paired-samples *t*-tests were used on subset scores of Likert scale responses to the RET survey and focus group to assess positive growth in the aforementioned areas. In each case, effect size was determined using Cohen's *d* as a measure of practical (educational) significance (9). Notes taken by RTOP observers were analyzed for cited evidence in the classroom. Teacher efficacy, confidence, and overall job satisfaction were used as a categorical guide to code all written responses from each instrument to determine if individual beliefs, backgrounds, and attitudes about teaching display similar growth after treatment.

Reformed lesson plan development. As part of the SERF program, participants were expected to generate individual classroom activities grounded in reformed teaching and inquiry-based instruction. Furthermore, these activities were expected to pull from inspiration generated during their laboratory-based research experience. As a result, activities were inherently physiological and pediatric health oriented in nature. Although not included in the data analysis, these lessons served as artifacts of participant growth and development as well as program success.

Institutional review board approval. This research project was completed with the approval of Institutional Review Boards at Sanford Research (Project 03-13-003) and The University of South Dakota (Project 2013.110).

Instrument	Research Question 1		Research Question 2	
	Qualitative	Quantitative	Qualitative	Quantitative
RTOP	Observer Notes	4 Groupings: I. Overall Rating II. Lesson Design & Implementation Rating III. Content Rating IV. Classroom Culture Rating	Observer Notes	N/A
Pre-/Post-Program RET Survey	Part I items 12a-d	2 Groupings: I. Part I items 3d-e, 4a-b, 4d-j, Part II items 2a-c, 3a-b (<i>pro-reform</i>) II. Part I items 3a-c, 3f, 4c (<i>anti-reform</i>)	Part I items 8, 9	Part I items 6a-f, 7a-f Part II items 1a-c, 7a-d
Focus Group	Items 1, 3	Item 5	Items 2a, 5a, 6-8	Items 2, 4 and 7

Fig. 2. Categorization of data subsets for analysis of *research questions 1* and 2.

Table 1. *Quantitative data pertaining to analysis of research question 1: evidence of reformed teaching*

	Preprogram Score		Postprogram Score		<i>t</i>	<i>P</i> Value	Cohen's <i>d</i>
	Mean	SD	Mean	SD			
Reformed teaching observation protocol							
Overall	48.57	16.23	67.86	12.31	2.34	0.033*	0.847
Lesson design and implementation	8.71	4.82	10.86	3.53	0.78	0.234	0.293
Content	23.29	6.37	29.71	4.72	2.22	0.034*	0.837
Classroom culture	16.57	5.86	27.29	4.86	3.35	0.008*	1.266
RET survey							
Prereform responses	39.00	8.41	43.14	7.78	1.72	0.068	0.651
Antireform responses	15.00	2.16	15.14	2.54	0.35	0.368	0.134
Focus group	3.21	0.39	3.14	0.69	−0.20	0.577	−0.077

RET, Research Experiences for Teachers.

RESULTS

General outcomes for evidence of reformed teaching. The first research question examined what impact(s) laboratory-based professional development, which includes advanced training in laboratory technique, research principles, and innovative lesson plan development, had on the likelihood of reformed teaching practices and inquiry-based learning being adopted by the participants in their science classrooms. To that end, the overall and subgroup RTOP scores, RET survey subgroup scores, and mean focus group Likert scale scores of all seven participants were analyzed. The results of each quantitative analysis pertaining to the first research question are shown in Table 1. With respect to the RTOP analysis, content ($t = 2.22$, $d = 0.837$, $P = 0.034$), classroom culture ($t = 3.35$, $d = 1.266$, $P = 0.033$), and overall ($t = 2.34$, $d = 0.847$, $P = 0.033$) reformed classroom instruction showed significant improvement. This suggests that SERF participants have modified their curriculum to provide a more effective approach that allows for students to drive the instruction rather than the other way around. However, the results of the lesson design and implementation analysis ($t = 0.78$, $d = 0.293$, $P = 0.234$) suggest that while overall instruction indicated progression toward the desired instructional techniques, actual lesson design did not change significantly. This is likely the result of teachers being “creatures of habit,” and although delivery and approaches were strongly influenced, participants chose not to redevelop lesson plans that had proven worthy in previous years of instruction.

Observer notes from the RTOP evaluations supported the notion of improvement in the desired teaching practices upon completion of the program. While results varied among individual subjects, the overall results were positive toward noticeable change in student relationships and engagement in the lesson. Specifically, observer notes indicated a high level of respect and interaction in and among students and instructors, noticeable (although variable) improvement between spring and fall observations, strong topics of discussion and curriculum content, and at least some level of reflection by the students in most cases. It was noted by all observers that the level of confidence among SERF participants appeared to improve significantly upon completion of the program. Specific responses included the following:

- “While individual performances varied, there was a definite improvement in reformed teaching over the course of the study.” (*Observer 1*)

- “Some teachers appeared reluctant to change their approach to lesson plans and implementation.” (*Observer 2*)
- “The content and interaction in many of the classes appeared to be functioning at a much higher level for some teachers in the fall observations.” (*Observer 3*)

A second portion of the analysis using the RET survey results and two paired-samples *t*-tests followed by a measure of Cohen's *d* for effect size measured changes in classroom practices favoring reformed teaching principles or traditional approaches. In this case, significant changes were not reported for either reformed ($t = 1.72$, $d = 0.651$, $P = 0.068$) or traditional ($t = 0.35$, $d = 0.134$, $P = 0.368$) tendencies. However, based on the medium to large effect size of the reformed measurement and near significance, it could be suggested that early signs of posttreatment enhancement of instructional techniques were present.

While the statistical results of the RET survey indicated minimal evidence of improved use of reformed teaching practice, promise of a belief toward that transition could be found in the qualitative responses to *part I, items 12a–d*, which asked participants to describe their recent professional development activities in the context of innovative and technologically driven pedagogy. When asked about participation in professional development experiences since the SERF program, each of the seven program participants indicated active involvement in curriculum and methodology programming geared at improving student questioning, invention, and engagement in STEM areas. Thus, one could imply that these individuals share a strong desire to improve their ability to involve students in approaches consistent with constructivist beliefs regarding student participation and direction.

A quantitative analysis of focus group responses indicated no statistical significance toward improved reformed instruction ($t = -0.20$, $d = -0.077$, $P = 0.577$). However, qualitative responses to focus group questions also indicated a strong dichotomy between the desire to implement and actual implementation of those teaching practices in the classroom. While many of the subjects indicated an increased ability as teachers to integrate current, applied, and relevant topics into their daily instruction and a desire to move forward with applied activities, they felt that the reluctance to fully adopt student-driven activities fell with their students' inexperience in being able to successfully complete assignments in which they were asked to create driving questions and guide the direction of the lesson. Specific responses to this topic are shown in Fig. 3.

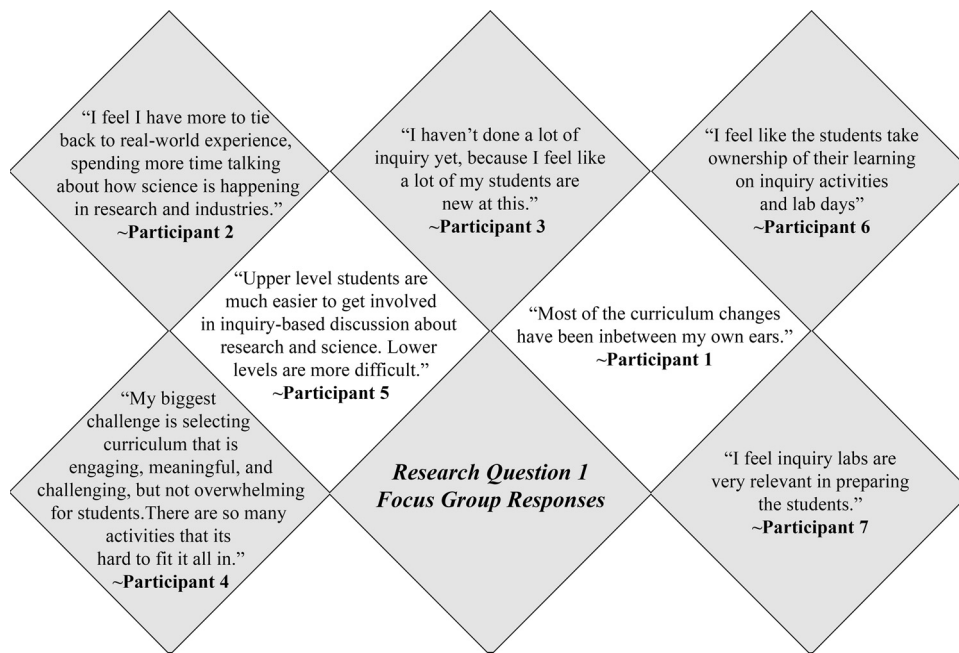


Fig. 3. Focus group responses to *research question 1*.

General outcomes for evidence of teaching efficacy, confidence, and job satisfaction. Research question 2 sought to determine what measurable effect participation in the SERF program had on improving teacher efficacy, confidence, and overall job satisfaction. To answer that question, three separate analyses were completed. The results of each of those analyses are shown in Table 2 for both the RET survey ($t = 4.34$, $d = 1.642$, $P = 0.002$) and focus group responses ($t = 5.28$, $d = 1.997$, $P = 0.001$) and suggest a profound impact on overall pedagogical performance. This supports the notion that teachers who are provided the opportunity to develop skills learned during professional development are much more likely to implement those processes in the classroom.

Qualitative responses to the RET survey (*part I, items 8 and 9*), which asked the participants to identify their strengths and weaknesses as a teacher, demonstrated a high level of confidence in each participant's ability to incorporate real-world and laboratory-based application into their curriculum, to communicate with students in a manner that is backed up by actual scientific experience, and to develop student-teacher relationships with those students based on their passion and enthusiasm for their content area. Each participant also indicated a strong desire to improve on the implementation of laboratory experiments, problem solving, and guided inquiry in his or her classroom. Specific responses to this line of questioning are shown in Fig. 4.

Qualitative responses to the focus group indicated a vast improvement in overall teaching efficacy, confidence, and

job satisfaction as a result of participating in the SERF program. Comments indicated a positive outlook on each participant's ability to inspire their students to become curious and effective observers of the world as it pertains to successful science education. As a result, participants felt that their overall confidence and job satisfaction had improved, and each indicated that they planned to continue their career as a science educator for the foreseeable future, although several have been offered and are pursuing secondary jobs in laboratory research. A sample of their responses is shown in Fig. 5.

In a final analysis, qualitative responses to the postprogram RET survey indicated that many of the SERF participants felt that they had improved teaching efficacy, confidence, and job satisfaction as a direct result of their experience in the program. Likert scale responses pertaining to questions about beliefs in practice and knowledge of content resulted in mean valuations of 2.92, 3.43, and 3.14 on a four-point scale for improved teaching efficacy, confidence, and job satisfaction, respectively. Individual statements in response to such questions are shown in Fig. 6.

Lessons as artifacts of participant growth and development. As a pedagogical training exercise, SERF participants were expected to develop lessons inspired by their experience in the program. Each teacher was matched with a research mentor performing biomedical research on pediatric health projects spanning molecular and physiological processes across a variety of cells and tissues. As previously stated, placement was

Table 2. *Quantitative data pertaining to analysis of research question 2: evidence of efficacy, confidence, and job satisfaction*

	Preprogram Score		Postprogram Score		<i>t</i>	<i>P</i> Value	Cohen's <i>d</i>
	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>			
RET survey	59.43	4.16	64.57	3.78	4.34	0.002*	1.642
Focus group	16.36	2.69	19.50	3.01	5.28	0.001*	1.997

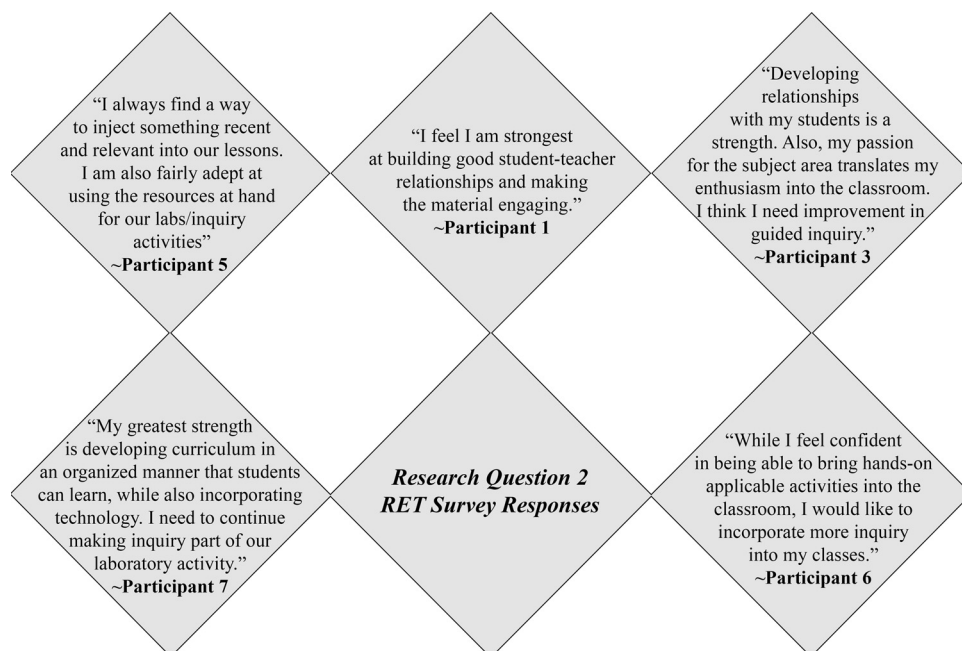


Fig. 4. RET survey responses to *research question 2*.

based on an examination of individual interests, experience, and laboratory availability within a pediatric research department that housed a diverse number of research projects being conducted by both MD and PdD researchers with medical and basic science training. Examples of projects included the following: 1) mapping protein interactions in laminopathy-related gene mutants by expressing proximity-based promiscuous biotin ligase fusion proteins in immortalized human cells, 2) maternal programming of fetal cardiogenesis in rats through a high-fat diet and gestational diabetes, 3) characterizing motile ciliary defects during organogenesis in a novel mouse mutant of primary ciliary dyskinesia, 4) hyperoxic disruption of mitochondrial redox homeostasis in cultured alveolar epithelial

cells, 5) movement performance to predict injury susceptibility in healthy athletes, and 6) maternal drinking behaviors pre- and postconception. Multiple lessons were generated by teachers as a result of their experiences that allowed for translation of these complex topics into relevant and applied physiology topics for classroom instruction, including proteomic comparisons of biological samples by SDS-PAGE, evaluating genetic status by PCR and gel electrophoresis, behavioral observations of organisms fed high-fat diets, testing exercise programs for injury risk reduction, and creating service announcements about fetal alcohol spectrum disorders. In each case, projects were presented with the intent of engaging students through reformed, student-led, and inquiry-based instruction. These lessons serve

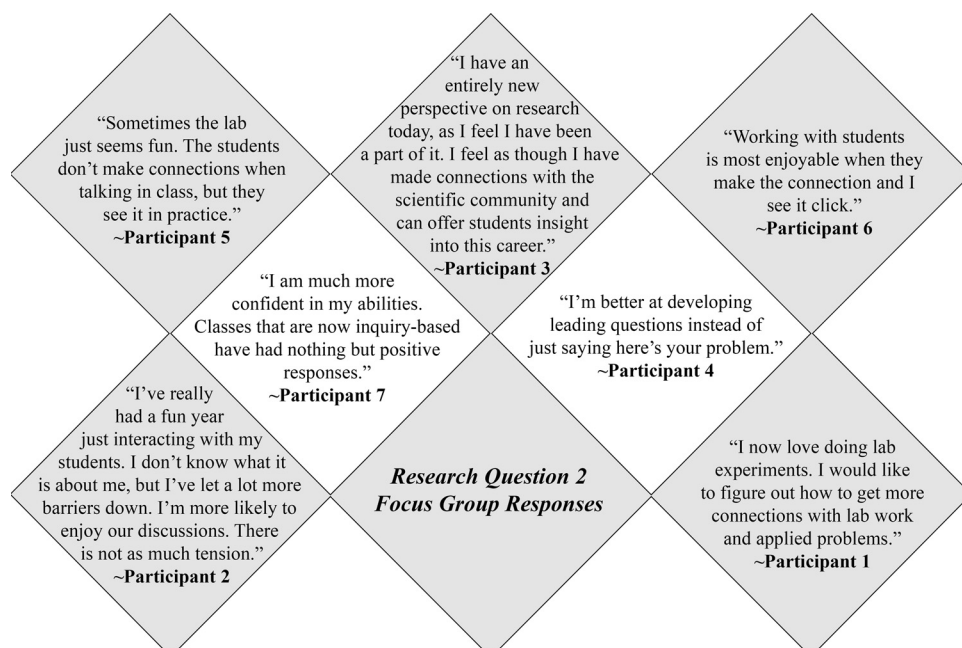


Fig. 5. Focus group responses to *research question 2*.

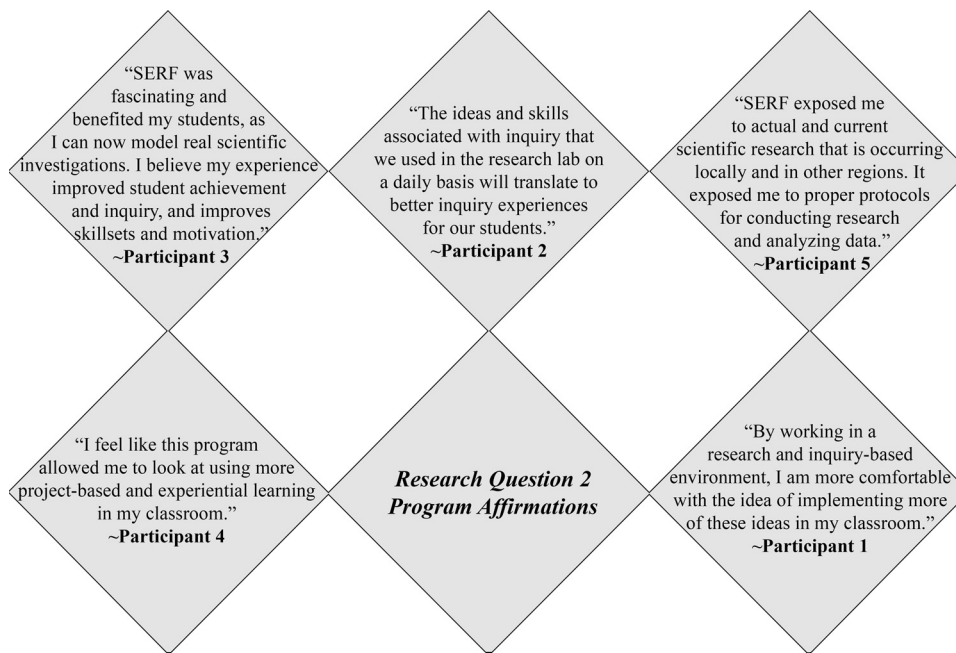


Fig. 6. Research question 2 program affirmations.

as artifacts of positive growth and development of program participants and the SERF program itself.

DISCUSSION

Over the last quarter century, research reports pertaining to laboratory-based professional development programs have demonstrated outcomes that improved teacher performance, provided practical experience, and promoted high technical science standards (8, 40, 41, 52, 53, 54). While this mode of training has been validated as being successful in the development of laboratory skillsets, such attempts have mainly focused on the laboratory experience without including the instructional and pedagogical intervention that would ensure translation into the classroom (35, 39). Thus, a direct connection between laboratory-based professional development and an improvement in instruction, based specifically on the unique pedagogical intervention and training provided during the SERF program, has not been commonly observed in previous investigations.

The present study illustrated that classroom instruction for SERF participants seemed to directly impact their participation in laboratory-based professional development supported by pedagogical training. This was seen in its successful translation into inquiry-based lessons in the secondary classroom. On the basis of the findings described above, supported by additional evidence found in lessons developed by program participants, a number of observations can be noted regarding the state of teacher progress in this study of reformed practices and inquiry-based instruction, teacher efficacy, confidence, and overall job satisfaction as it pertains to their participation in the SERF program. Although there was evidence of a desire to resist changes in lesson planning and design, indication of positive growth toward such practices could be documented on a number of fronts. This included growth in the beliefs of SERF participants as well as hard evidence of student engagement, student-teacher relationships, curriculum and content selection, and improvements in classroom culture as prescribed by the outcomes of the RTOP evaluation. Second, it was evident that

the SERF program had a profound positive impact on teaching efficacy, confidence, and job satisfaction among program participants.

One could speculate that these two general findings are correlated, based on subject response and observer notes recorded during data collection. Participants were found to have enhanced student participation and classroom leadership by placing the onus for educational advancement on the student rather than the teacher, in addition to improved their overall classroom culture by developing quality STEM curriculum, guided inquiry, and technology-driven activities upon completion of the SERF program. Although teachers were found to have some level of difficulty transitioning to wholly student-led instruction due to both student influence and a desire to maintain common practice, this study did determine an increased belief in, and progression toward, such teaching practices both in terms of delivery and student performance. However, this study did not specifically determine which aspects of the SERF program had led to these pedagogical outcomes. Moreover, because of the small number of participants, and therefore limited sample demographics, it would be unwise to extrapolate these findings to the general population of middle and high school science teachers without further study and a larger sample.

Previous studies have indicated that the absence of novel student innovation and guided inquiry and instead the presence of predetermined "cookie cutter" activity in the classroom have a negative impact on teacher attitude and performance (18, 47). This effect contributed to a lack of teacher confidence and efficacy that ultimately led to higher attrition rates (17). These characteristics were found to be particularly evident in rural Midwestern communities, where teachers are often expected to teach a significant course load with limited resources and were highlighted as an area in critical need of improvement (38, 48, 49).

This study supports that, in the case of these seven program participants, the integration of constructivist practices, specif-

ically the reformed instructional practices highlighted in this study, into a laboratory-based professional development program can have a profound positive effect on teacher efficacy, confidence, and overall job satisfaction. It also supported the notion that such changes can have a significant influence on overall classroom culture, productivity, and student engagement. Despite the small number of study participants, these results also seem to strongly suggest that professional development such as that described above can significantly enhance the participants' pedagogical approaches, self-efficacy, confidence, and overall performance.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: M.A., C.E., and P.F.V. conception and design of research; M.A. performed experiments; M.A. analyzed data; M.A., C.E., and P.F.V. interpreted results of experiments; M.A. prepared figures; M.A. drafted manuscript; M.A. and P.F.V. edited and revised manuscript; M.A., C.E., D.P., A.E., and P.F.V. approved final version of manuscript.

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