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Evaluation of an NSF Research Experience for Teachers (RET) Program for STEM Development: Water-Energy Education for the Next Generation (WE^{2}NG)

KATIE SCHNEIDER
AMY MARTIN

AND

TERRI S. HOGUE
Colorado School of Mines
Golden, CO

ABSTRACT

In recent decades much attention has been given to the optimization of professional development to support education reform; especially as it relates to science, engineering, technology and mathematics (STEM) fields. Many studies have shown that the most effective STEM professional development programs include active inquiry opportunities that take place over long durations. The Colorado School of Mines (CSM) has developed, and hosts, a professional program that works to address these needs. The *Water-Energy Education for the Next Generation* (WE^{2}NG) is a National Science Foundation funded Research Experience for Teachers (RET). The WE^{2}NG program is a six-week summer training that immerses K-12 educators in state-of-the-art research at CSM through the highly interdisciplinary lens of the water-energy nexus. The WE^{2}NG model also includes industry field trips, content and pedagogy workshops and book club focusing on science communication. Program effectiveness is evaluated through surveys given to participants before, during and after the program. Pre- and post-program surveys indicate that WE2NG supports teacher confidence and growth in teachers of all grade levels and that participant satisfaction outcomes are likely related to the ratio of elementary, middle and high school teacher participants. Surveys given during the program reveal consistently positive feedback and that satisfaction with collaborative program elements is related to program duration. Overall, survey results illustrate that the WE^{2}NG RET program is an effective professional development model for K-12 STEM educators.

Key words: program evaluation, STEM, self-efficacy

INTRODUCTION

Over thirty years ago, The National Commission on Excellence in Education (NCEE) published *A Nation at Risk*, urging the US Department of Education to reform the American education system. The report describes an ongoing decline in the United States' global competitiveness in education, and especially in science, technology, engineering and math (STEM) fields. Recognizing our emergence into the 'information age', the NCEE warned that "the educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a Nation and a people". While critics of this report have rejected this tone of "gloom-and-doom", (Association for Supervision and Curriculum Development) the NCEE supports its claims with empirical evidence. Since then, many reports have shown little-to-no improvement in U.S. educational measures; a significant contributor to America's "narrow lead" in overall prosperity. These more-recent reports have pointed to a lack of teacher enthusiasm and preparedness as a major culprit in educational decline (National Academy of Sciences). While the majority of high school science teachers have completed a science degree, less than half of middle school science teachers and only five percent of elementary science teachers hold science degrees. Thus, it is likely that the majority of K-12 STEM educators have experienced minimal opportunities to engage in scientific investigations that would support their ability to deliver STEM curriculum effectively (Wilson, et al).

In response to these warnings, initiatives to improve the American education system (especially in STEM fields) have arisen. These initiatives have taken many forms, but perhaps most-notably are improvements in curriculum and professional development programs for educators. These, of course, are not mutually exclusive, as advancement of curriculum calls for increased educator understanding of content material. The *National Science Education Standards* (1996) describes an effective secondary-level science teacher as one that is "familiar enough with a science discipline to take part in research activities with-in that discipline". *The Next Generation Science Standards: For States, By States* (NGSS) is an example of a more-recent effort (a collaboration among 26 states) to improve science curriculum by focusing on disciplinary core ideas (content), science and engineering practices (SEPs) and crosscutting concepts (CCs). The NGSS curriculum places emphasis on vertical alignment of K-12 science concepts in such a way that teaches SEPs and CCs in context where more-traditional science standards "express these dimensions as separate entities" (NGSS Lead States).

In recognition of the national shift toward NGSS, the National Academy of Sciences published *Science Teachers' Learning* (2016), a study that evaluates literature on professional support for science teachers. Among many conclusions from their study, those most relevant to this study include:

1. "many science teachers have not had sufficiently rich experiences with the content relevant to science courses they currently teach";

2. "very few teachers have experience with the science and engineering practices described in the NGSS";
3. lack of experience is "especially pronounced both for elementary school teachers and for schools that serve high percentages of low-income students";
4. the most effective professional development programs include a content focus and have "sufficient duration to allow repeated practice and/or reflection on classroom experiences".

The recommendations that follow call for district support of teachers' science content learning opportunities, learning opportunities that include specialized programs outside of school and ongoing learning opportunities built into the work day, development of partnerships with industry and institutions of higher-education, and introduction of science specialists at the elementary level through outside sources or internal vertical collaboration (Wilson, et al).

Professional development designed to support STEM educators in "integrating practices, cross-cutting concepts and disciplinary core ideas" is necessary for successful implementation of NGSS (Pellegrino et al.). Unfortunately, STEM professional development "is often short, fragmented, ineffective, and not designed to address the specific need of individual teachers" (Committee on Hightly Successful Schools of Programs for K-12 STEM Education). In agreement with the findings from *Science Teachers' Learning*, the National Research Council's Committee on Highly Successful Schools or Programs for K-12 STEM Education (2011) advocates for professional development that focuses on enhancing teachers' content knowledge and provides multiple opportunities for teachers learning over sustained periods of time. In a study of over 200 teachers in 30 schools spanning 10 districts in five states, Desimone and others (2002) found that the effectiveness of professional development programs (on enhancing teachers' instruction) are increased by active learning opportunities. Results from their study also suggests that professional development focused on fewer teachers is more likely to affect actual teaching practice than professional development designed for a greater number of teachers (Desimone et al.). Professional development as a driver of reform in STEM education is not a new concept and a substantial body of literature exists with recommendations to optimize professional development. While recommendations vary, support for long-term professional development opportunities is an obvious recurring theme (van Driel, Beijaard, and Verloop). To create these types of high-quality professional development opportunities, significant resources are necessary (Garet et al.) but are not always accessible or feasible within schools or even districts. Despite resource limitations, the demand for more rigorous state standards and teacher effectiveness continues to grow at district, state and national levels (Committee on the Evaluation Framework for Successful K-12 STEM Education).

A unique professional development program that addresses both the discrepancies and recommendations described above is the National Science Foundation's (NSF) Research Experience for

Teachers (RET) (NSF). RET programs are hosted by colleges and universities across the U.S. and provide an internship-type research experience for K-12 educators. As noted above, many K-12 teachers lack exposure to post-secondary and applied STEM. The RET provides an opportunity for interested teachers to be immersed (usually for many consecutive weeks) in scientific research under the guidance of college or university research faculty and graduate students. These programs have been shown to improve teachers' self-confidence in their science knowledge and in relating applied science to their classroom practices through inquiry-based pedagogy (Saka; Klein-Gardner, Johnston, and Benson; Trenor et al.), and to indirectly improve retention of student motivation (Klein-Gardner and Spolarich).

RET WE²NG PROGRAM

The Colorado School of Mines (CSM) hosts a summer RET program for local public K-12 STEM teachers. CSM is one of the world's leading science and engineering schools with a long-standing and successful relationship with industry partners. With a focus on the water-energy nexus, the CSM RET site - *Water-Energy Education for the Next Generation* (WE²NG) - seeks to enhance STEM teachers' content knowledge and to advance public knowledge and dialogue on the water-energy nexus through integration of teachers, and ultimately cutting-edge water-energy research and technology. The U.S. Energy Information Administration and American Wind Energy Association rank Colorado 7th in the nation for total energy production of non-renewables (crude oil, natural gas and coal), 10th in the nation for installed solar capacity (U.S. States – Rankings) and 9th in the nation for installed wind capacity (State Wind Energy Facts). Colorado is also home to the headwaters of the Colorado River – the vitality of which seven western states and parts of Mexico depend on for water supplies, per the *Colorado River Compact* of 1922 ("Colorado River Compact."). As a national leader in natural resource development, Colorado is an especially unique setting to host an RET focused at the intersection of water and energy issues. This environment provides opportunities for teachers and students to engage with cutting-edge science and policies that are immediately relevant to them. The study of the water-energy nexus also requires interdisciplinary collaboration (especially connecting STEM disciplines) and has relevance to all grade-levels; serving as an optimal inquiry lens for the WE²NG professional development model.

Through immersion in applied science and inquiry at this duration, the six-week WE²NG program is structured to address some of the education gaps described above. The primary goal of the WE²NG program is to infuse current research in the water-energy nexus into local K-12 classrooms. Specific objectives of the WE²NG program are as follows:

O1: *To impact teacher participants by increasing their knowledge of the water-energy nexus and by expanding their perspectives on science, engineering, and research.*

O2: *To indirectly impact K-12 students' learning, motivation, and engagement by increasing teacher passion and awareness and by providing mentors from CSM in the K-12 classroom.*

O3: *To impact K-12 STEM curricula via the creation of standards-based active learning lessons infused with current research which will be available through local, regional, national, and global forums.*

Since each RET program uses a different approach to support teachers, comparability between programs can be difficult. Consequently, the body of literature that evaluates these programs also employs various approaches, or metrics, to describe program success. The purposes of the current study are to 1) evaluate the effectiveness of the WE^{2}NG RET model as a means of professional development, in a way that provides insight into the successful structuring of future RET programs, and 2) to introduce a non-parametric method for evaluating how various program elements change with time (given small participant populations, n<30). To our knowledge, the non-parametric method employed in this study has not been utilized in professional development evaluation but is a valuable tool for evaluating change over time and has been previously and successfully used in natural science studies. The study described herein aligns most closely with the first program objective (O1), evaluating the impact of the WE^{2}NG program on teachers and how that relates to the structure of the program as a professional development model. We assume that by impacting teachers (O1), that their students will be similarly impacted (O2). However, directly addressing O2 and O3 is more difficult due to limitations on obtaining student information. Specifically, the research questions motivating this study include 1) What WE^{2}NG RET program elements have the greatest control on teacher experience and is teacher learning affected by those elements? And 2) How does teachers' confidence (in their understanding of STEM curriculum) change due to their participation in the WE^{2}NG RET program?

General Program Logistics

The WE^{2}NG program supports teacher participants to attend a full-time (40 hours/week) paid six-week summer training at CSM where they engage in research under the direction of faculty and graduate student mentors. Participants are paired with a research group on campus (including a faculty advisor and graduate research assistants) based on their STEM content interests and the scope of work of the research group. All research groups affiliated with the WE^{2}NG program have a water and energy focus; with research topics including the remediation and reuse of water affected by energy production. The general weekly structure of the WE^{2}NG program includes; curriculum development (Mondays and Wednesday afternoons), research within faculty research groups (Tuesday, Wednesday mornings and Thursdays), and industry field trips (Fridays).

The current RET WE^{2}NG grant has supported a total of 27 Denver-metro-area teachers over the course of the first three summers (nine new teacher participants per summer). Due to proximity, most WE^{2}NG participants teach in the Jefferson County School District (JeffCo) – the second largest K-12 school system in Colorado. The demographics in JeffCo vary extensively from school-to-school, with minority populations exceeding 85% and students on free/reduced rates exceeding 90% in certain areas. Initial participant recruiting efforts (for the first summer) were targeted at the Golden and Jefferson articulation areas within JeffCo. These areas were chosen based on greatest potential impact of STEM professional development, the opportunity for vertical teaming benefits and the relative proximity to CSM to enable sustained long-term interaction between CSM faculty and students and K-12 classrooms. During the second and third summers (2017, 2018), recruiting efforts extended beyond JeffCo and into the Denver Public School (DPS) district; an area close enough to CSM to experience the same beneficial impacts of the professional development program. Inclusion of teachers representing all grade levels in close-geographic proximity creates an environment conducive to both vertical and horizontal collaboration. Participants in the 2017 and 2018 cohorts represented elementary, middle and secondary grade levels.

During the 2017 and 2018 summer trainings, teachers from previous cohorts were invited to return in a part-time capacity as 'Master Teachers'. A maximum of five participants were slotted into the program to return as Master Teachers; 4 teachers took advantage of this opportunity in 2017 and 4 again in 2018. The primary role of the Master Teachers was to attend and lead collaboration meetings with new participants, typically held once per week. Master Teachers also provided support to new teachers in the development of their final deliverables (lesson or unit plans) that were presented at the showcase of lessons and developed (and presented) a new lesson or unit plan for their own classrooms. The 2017 and 2018 summer trainings also hosted science curriculum specialists from JeffCo and Denver Public Schools. The inclusion of a district curriculum specialist in the WE^{2}NG program was a huge asset to the other teachers participating that summer and played a critical role in vertical and horizontal collaboration efforts.

Summer Program

WE^{2}NG summer trainings begin with an orientation session that includes an introduction to campus and the various research projects connected to the WE^{2}NG program, as well as a laboratory safety training. In the weeks following orientation, teachers spent two and a half days per week immersed in a research project that best fit the needs of their classroom goals. They also spent one day per week at a teacher-training workshop (various topics), one day per week on an industry field trip related to water and energy, and a half day focusing on science communication; through a book club led by new teachers and through curriculum development led by master teachers. The book club was designed with the intention to increase participant exposure to: 1) regional water and energy issues and 2) to explore methods of science communication used in different types of science literature (Table 1).

Table 1. Reading List for the 2017 WE²NG Book Club. Note: the 2018 Book Club followed a very similar format.

Literature Type	Selected Publication
Public information release (online)	Colorado's Water Plan (Colorado Water Conservation Board) – Executive Summary – Chapter 4 (Water Supply) – Authors: The Colorado Water Conservation Board and other collaborators
Public information release (booklets, hard copy)	Selected Colorado Citizen's Guides – Citizen's Guide to Colorado Water Quality Protection (Frohardt) – Citizen's Guide to Where Your Water Comes From (Grigg) – Citizen's Guide to Colorado Water Conservation (Coleman) – Publisher: Colorado Foundation for Water Education
Book	*Water is For Fighting Over and Other Myths about Water in the West* – Author: John Fleck
Technical publications	Increased Dry Season Water Yield in Burned Watersheds in Southern California (2015) – Authors: Kinoshita & Hogue – *Environmental Research Letters* Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity (2006) – Authors: Westerling, et al. – *Science*

The time reserved for curriculum development created an opportunity for new teachers to work on lesson planning in a space conducive to alignment of curriculum, both horizontally and vertically. At least one 'working-lunch' per week included a research presentation by graduate students involved in work relating to the water-energy nexus. Additional optional opportunities arose throughout the program, including helping other research groups with data collection (on or off site), field activities and campaigns, or instrumentation assembly. The final week of each program included a 'showcase of lessons' where teacher participants presented a final deliverable, in the form of a lesson or unit plan that met the needs of their classroom, to WE²NG faculty, CSM students and local school district personnel. After the showcase, the program closed with an extended overnight field trip to parts of Colorado that face unique water and energy challenges (Colorado's Rio Grande basin in 2017 and Colorado's West Slope in 2018). The extended field trip included a variety of industry tours, research-site visits and meetings with local water-energy stakeholders. As an example, a detailed outline of the 2017 WE²NG summer training calendar is presented in the Supplemental Information.

METHODS

Data Collection: Surveys

WE²NG program evaluation was achieved entirely through surveys (using the Google Forms product) administered to teacher participants during the program. Surveys were given immediately before the program began (one pre-survey), at the end of each week of the program (weekly surveys) and immediately after the program (one post-survey). Pre- and post-surveys were the most extensive, asking different questions before and after the program. Pre-program surveys were geared toward gauging teacher perceptions of strengths and weaknesses prior to the program and post-surveys did the same (after the program), while also vetting teacher satisfaction with various program elements. Weekly surveys were relatively brief, and for purposes of consistency, presented the same questions each week.

To satisfy the requirements of the NSF funding supporting the WE^{2}NG program, all survey questions were collaboratively designed with, and ultimately approved by, an external program evaluator. Hence, evaluation of WE^{2}NG was confined by external evaluator oversight (on surveys). Additionally, program managers are only allowed to evaluate teacher development *without* obtaining information on their students. A CSM Internal Review Board (IRB) Exemption for Human Subjects Research was obtained to protect the privacy interests of teacher participants. Approval form the JeffCo Review of External Research (JRER) Committee was also obtained to conduct this research and protect the identities of the students that would be affected during the following school year. To encourage un-biased feedback, survey participants were assigned random numerical-identifiers, which were kept anonymous to the authors of this study. To allow time for reflection, but also encourage timely responses weekly surveys and the post-survey were made available for a short window of time (2-3 days for weekly and approximately 1.5 weeks for post). For purposes of consistency, master teachers did not participate in these surveys.

Data Analysis

Analysis was undertaken for new participants (non-master teachers) who participated in both the 2017 and 2018 WE^{2}NG cohorts. Surveys included both written/non-numerical and quantitative ranked/numerical responses. The results presented here primarily consider numerical survey results, however, because all survey questions were qualitative in nature, the presented analysis is considered qualitative, and any potential error associated with the results are not quantified. Due to a low number of survey participants (n = 9 in 2017 and n = 9 in 2018) question responses do not fit a normal distribution and are evaluated using a non-parametric approach.

To determine if participant feedback is related to program duration, Kendall rank correlation coefficients ("Kendall's Tau") were determined for median weekly survey responses (note: the median is used here because the median does not assume a distribution). Since Kendall's Tau (KT) provides information on whether a monotonic relationship exists between two variables (in this case; feedback and program duration), and does not imply correlation type, Kendall-Theil robust lines (KTRL) were also fitted to weekly survey responses to determine how/if feedback truly changes with time.

Non-zero KT values indicate that a monotonic relationship does exist between variables, and KT = 0 implies no correlation. For KT = +1, a perfect positive monotonic relationship exists and for KT = –1, a perfect negative monotonic relationship exists. Kendall-Theil robust lines were determined using **Equations 1a and 1b,** and KT correlation coefficients were calculated according to **Equations 2a and 2b**.

Kendall-Theil Robust Lines:

$$Y = b_0 + b_1X \qquad \textbf{Equation 1a}$$

Where Y is the dependent variable (survey responses), X is the independent variable (week), b_1 is the slope of the line (found by taking the slope between all possible data pairs; the median slope is b_1) and b_0 is the y-intercept, defined as follows;

$$b_0 = Y_{med} + b_1X_{med} \qquad \textbf{Equation 1b}$$

Where Y_{med} and X_{med} are the median Y and X values respectively.

Kendall's Tau (τ):

$$\tau = \frac{S}{n(n-2)/2} \qquad \textbf{Equation 2a}$$

Where n is the number of data pairs and S is defined as follows;

$$S = P - M \qquad \textbf{Equation 2b}$$

Where P is the number of times Y and X increase together, and M is the number of times Y decreases as X increases.

To our knowledge, Kendall-Theil robust lines and Kendall's Tau correlations have not been previously been applied to any similar educational studies. However, KTRLs and KT correlations are appropriate and well-suited inferential statistical methods for small data sets that do not fit a probability distribution. These methods are applied here because they are not strongly affected by outliers (Helsel and Hirsch) and because the datasets are small. Another important consideration is that the sample of responses under question represent 100% of teacher participants for the 2017 and 2018 WE^{2}NG programs but represent only a small convenience-sample of STEM teachers in general. Thus, results of inferential statistical methods should be treated with caution when considering their applicability to the entire population of STEM teachers.

RESULTS & DISCUSSION

Pre- and Post-Program Surveys

Prior studies have shown that self-efficacy in teachers is critical to both teacher and student performance (Doménech-Betoret, et. al; Annetta et al; Lakshmanan et al.). While other studies have evaluated the types of teachers (with respect to pedagogical discontentment and self-efficacy) that participate in PD programs (Saka; Southerland, et. al.) we wish to understand how participation in the WE^{2}NG RET program affects self-efficacy in participants. Though this is not a self-efficacy study per-se, the pre- and post-program surveys were administered with the intention of gauging WE^{2}NG participant self-perceptions of STEM knowledge, understanding, ability and proficiency (KUAP) prior to the start and after completion of the program.

In 2017, KUAP surveys were given only in the pre-program survey and in 2018 KUAP was evaluated in both pre- and post-program surveys. Boxplots of these data (Figure 1) exemplify participant responses in these areas. In both years, participant perceptions of KUAP was variable, especially in the 2017 cohort. Of all survey data presented in this study, 2017 pre-program KUAP levels of confidence show the greatest variability. In addition to the observed variability, the 2017 cohort also had noticeably lower levels of confidence in KUAP than the 2018 cohort. The authors believe the relatively low and variable confidence of the 2017 cohort is related to the ratio of elementary, middle, and high school ("e:m:h") teacher participants, where the 2017 and 2018 e:m:h ratios were 3:3:3 and 0:3:5 respectively. Further, almost all 2018 participants had background experiences in STEM outside of a K-12 teaching context, and several were qualified to teach advanced placement (AP) science courses. Thus, these results are congruent with the tendency of lower-level educators having less exposure-to, and therefore lower confidence-in their abilities to teach, STEM subjects (Smith and Nadelson; Ramey-Gassert, et. al.).

With respect to knowledge and understanding, the two lowest and most variable responses are related to current scientific technologies and issues. In terms of ability and proficiency, the weakest responses are seen for participant access to science experts and in their ability to use examples from personal science experiences. Even with differing e:m:h ratios, the lowest levels of confidence were observed in the same areas for both cohorts. This observation agrees with the findings of *Science Teachers' Learning* and suggests that 1) the sample of teachers who participated in 2017 and 2018 WE^{2}NG programs are likely representative of the greater body of K-12 educators and 2) that educators of all K-12 levels have high potential for growth through participation in WE^{2}NG or related activities because the program is designed to provide industry connections and first-hand STEM research experiences through the lens of real-time and real-world STEM issues and innovations. When KUAP surveys were given as part of the post-program survey in 2018, suspected growth was confirmed in all areas.

Compared with the pre-program survey, the post-program survey was more extensive, so additional results are broken down into categories of questions relevant to this study including: "*Types-of-Learning*" (during the WE^{2}NG program), "*General Program Satisfaction*", "*Mentor Relationships*", "*Level of (program) Fit to Each Participant*", and "*Personal Impact*". The range of median responses

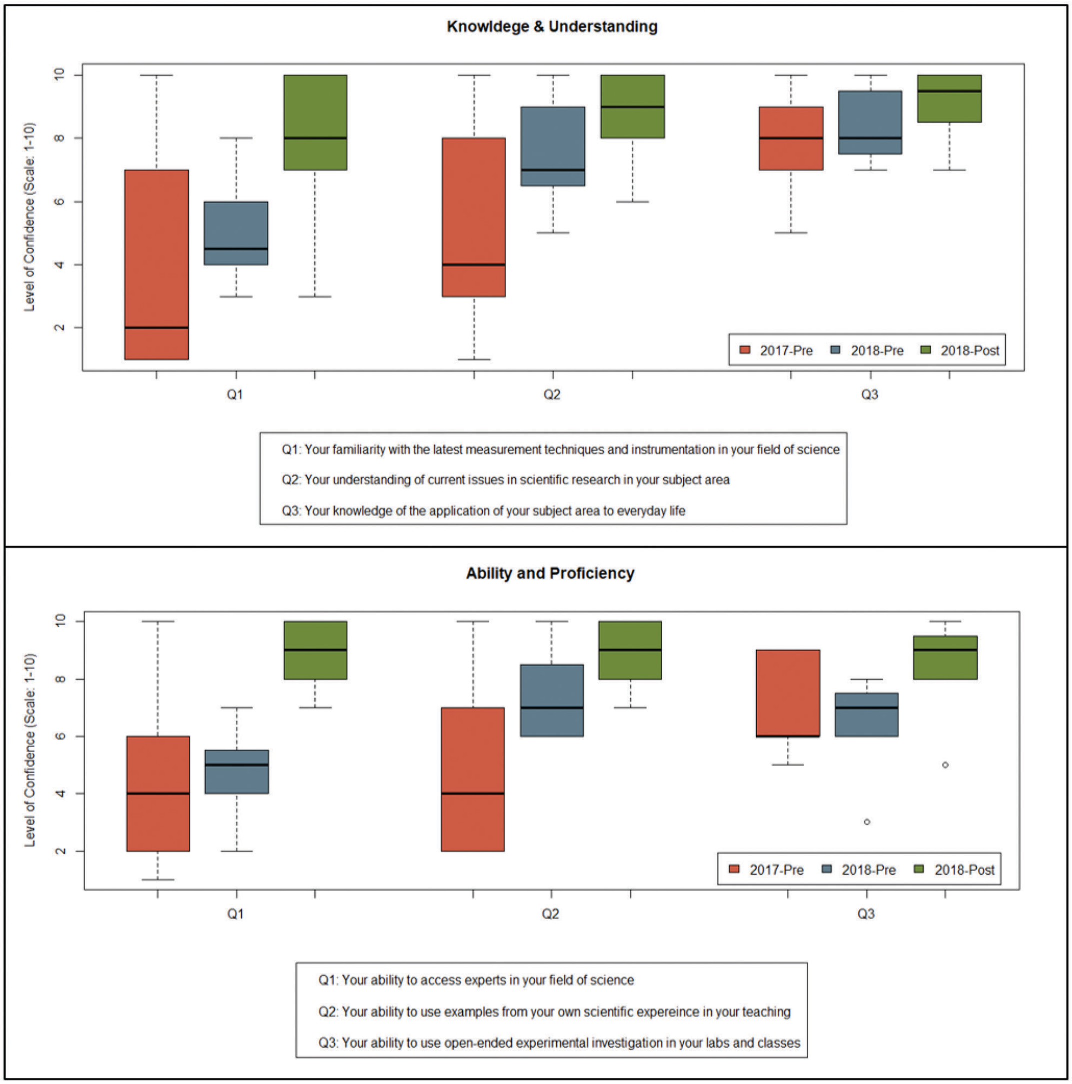

Figure 1. Sample Pre- and Post-Program Survey Results Measuring Participant Perception of Knowledge & Understanding (top), Ability & Proficiency (bottom) in Selected STEM Areas. While many questions were asked in each KUAP category, the three most-representative responses are shown here for illustrative purposes. For a complete list of questions asked in these categories, please see the Supplemental Information section. The bottom and top of each box represents the 25th and 75th quartiles of responses (respectively) and the median is illustrated by a solid line through each box. 'Whiskers' extending from each box show the highest and lowest responses for each question that are not considered outliers. Outliers are indicated by solid dots above or below a box.

Table 2. Range of Median Responses to Categories of Post-Survey Questions. Note: all median responses shown here are normalized to a scale of 1:10 for consistency (some questions were originally ranked on a scale of 1:5).

Question Category	Year	Lowest Median	Highest Median
General Satisfaction	2017	7	10
	2018	8	9
Relationships with Mentors	2017	8	10
	2018	7	8
Program Fit to Participants	2017	10	10
	2018	6	10
Types of Learning Experienced During WE^{2}NG	2017	8	10
	2018	9	10
Personal Impact	2017	10	10
	2018	8	10

in each category of questions is summarized in Table 2. Overall, participant satisfaction was high for each category of questions, however, levels of satisfaction were slightly higher in 2017 than in 2018. Again, this is likely related to the more evenly distributed e:m:h ratio of the 2017 cohort. Despite efforts by program coordinators to make improvements to each iteration of WE^{2}NG (to maximize participant satisfaction), we suspect that the degree of prior STEM exposure/experience of each participant has a non-trivial control over satisfaction outcomes. Specifically, participants with less prior STEM exposure are expected to show the greatest KUAP growth and, consequently, experience higher levels of satisfaction with the program.

Similarly, when asked about the "*Types of Learning*" experienced during the WE^{2}NG program, the 2017 cohort agreed more strongly (and in some cases, unanimously) that they increased their knowledge or understanding in various ways during the program (Figure 2). Even with slight differences in feedback from the 2017 and 2018 cohorts, participant feedback with respect to the "*Types of Learning*" they experienced during WE^{2}NG was high overall (lowest median = 8, highest median = 10).

Post-program surveys evaluating the WE^{2}NG "*Level of Fit*" and "*Personal Impact*" for each participant show relatively low variability in responses (most agreement between participants especially in the 2017 cohort). In both categories, five (out of five) was the lowest median response in 2017 (Figure 3). The 2018 cohort also responded positively to these program elements, but with more variability in responses. Thus, participants mostly agreed that these areas of the program were successful. Taken together with "*Types of Learning*" (Figure 2), these results are important in addressing the first program objective (O1) because they expose personal responsiveness of participants to the WE^{2}NG program.

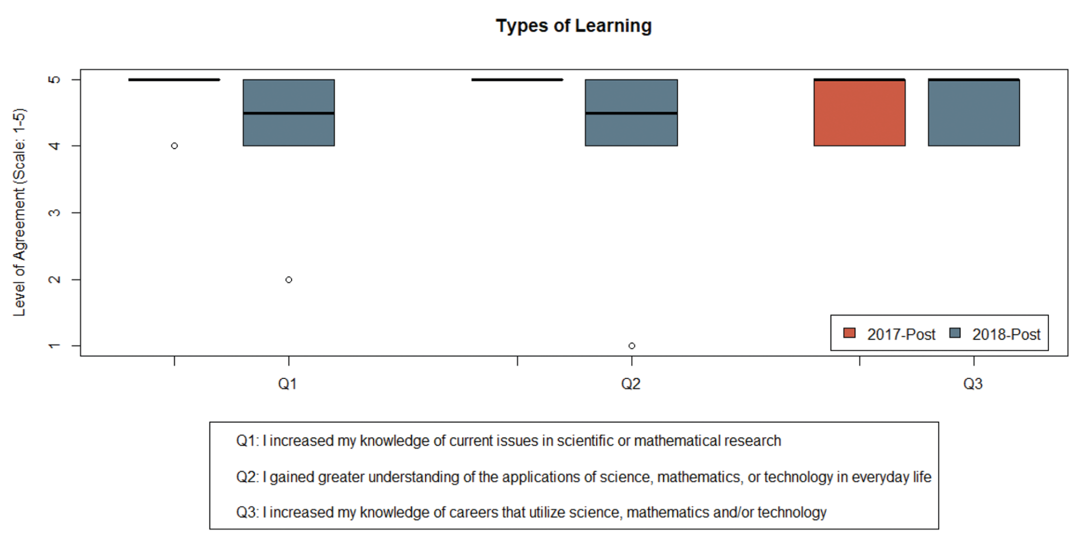

Figure 2. Sample Post-Program Survey Results Evaluating Types of Learning during the WE²NG Program. For a complete list of questions asked in each category, please see the Supplemental Information section.

Since KUAP questions were only asked in the pre-program survey in 2017 (and not repeated in the post-program survey), 2017 post-program responses to "*Types of Learning*" (Figure 2), "*Level of Fit*" to each participant and "*Personal Impact*" (Figure 3) offer some insight into the growth of 2017 participants. For example, in 2017, agreement was extremely high in these categories, but highly variable in pre-program surveys relating to KUAP. While these post-program questions are not identical to the KUAP pre-program questions, their results do indicate that 2017 participants increased their knowledge, understanding and interest in STEM content as a result of their participation in the program.

With overall high feedback in post-program surveys, implied (2017) and explicit (2018) gains in teacher's KAUP in STEM content, the authors feel confident that the WE²NG program is well-structured to meet the needs of K-12 teachers with varying levels of STEM knowledge and abilities. These results suggest that the WE²NG program is a strong RET model with promise for other institutions who wish to promote increased STEM knowledge, perspective and enthusiasm in K-12 teachers. While the sample of teachers responding to these surveys represent a convenience sample of teachers-in-general, it is likely that other RET host-institutions would recruit similarly-representative samples of teachers, as we assume that teachers willing to dedicate their summer to STEM professional development tend to be highly motivated and opportunistic educators.

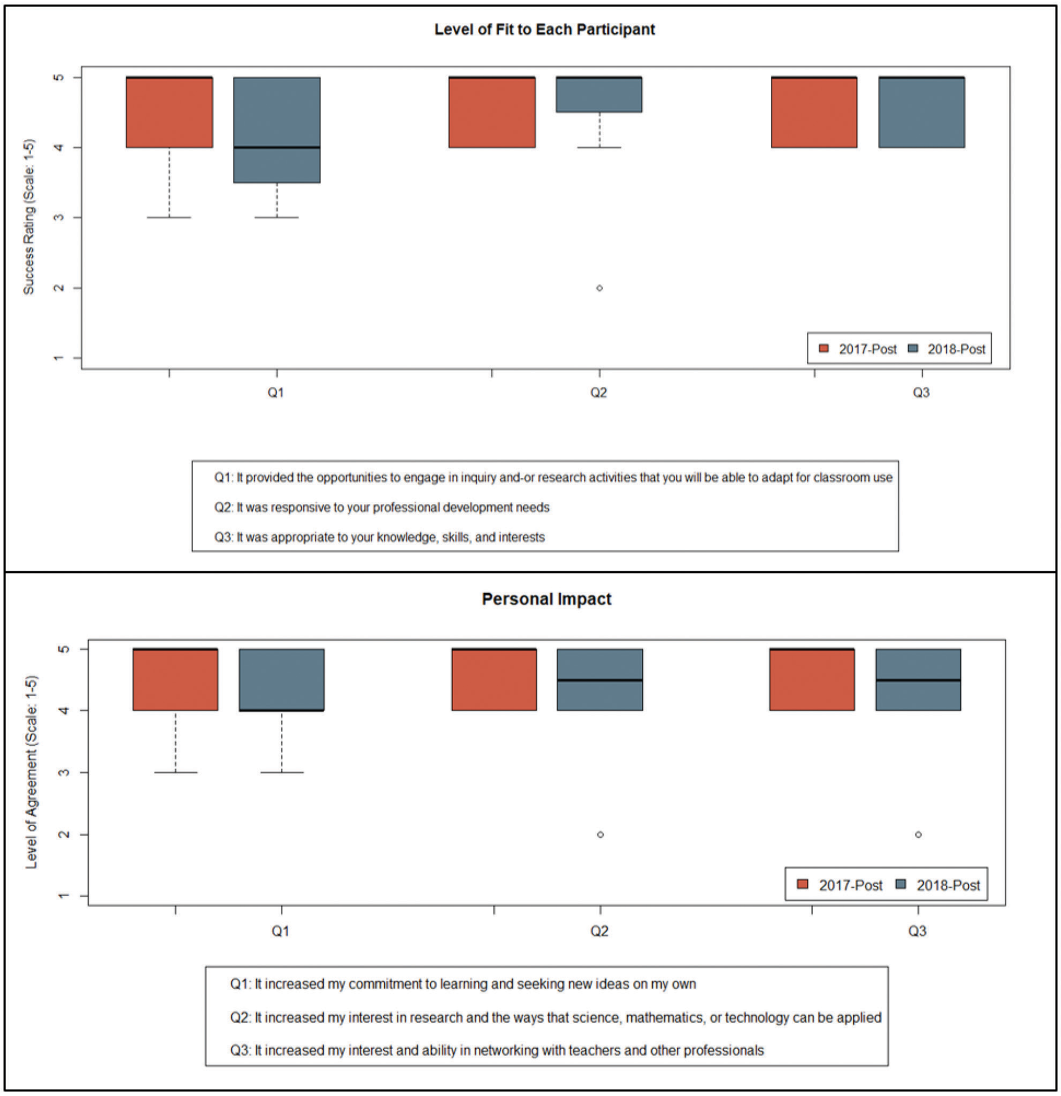

Figure 3. Sample Post-Program Survey Results Measuring Level of Fit (top) to Participants and Personal Impact (bottom) of the WE²NG Program. For a complete list of questions asked in each category, please see the Supplemental Information section.

Weekly Surveys

Another metric of program evaluation took the form of weekly surveys; used to determine if certain elements of participant satisfaction change during the course of the program. Identifying which feedback elements change the most with time is valuable information to future program structuring, and similarly, knowing which types of feedback stay constant is also useful. At the end of each week of the program participants took relatively short surveys to assess their ongoing levels of satisfaction with various program aspects, and to vet their responsiveness to program activities specific to that week. In this way, program coordinators were able to determine which activities were best-fit to participants and to see what program elements see the most development over time. Of particular interest here is distinguishing between elements of the program that show growth (or otherwise) with time, and those that are consistent throughout the program.

Eight questions (Q1–Q8) and median ranked responses are presented (Figure 4 and Table 3) in the order that they appeared in weekly surveys. Weekly trend analyses are notably different between

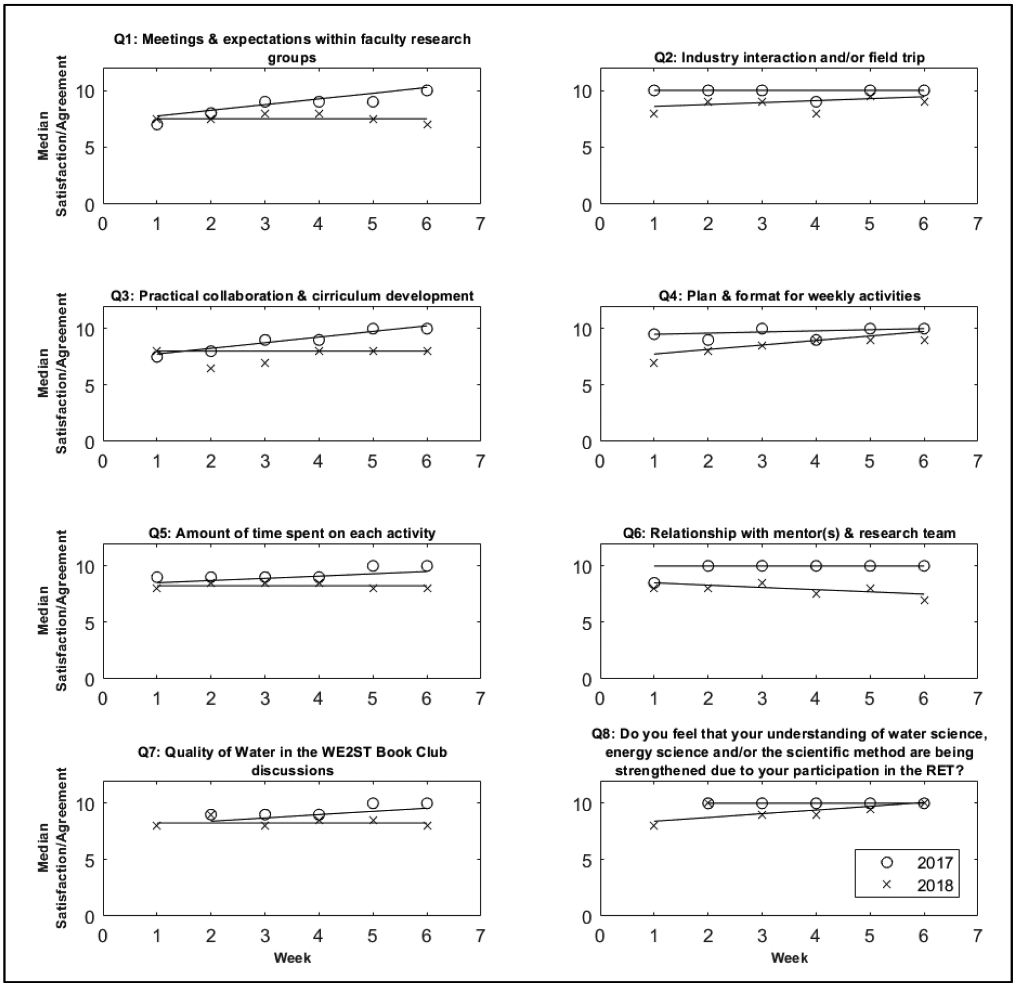

Figure 4. Weekly Survey Results. KTRL lines plotted for 2017 (marked with circles) and 2019 (marked with Xs). See Table 3 (below), for accompanying KTRL line equations and their respective Kendall's Tau correlation coefficients.

Table 3. Summary of KTRL Equations and Kendall's Tau Correlation Coefficients. Note: ("KT" = Kendall's Tau, no KT value for Q8 because KT cannot exist without any change in slope between all points)

2017 Weekly Survey KTRL Results			
Question	**KTRL Equation**	**Kendall's Tau**	**p-value**
Q1	y = 0.5x + 7.25	0.89	0.016
Q2	y = 10	–0.12	0.770
Q3	y = 0.5x + 7.25	0.93	0.011
Q4	y = 0.1x + 9.4	0.39	0.304
Q5	y = 0.2x + 8.3	0.73	0.064
Q6	y = 10	0.58	0.143
Q7	y = 0.29x + 7.83	0.77	0.083
Q8	y = 10	–	–
2018 Weekly Survey KTRL Results			
Q1	y = 7.5	–0.23	0.547
Q2	y = 0.17x + 8.42	0.39	0.304
Q3	y = 8	0.43	0.260
Q4	y = 0.4x + 7.35	0.89	0.016
Q5	y = 8.25	–0.26	0.513
Q6	y = -0.2x + 8.7	–0.45	0.227
Q7	y = 8.25	–0.08	0.837
Q8	y = 0.33x + 8.08	0.50	0.173

2017 and 2018 cohorts (Figure 4). First, looking at weekly trends in 2017, non-zero Kendall's Tau (KT) correlations are produced for all weekly questions, indicating that some correlation does exist for each question with time (where greater KT absolute values indicate stronger correlations). Kendall-Theil robust lines, shown as black trend lines, agree with KT correlations, where the weakest slopes (or responses lacking slopes) are associated with the lowest KT correlations. Illustrated by KTRLs, all trends are either increasing (positive slope) or constant (slope = 0). However, the only trends satisfying a 95% significance level are evident in Q1 ($p = 0.016$) and Q3 ($p = 0.011$), with Q5 ($p = 0.064$) and Q7 ($p = 0.084$); just outside the statistically significant range. Not surprisingly, trends with the greatest significance are, more often than not, related to group collaboration. The opposite is true for less significant trends (with the exception of Q6, which asks about mentor relationships), where more consistent responses are seen for program logistic (Q2, Q4) and self-assessment (Q8) type questions. Note: in 2017 responses for Q1–Q6 were collected for all six weeks, and due to an administrative error, Q7–Q8 were only collected for five weeks (weeks two through six).

Similar to the 2017 cohort, 2018 KT results are all non-zero. However, KT results for the 2018 cohort are more variable; with several negative KT values and only one KT value meeting significance criteria (Q4, $p = 0.016$). Also, for all weekly questions, 2018 KRTLs are lower than those from 2017. These results align with those from the 2018 pre- and post-program surveys, where participant satisfaction tended to be higher in 2017. Taking a closer look at 2018 weekly surveys, we see that meetings within assigned research groups (Q1) and relationships with research teams (Q6) decline slightly over the course of the program. Although KT trends for Q1 and Q6 were not significant, this information is an important indicator for teacher-researcher relationships. The fact that experiences with faculty research groups and mentors are distinctly different between 2017 (Q1: KT = 0.89, Q6: KT = 0.58) and 2018 (Q1: KT = -0.23, Q6: KT = –0.45) has prompted further investigation into 1) how invested research mentors are in their teacher mentees and 2) how to cultivate positive and lasting relationships between the two. In 2014, Faber and others found that too much or too little research mentor involvement could negatively impact RET teacher learning outcomes (Faber et al.). These findings support those of Reimers and others (2015), who stress the importance of "building community" among professional development participants, including both teachers and scientists (Reimers, et. al.).

Tying weekly trends in with the first program objective, Q8 shows encouraging results from both years; evaluating teacher's perceptions of how their understanding of STEM was being strengthened due to their participation in the WE^{2}NG program. In 2017, median teacher responses were 10 (out of 10), each week this question was asked. In 2018, teachers felt that their understanding of STEM was progressively improved, with final median score of 10 on the last week of the program. So, despite variability in responses to other program elements, by the end of the program, teachers strongly agree that they have strengthened their STEM understanding through the lens of the water and energy nexus. While all program elements (i.e. mentor relationships, book club discussions, etc.) are important to a teacher's overall experience in the WE^{2}NG program, the authors do not believe that they have a strong control over learning-outcomes, which are arguably the most important indicator of program successfulness. This piece of evidence supports pre- and post-program survey results; that the WE^{2}NG model is a well-designed and robust professional development program for K-12 STEM educators.

CONCLUSIONS

In response to the growing need to strengthen K-12 STEM education in the U.S., the RET WE^{2}NG program was designed to enhance the STEM teaching capacity in K-12 educators by immersing participants in an environment where they were exposed to (and participated in) scientific research and other professional development activities, all through the lens of the water-energy nexus. The current study evaluated the effectiveness of the WE^{2}NG RET model as a professional development tool through participant surveys taken before, during and after the 2017 and 2018 WE^{2}NG programs. The greatest variability in participant response is seen in pre-program surveys; relating to participant self-perception of STEM knowledge, understanding, ability and proficiency. In post-program surveys, where teachers evaluated various aspects of the WE^{2}NG program, feedback was highly positive across-the-board. Thus, the authors believe that the WE^{2}NG program is a highly effective STEM professional development model for educators of ranging abilities and K-12 grade levels, with the ability to increase STEM knowledge, perspective and enthusiasm in participants.

Key findings from our analysis include: 1) the WE^{2}NG RET program can support growth in teacher confidence in participants of all grade levels, 2) program satisfaction outcomes are likely controlled by the e:m:h ratio of each cohort, 3) learning/growth outcomes apparently are not controlled by participant satisfaction with logistical program elements, and 4) the development of collaborative program elements tend to depend on program duration while non-collaborative program logistics do not. Based on results, we recommend that longer-term STEM professional development programs (such as WE^{2}NG) allocate ample time for collaborative efforts among all program participants; especially near the beginning of the program.

Survey results are being utilized to inform planning efforts for future WE^{2}NG iterations. Due to positive program feedback, the general structure of the WE^{2}NG program will continue, and minor adjustments will be implemented to address program elements that received highest variability in post-program survey responses. Results suggest that future iterations of WE^{2}NG should tailor activities more specifically to the e:m:h ratio of each cohort. To support teachers with the greatest potential for growth, future program advertisements will specifically target teachers lacking STEM exposure outside the classroom setting. With the knowledge that the development of collaborative program elements (especially intra-research group dynamics) depends on program duration, the structure of future WE^{2}NG programs will continue to cultivate and strengthen collaboration by intentionally allocating time for collaborative meetings among teachers (vertical and horizontal alignment) and research mentors throughout each week of the program. Teachers likely need enough mentorship to begin working independently with periodic guidance, but not so much guidance that they never experience cognitive dissonance.

New questions have also arisen during the evaluation of the 2017 and 2018 WE^{2}NG programs and call for modification of future survey questions. Most notably, WE^{2}NG coordinators are interested in: 1) vetting program effectiveness for master teacher participants, 2) taking a more in-depth look at how the WE^{2}NG program shapes-up as a tool for enhancing science communication skills and

3) gathering satisfaction feedback from research mentors. To determine program effectiveness for master teachers, a set of surveys exclusively designed for master teachers will be developed with a primary goal of assessing the degree to which their leadership role reinforces and enhances their STEM knowledge and understanding. Further, since K-12 educators require a range of science communication skills to adequately deliver STEM curriculum to students of varying ages and abilities, WE^{2}NG coordinators wish to include questions specific to the science-communication development aspect of the program in future surveys. With greater insight into participant satisfaction as it relates to relationships with research mentors, we believe that creating additional surveys for research mentors (to better understand their satisfaction with their WE^{2}NG experience) will provide useful information in optimizing participant experience.

While these results are encouraging, the sample of teachers responding to surveys described in this work represent a small sample of teachers-in-general and should be interpreted with caution when considering the entire population of STEM teachers. However, it is assumed that teachers who are willing to spend the majority of their summer in an intensive professional development training (i.e. WE^{2}NG participants) are highly motivated educators, and likely represent the population of teachers who seek intensive professional development. Data obtained in this study will inform the structuring of future WE^{2}NG programs, and the authors hope that dissemination of these findings will serve other institutions who are currently hosting (or plan to host) an RET or other STEM professional development programs.

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AUTHORS

Katie Schneider is a PhD student in the Hydrologic Science and Engineering program at Colorado School of Mines, where she holds appointments as the Program Coordinator for the WE^{2}NG RET summer program and as a Graduate Research Assistant under Dr. Terri Hogue. In 2012, she received B.S. degrees in Chemistry and Environmental Science at Appalachian State University, and in 2018, she received an M.S. in Hydrologic Science and Engineering at Colorado School of Mines. In the years between technical degrees she taught high school science and obtained her teaching license through the North Carolina STEM Teacher Education Program. Katie's current research efforts are centered on STEM education and hydrologic modelling of snow dominated watersheds.

Amy Martin is the Program Manager for the Center for a Sustainable WE^{2}ST, which was formulated to promote the joint sustainability of unconventional energy production and water resources through education of energy-water literate graduate and undergraduate students at Colorado School of Mines, and the Program Manager for the WE^{2}NG RET summer program. In 1997, she received a B.S. in Civil Engineering at Colorado School of Mines. Amy spent 14 years in the water and wastewater treatment consulting industry, obtained a Texas teaching certification and taught 8th grade math, and volunteered as a science lab coordinator and instructor in Golden, CO before obtaining the current positions focused on student and teacher development and community education and outreach.

Terri Hogue is a professor and head of the Civil and Environmental Engineering (CEE) department at Colorado School of Mines. Professor Hogue's research centers on understanding hydrologic and land surface processes, with much of her work focused in semi-arid regions. The overarching goal of her work is to improve the prediction of hydrologic fluxes for better management of water resources, to assess human impacts on the environment, and to mitigate the effects of natural hazards. In addition to technical research, Dr. Hogue is committed to the enhancement of K-12 STEM education through community outreach. She serves as the primary investigator for WE^{2}NG RET program which has expanded her research efforts into the engineering education space.

APPENDIX

2017 WE^{2}NG Calendar

Note: the 2018 Calendar followed the same general format

Week	**Monday** *Workshops & Curriculum Development*	**Tuesday** *Research*	**Wednesday** *Research & Collaboration*	**Thursday** *Research*	**Friday** *Industry Field Trips*
1			**Orientation** – Campus Tour – Program expectations – Showcase demos by Master teachers	**Orientation** – Environmental health and safety presentation – Initial faculty research group meetings	– JeffCO PBL template intro – Tour of Ballistreri Vineyard – Exploration of personality and social styles
2	– Introduction to Colorado water, "The Great Divide" film – Colorado Water Quality Ted Talk, Wildfire Talk (Dr. Terri Hogue) – Grade-level based team meeting	Research within faculty group	**Morning** – Research within faculty group **Afternoon** – Water in the WE^{2}ST Book Club *(Topic: Colorado Water Plan Executive Summary)* – Collaboration Meetings	Research within faculty group	– City of Golden water and energy infrastructure site visit – Coors Brewery Wastewater tour
3	Project Learning Tree Workshop (all day)	Research within faculty group	**Morning** – Research within faculty group **Afternoon** – Water in the WE^{2}ST Book Club *(Topic: Citizens Guides by CO Foundation for Water Education)* – Graduate Presentation: Water Law – Collaboration Meetings	Research within faculty group	Northern Integrated Supply Project presentation & tour
4	– Storytelling in Science workshop – Grade-level based team meeting	Research within faculty group	**Morning** – Research within faculty group **Afternoon** – Water in the WE^{2}ST Book Club *(Topic: Water is for Fighting Over- Book)* – Graduate Presentation – Collaboration Meetings	Research within faculty group	Denver Botanic Gardens: Gardening Workshop
5	– Water perception activity – Overview of CSM water treatment research (Dr. Tzahi Cath) – Presentation on social science in oil and water industry (Dr. Jessica Smith) – Finalize showcase ideas	Research within faculty group	**Morning** – Research within faculty group **Afternoon** – Water in the WE^{2}ST Book Club *(Topic: Selected science articles from peer review)* – Graduate Presentation – Collaboration Meetings	Research within faculty group	ConocoPhillips well pad and drilling site visit
6	Project WET workshop (all day)	– Showcase of Lessons – Prep for extended field trip	**Extended Field Trip:** Creede, CO & Rio Grande Basin Focus: Fire, floods, agriculture, fish, water and energy in the Western US		

Complete List of Survey Questions by Category

Knowledge and Understanding (Pre- and Post-Surveys)

Please rate your confidence in the following aspects of your teaching, within the particular subject area(s) that you teach.

- *Your familiarity with the latest measurement techniques and instrumentation in your field of study*
- *Your understanding of current issues in scientific research in your subject area*
- *Your knowledge of careers that utilize science, technology, engineering or math*
- *Your knowledge of the application of your subject area to everyday life*
- *Your understanding of the fundamental concepts in your subject area*

Ability and Proficiency (Pre- and Post-Surveys)

Please rate your confidence in the following aspects of your teaching, within the particular subject area(s) that you teach.

- *Your ability to access experts in your field of science*
- *Your ability to use examples from your own scientific experience in your teaching*
- *Your ability to advise students about career opportunities in science, technology, engineering, or math*
- *Your ability to teach lab courses effectively*
- *Your ability to use open-ended experimental investigation in your labs and classes*
- *Your ability to effectively use open-ended problems in your labs and classes*
- *Your ability to create presentations at teacher in-services or professional meetings*
- *Your ability to network effectively with teachers and other professionals*
- *Your ability to effectively teach and explain scientific ideas and concepts to your students*
- *Your proficiency in using the Internet to access information useful for teaching*

Program Level of Fit to each Participant (Post-Survey Only)

To what extent, if any, was your RET experience successful in each of the following areas:

- *It was responsive to your professional development needs*
- *It was appropriate to your knowledge, skills and interests*
- *It provided the opportunities to engage in inquiry/research activities that you will be able to adapt for classroom use*
- *The research assignments were clearly defined*
- *The work was enjoyable and stimulating*
- *The scope of the project was appropriate for the time you were on site*

Personal Impact of the WE^{2}NG Program (Post-Survey Only)

To what extent do you agree or disagree with each of the following statements concerning the impact of the experience on you personally?

- *It increased my confidence in myself as a teacher*
- *It elevated my enthusiasm for teaching*
- *It increased my interest in research and the ways that science mathematics, or technology can be applied*
- *It stimulated me to think about ways I can improve my teaching*
- *I believe I will be a more effective teacher*
- *It increased my interest and ability in networking with teachers and other professionals*
- *It increased my motivation to seek out other experimental professional development activities*
- *It increased my commitment to learning and seeking new ideas on my own*
- *Adjusted to the challenges of the laboratory environment*
- *Shared with your mentor ways in which you might use your research experience in the classroom*
- *Communicated with your mentor that this program is worthwhile for you and other teachers*

Types of Learning as a Result of the WE^{2}NG Program (Post-Survey Only)

To what extent, if any, did you feel that you experienced each of the following types of learning as a result of your summer experience?

- *I gained greater understanding of the applications of science, mathematics, or technology in everyday life*
- *I acquired greater understanding of the fundamental concepts in science or mathematics*
- *I became more familiar with new materials and equipment that I can use in my teaching*
- *I learned about innovative ways to use standard materials and equipment in my field*
- *I increased my knowledge of current issues in scientific or mathematical research*
- *I gained a greater appreciation of the difficulties some students encounter when learning science or mathematics*
- *I better understood how collaborative inquiry can be done successfully*
- *I learned about magazines, professional journals and websites that will be relevant to me as a teacher*
- *I increased my knowledge of careers that utilize science, mathematics, and/or technology*