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Research Experience for Teachers: Teachers as Learners and Facilitators

Dr. Stephanie Philipp, University of Tennessee at Chattanooga

Dr. Stephanie Philipp is an assistant professor for science education at the University of Tennessee at Chattanooga and works closely with engineering faculty to teach and research STEM education.

Dr. Olfa Nasraoui , University of Louisville

Olfa Nasraoui is Professor of Computer Engineering and Computer Science, Endowed Chair of e-commerce, and the founding director of the Knowledge Discovery and Web Mining Lab at the University of Louisville. She received her Ph.D. in Computer Engineering and Computer Science from the University of Missouri-Columbia . From 2000 to 2004, she was an Assistant Professor at the University of Memphis. Her research activities include Data Mining/ Machine Learning, Web Mining, Information Retrieval and Personalization, in particular in problems involving large multiple domain, high dimensional data, such as text, transactions, and social network data. She is the recipient of the National Science Foundation CAREER Award, and the winner of two Best Paper Awards, a Best Paper Award in theoretical developments in computational intelligence at the Artificial Neural Networks In Engineering conference (ANNIE 2001) and a Best Paper Award at the Knowledge Discovery and Information Retrieval conference in Seville, Spain (KDIR 2018). She has more than 200 refereed publications, including over 47 journal papers and book chapters and 12 edited volumes. She is the PI of University of Louisville's NSF ADVANCE initiative, ATHENA. Her research has been funded notably by NSF and NASA. Between 2004 and 2008, she has co-organized the yearly WebKDD workshops on User Profiling and Web Usage Mining at the ACM KDD conference. She has served on the program committee member, track chair, or senior program committee of several Data mining, Big Data, and Artificial Intelligence conferences, including ACM KDD, WWW, RecSys, IEEE Big Data, ICDM, SDM, AAAI, etc. In summer 2015, she served as Technical Mentor/Project Lead at the Data Science for Social Good Fellowship, in the Center for Data Science and Public Policy at the University of Chicago. She is a member of ACM, ACM SigKDD, senior member of IEEE and IEEE-WIE. She is also on the leadership team of the Kentucky Girls STEM collaborative network.

Dr. Jason Immekus, University of Louisville

Dr. Immekus is associate professor in the Department of Educational Leadership, Evaluation, and Organizational Development.

Ms. Jody Zhong, University of Louisville

Ms. Zhong is a fifth-year doctoral student in the College of Education and Human Development at the University of Louisville. Ms. Zhong's interests lie in researching identity, diversity, and professional development/thriving within the academy.

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RET Site: Big Data and Data Science

Research Experience for Teachers: Teachers as Learners and Facilitators

Stephanie B. Philipp, Olfa Nasraoui, Jason Immekus and Jody Zhong

Abstract

A National Science Foundation Research Experience for Teachers site has hosted authentic research in machine learning for 20 middle and secondary school STEM teachers who are either members of underrepresented groups in computer science and engineering or who teach students from underrepresented groups. These teachers are evaluated by their districts, in part, by using the International Society for Technology in Education (ISTE) Educator Standards. The seven ISTE Standards for Educators were used to evaluate the learning of teachers in the RET program after a six-week research experience in partnership with graduate research groups at a metropolitan research university in the south-central U.S. From participation in focus groups and program products such as seminar presentations, we found that teachers expressed value in being able to feel like a student again (ISTE Standard #1; Teacher as Learner). Additionally, teachers expressed that thinking critically and using problem solving skills in an area with which they were not familiar offered necessary insight towards how their own students might feel at times. RET participants described having to engage problem solving skills and figure things out on their own, which in turn led to them wanting to provide that same experience for their own students (ISTE Standard #6: Teacher as Facilitator). Some participants spoke of incorporating more real-life data to challenge their students to apply their learning to real life problems and challenges. Other individual participants reported feeling more qualified to meet their schools' teaching standards and that the RET experience influenced the overall curriculum and approach to how their school teaches physics and engineering.

Introduction

This paper describes an RET Site offering an authentic research experience and curriculum development in Big Data, especially machine learning, to experienced science, technology, engineering, and mathematics (STEM) middle and high school teachers. We hosted two summer cohorts in the labs of the engineering school at our metropolitan research university before the pandemic forced us to postpone the third planned cohort until it is safe to meet in person. This paper illustrates the importance of the in-person cohort experience for developing teachers as learners and facilitators of computational thinking using the concept of machine learning.

Machine learning (ML) models are now being used increasingly in many sectors, ranging from health and education to justice and criminal investigation. Hence, these algorithmic models are starting to increasingly affect the lives of humans at the individual and social scale. All the RET projects were selected because they have significant human impact, ranging from energy sustainability to smart city planning, humanitarian land mine detection, and fairness in recommender systems. Two teacher teams, (one half of Year 2 cohort) were hosted in the PI's lab working on two projects that are directly addressing the impact of Machine Learning on society from the perspective of fairness [1]. Some projects addressed building explainability or transparency in these algorithms [1], while others studied the fairness of the algorithms from the perspective of bias and group fairness [2,3]. As machine learning is used more and more, problems and questions often arise in diverse disciplines, not just the computing field. Machine learning is revolutionizing the way that scientists and engineers practice, understand, and make discoveries in diverse disciplines. This means that machine learning can have a significant impact on all STEM subjects. Therefore, machine learning, with socially relevant applications and interdisciplinary reach, is a good way to interest students and teachers in computer science as a discipline and in Computational Thinking (CT) as a powerful problem-solving approach.

In addition to planning instruction aligned with state academic standards, middle and secondary school teachers are expected to guide their instructional practice using national standards for teaching. One set of standards is from the International Society for Technology in Education (ISTE). A link to the ISTE Standards for Educators (ISTE-E) is found in the reference list [4]. The ISTE-E are used to develop and support teachers' ability to integrate technology for empowered student learning. Experienced teachers possess the background knowledge to contextualize the ISTE Educator standards and can visualize what increased ability in each standard might look like in their own classrooms. Professional learning experiences like a RET can help teachers increase their ability in each of these standards. Based on feedback from our first cohort of teachers, we predicted that the RET experience would impact both Summer 2018 (Cohort 1) and Summer 2019 (Cohort 2) teachers' practice relating to two of the standards, ISTE-E Standard #1: Teacher as Learner and ISTE-E Standard #6: Teacher as Facilitator. The Teacher as Learner standard calls for teachers to "continually improve their practice by learning from and with others and exploring proven and promising practices that leverage technology to improve student learning." [4]. This standard also asks teachers to participate in learning networks such as the one we have attempted to establish with this RET, between local teachers and computer science researchers. The Teacher as Facilitator standard calls for teachers to "facilitate learning with technology to support student achievement of the ISTE Standards for Students," including "fostering a culture where students take ownership of their learning goals and outcomes in both independent and group settings and "creating learning opportunities that challenge students to use a design process and computational thinking to innovate and solve problems." [4].

During this RET, we were interested in the following research questions:

1. For which ISTE Educator Standards did teachers develop more mastery?

2. How did this RET help teachers master these standards?

Data collected to answer these research questions included qualitative responses to focus group questions, curriculum materials developed by the teachers, and field notes taken while observing teachers implement their developed curriculum in their own classrooms. Additionally data was collected from 1) teacher applications, 2) surveys, 3) weekly research seminar presentations, and 4) dissemination of project results at conferences that helped to triangulate the focus group responses and field observations.

Project Activities

The teacher participants in each of our two summer cohorts had either their first or second choice in joining an active graduate research group focused on various computer science questions and problems centered on machine learning, including 1) building an adaptive robotic assistant, 2) humanitarian landmine detection, 3) fair and explainable recommender systems, 4) wireless traffic surveillance, 5) energy efficient high performance computing, and 6) health data visualization.

After teachers were recruited from the large urban district and surrounding rural districts within an hour of our university, prospective participants submitted an online application which informed us of their STEM and research background, their educational experiences, and their goals and motivations for participating. Using our relationships with district administrators, we targeted teachers that had at least five years of successful teaching experience so that classroom management and curriculum development skills were beyond a novice level. Most teachers who applied to the program reported *pedagogical discontentment* [5], or a dissatisfaction with their current practice or content knowledge in meeting their own teaching goals, and they were ready to improve their practice and learn new content.

Much of our plan to broaden participation in computing and computational skills is dependent on who participates in our program. We have actively searched for and recruited teachers from underrepresented groups in computer science and engineering, e.g., women and teachers of color (especially African-American, Hispanic/Latinx, and Native American teachers), in local districts with whom we have ongoing collaborations. We also have successfully recruited teachers from schools that serve a high percentage of students from these underrepresented groups. Of the 19 RET teacher participants in Cohorts 1 [6] and 2, four teacher participants identified as non-white and 11 were female. All but five teachers taught at schools that served students of lower socioeconomic status. Sixteen of the teacher participants had between eight and 20 years of teaching experience while the other three had three years of experience. This RET is also managed by two women with careers in STEM, one an immigrant from North Africa. We worked intentionally to create a welcoming research culture with our diverse teacher participants. The location of our RET site, a diverse urban metropolitan area surrounded by lowincome rural areas, has helped our efforts to involve participants that have had little professional development in computer science. In addition, our faculty-led research projects have appealed to teachers' many different interests and tackle real-world problems that involve societal issues. We plan to leverage these close connections and interactions with local school districts for future outreach activities.

The RET experience began for teacher participants each summer with a two-week "boot camp," where teachers were immersed each morning in learning the programming skills and computer science principles, they would need to participate meaningfully in their chosen research groups. After completion of the first cohort in Year 1, we asked teachers for feedback on this intense learning experience. Teachers indicated that there was too much content, it was too fast paced, and that some of them preferred more boot camp material that was directly relevant to their specific research projects in their hosting lab. Based on results from the year 1 evaluation, we made the following changes to the initial training structure and content:

- Reduce the amount of material on the curriculum to only the necessary concepts with additional extension material that was labeled as "optional" for those who were either more advanced and could handle them, or for teachers to pursue and explore on their own time or to refer to in case they needed it for future curriculum development needs.

- Include more hands-on activities that directly apply the concepts learned and dedicate a special time for activities every day.

- Teach participants to use Google cloud-based tools to do their hands-on coding exercises so that we avoid local computer system issues that would take away from the time dedicated to learning and applying machine learning concepts and techniques.

- More involvement of dedicated graduate students to play the role of mentors for any teachers who were having trouble with certain hands-on activities. The PI and graduate students should circulate amongst the teacher teams' stations to be immediately available if there is a question rather than wait for teachers to make the first move.

- Include more continuous early feedback mechanisms to adapt the training session, especially in Week 2:

    - One example was a feedback system via sticky notes colored according to theme or kind of challenge. The notes were distributed to teachers to ask them to identify specific subtopics they found interesting and others they found challenging and on which they would like to have more instruction and application.

    - The PI devoted one session to go over different topics mentioned in the teacher feedback and specify exactly where and why they would be critical to certain projects, and whether teachers would be expected to master them in depth or simply have a broad knowledge for now and go back to them later.

    - The PI also created a concept map with the teachers that showed the dependency between the different sub-topics and techniques and concepts and mapped these components to specific lab research projects.

- Furthermore, Week 2 activities were changed to encourage teachers to apply the concepts and techniques learned in Week 1 by practicing hands-on mini-project applications to solve problems that were assigned by their lab mentors and specifically related to their research projects. Teachers were urged to discuss ideas with their mentors and with the PI and graduate students. Teachers were encouraged to make choices, i.e. to complete a mini-project that was not completely "canned," but rather refined in collaboration with the mentors and with each other as a team. The mini project was designed to transition teachers to practice what they learned in training in Weeks 1-2 and was not the same problem as their research project. Each team of teachers (from the same lab) worked together on the same mini project.

After the boot camp, teachers joined their research group in pairs and spent the remaining four weeks working on a research project with a mentoring team consisting of a computer science faculty member and graduate students. Weekly social events were planned and attended by all participants and research group members. Weekly research seminars gave teacher participants a chance to reflect on what they learned each week and to report their progress and next steps to the entire cohort of teachers and research lab members. During the six-week experience, teachers also worked regularly with a science education faculty member to develop student-centered curricular materials using a lesson plan template shown to be effective for deeper learning and considered to be best practice in STEM education [7, 8]. At the end of the research experience, teachers gave a professional presentation of their research findings and curriculum development to an audience consisting of invited members of the University community, teacher colleagues and participants from the previous teacher cohort, teachers' families, and related civic data affinity groups. In addition, several teachers later disseminated their work at regional and national conferences.

Findings

While we have reported on the first cohort of teachers previously, for this paper we observed and took copious field notes in several Cohort 2 teachers' classrooms as they implemented the curriculum that they developed during the RET. These observations were gathered before the schools were closed in 2020 due to the pandemic. What follows is a narrative of those observations, with the teachers identified by pseudonyms.

Mr. W. has taught computer science, programming, and networking at a rural technical high school for 10 years. Most of his students come from households of lower socioeconomic status.

- Some of his students approached his developed curriculum activity (programming a LED light ring) by feeling out the rules and limits of the technology, e.g. one student wrote code to test the limits of how bright and dim the light ring could get, using huge outlier numbers to see if the light ring could accommodate them and finding out that the range only went so far when he got an error message back. His classmate beside him was doing the same thing and informed him that the range went up to a specific number based on what he himself had tried. This type of trial and sharing happened in several of the groups, generally in pairs. The class seemed divided at any given time into students who worked solo and students who were working together, in pairs or groups. Some students were quick to consult their classmates or the teacher while others attempted to figure things out on their own for longer. However, the configurations of working together appeared fluid, with students moving to other workstations to talk to classmates and sometimes working alone for a period before consulting with a classmate. It is possible that cross-station conversations may have been based on pre-existing friendships. Mr. W asked groups of students to take turns presenting their solutions to each of the five problems he had given them. One member of the first group stated that he "didn't know what to explain" and had to be prompted to reflect on the group's design process. Another student talked through his process for figuring out a problem in which he had to get a particular pattern of lights to shift down one spot after a brief time delay and have this sequence play on loop.

Ms. T has taught math and computer science at an all-female parochial high school for the last ten years. Before she was a teacher, she was a computer systems analyst for insurance, retail, and financial companies. She is passionate about sharing the possibilities of computer science with her female students.

- Ms. T's students quickly observed the limitations of the technology she was demonstrating in her developed curriculum activity using Google artificial intelligence kits. Ms. T led students through a discussion of how this technology would work in the real world, with the machine increasing accuracy by receiving feedback from users. Students were able to point out that since the basic AI kits they used did not have a function that allowed feedback to be provided, the program was unlikely to become more accurate over time.

Mr. S. has taught middle grades at two different rural schools for the past 10 years. The academic year following the RET, he switched to teaching ninth graders in the same rural system's high school.

- Mr. S' developed curriculum activity featured an introductory look at wireless communications in his integrated science course that he shared with his ninth-grade students. Aside from a Morse code activity for the students to complete, the lesson was mostly a lecture format with Mr. S asking frequent questions for comprehension checking. Students did indicate their understanding of the key points being illustrated by the teacher through discussion responses.

Ms. M. has taught mathematics at a rural but higher socioeconomic-level high school for the past three years. As an undergraduate, she participated in two NSF Research Experience for Undergraduate projects in STEM Education and graduate level mathematics.

- Ms. M's developed curriculum included a hands-on inquiry activity demonstrating K-means cluster analysis with her math students. Students worked diligently with geoboards in small groups, as they were familiar with doing during other learning activities.

Ms. J. has taught middle school science at a rural school for about 10 years. She mentioned before the RET that she felt that the new Framework for K-12 Science Education had changed teaching science in very dramatic ways, shifting students to thinking and working like professional scientists. She wanted more experiences in doing and teaching the science and engineering practices. She had less experience in research and technical work than any of the other teacher participants.

- Ms. J developed a lesson sequence to meet the standard on waves used in communications, a content area she had previously struggled to teach. Her seventh graders constructed an understanding of the differences between digital and analog technologies, including how they worked and how their output differed from each other. Her students completed several guided inquiry activities that supported them in connecting the crosscutting concept of energy and disciplinary core idea of waves in multiple ways.

Focus group quotes

Gathered anonymously during the focus group meetings facilitated by our evaluator with the 2nd cohort, here is an illustrative group of direct quotes from the teacher participants in response to the focus group prompts.

What have you learned during the 6-week RET experience?

- I helped teach a dual credit computer science python course last spring… so I was able to learn some of the coding techniques, but I mean that was baby steps compared to what I've done this summer.

- I'm going to attempt to use [Python] in my classroom. Just to give my kids the experience and understanding of what programming is like, just a really small peek into what it looks like and how it can be used.

- I actually teach Snap and now I'm hoping if I can get them through the basics early enough, I'd like to go from Snap to Python because I feel like it's been an easy transition and give them a little bit of real code instead of the block.

- Just being able to talk to students about social media and, and kind of, what's happening with Facebook…

- I think as a student, to go from being the person in charge in the classroom and feeling confident in my abilities, to going really far back into feeling very insecure. And you know, kind of learning different ways to look at how my students feel and think and maybe look at processing computational thinking.

How can you incorporate this learning into your classes?

- So letting them have, not complete freedom on that project, but letting them realize that there's some stuff that you're going to have to figure out and the teacher is not always going to be here to be able to tell you this is what you need to know.

- Just looking at the standards for seventh grade science, and especially incorporating digital information and technology are a huge part of my standards. Um, and I actually think I can teach it now.

- My goal was to interact with data and see what I can do to change traditional high school… from the not qualified for Calculus catchall to something where students are actually interacting and doing something meaningful with data.

- I would like for my students to experience something like my own RET experience. It's just kind of a goal for me to not give them so much direction and let them learn by design, test, and revise or by experimenting.

What are the strengths of the RET for you?

- I've benefited from the people I'm working with and probably learn more in the group I'm in than I may have if I was placed somewhere else.

- I think the collaboration overall from the groups, so not only did the people that I worked with daily, but I think as a team of individuals that eleven of us together, I think I got a lot from everyone.

- I think the diverse group, like none of us really teach the same thing.

- I love the fact you get six weeks to just learn all you can, and then you'll get to meet new teachers from around the state… and also just to be a part of a university research lab which is just another layer of unique experiences. And meeting the grad students and the mentors… and the money's good.

What were the limitations of the RET?

- Well it's like it’s just one year… [After 6 weeks here] I feel like we're all hitting our stride right now.

- We need all this background information and stuff that we'd go through at the beginning and now that we're, feeling a little more confident in stepping out on our own, now it's time to go home.

- I could do the simple coding in Python and then what we went to was a lot more difficult. And so, if there was a little bit more transition time, I think in between those things then that would've been really helpful.

- I think that we're doing computer science is like more of a struggle than if we were to do like chemistry or something like that. Because in order for us to do anything computer science, we have to learn Python first. So, we lose like those first two weeks.

- I just don't feel like we've come out with, hey, you know, we accomplished this, we accomplished this, you know, and I'm not sure that there is something out there [research goals] that we can accomplish in six weeks.

Analysis of Data

We used the seven ISTE Standards for Educators as a framework for categorizing qualitative teacher data from the focus group responses and field observations of their developed curriculum from this RET. We categorized each teacher statement from the focus groups and each field observation statement into at least one of the ISTE teacher standards. From the categorization process, we were looking for patterns that would emerge, showing us which of the ISTE standards that this experience supported according to teacher statements and behaviors.

Teachers successfully met their lesson plan objectives, including providing their students with opportunities to use mathematical and computational thinking to learn science and engineering concepts and practice problem-solving. The words *explore, discover, problem-solve* could be used to describe the work students were engaged in. Only in one lesson did a teacher verbally present the information to students passively receiving it. In the other teachers' lessons, teachers created a situation where students had to test, reason, collaborate and reflect to reach a conclusion or craft an explanation.

Teacher participants expressed value in being able to feel like a student again, regardless of discipline taught or years of experience. This sentiment manifested in several ways. For example, some teachers expressed that thinking critically and using problem solving skills in an area which they were not familiar offered necessary insight into how their own students might feel at times. Teachers widely agreed that the sense of feeling insecure and vulnerable, and at times having to cope with challenging situations, was enlightening for the group both personally and professionally. Prior to the program, some participants were dubious about how much they would learn in such an expedited program. All participants agreed that learning so much content in a six-week timeframe was more than they had expected. They were especially impressed by how much they now understand computer science and big data programming.

RET participants felt they were compelled, at least some of the time, to use problem solving skills and figure things out on their own in their research groups, which in turn led to them wanting to provide that same experience for their own students. On one hand, this could be captured by higher degrees of student autonomy and less teacher involvement or "hand holding." On the other hand, some participants alluded to incorporating more real-life data to challenge their students to apply their learning with real life problems and challenges. One participant referenced how it was a struggle for her to get through a slow, unknown, tedious learning process, when all she wanted to do was get to the end and figure it out. She now has a better understanding of what her students go through and feels more prepared to guide them through that process. While this was the sentiment of the group, other individual participants reported feeling more qualified to meet the teaching standards they are held accountable to by their school, and to influence the overall curriculum and approach to how their school teaches physics and engineering.

Teachers associated many of their learning outcomes with a corresponding reference to how it might apply to their classroom or teaching methodology. Not only were teachers looking to make connections between the research experience and the classes they teach, but they were able to make those connections on their own and in talking with each other. Neither the number of years of experience nor the STEM discipline in which the teacher taught seemed to affect their ability to apply both newfound and traditional concepts that they teach in the classroom.

The greatest strengths of the RET program for the teachers related to group dynamics and having their fellow peers in the program as resources. In some instances, this referred to the entire group. For example, social hours and meals with the entire group allowed for special bonding, as well as an opportunity to talk openly and freely about the program and individual projects. This in turn allowed for a comfortable work environment where any participant felt as though he or she could freely "pop-in" to another project and offer an informed outsider's perspective. The importance of belonging and a supportive research community was the main reason that we have not attempted to manage the RET online or virtually, instead postponing experiences until teachers can work in person with each other and their research lab mentors. Additionally, some participants felt that the particular group they were placed in to work on their project was the greatest benefit. One person referenced this as the reason the entire experience was positive, and further expressed doubt that the program would have gone as well if he had been placed in a different group.

The duration of the RET program was its greatest limitation. In sum, it was agreed that after six weeks participants were "just starting to hit their stride" – and then the program ended. The training required to be part of a cyclical research process was seen as necessary, but because of the time it took, participants only felt confident stepping out on their own as it was time to go home. Similarly, as it related to their actual project, participants did not feel they were able to reach their goal to the fullest, and that with more time they might have been able to attain a feeling of major accomplishment. Due to the short duration, teachers also felt that content was being taught or introduced faster than they could consume. For example, learning the simple coding techniques of Python at the start of the program went well, but the quick transition to other advanced coding programs left some participants feeling lost. Notably, given these criticisms, participants also recognized the necessity of spending time on training, especially in a program on computer science. However, other timeframes would not be feasible, as teachers would find it difficult to spend even more of their summer weeks in the RET and could not participate in authentic research during the school year while still managing their teaching responsibilities.

Lastly, teachers reported that they have been more comfortable with rubrics and examples of desired product quality. While open-ended or ill-structured problems are desirable for learning, insecurity about what to reflect upon was felt by participants, so a rubric or guidelines would be helpful and may have produced higher quality reflection. Also, the starting boot camp was viewed by teachers as necessary but still could have been more targeted for specific skills and knowledge needed to get started in the research labs.

Conclusions

Teachers appreciated the role of teacher-as-learner during the RET research experience. They enhanced their practice by setting professional goals, giving themselves the time and opportunity to learn updated content and skills and to make sense of their new knowledge with others in the RET program. Instead of merely learning updated content knowledge about historical science and engineering discoveries and theories, teachers worked on the forefront of artificial intelligence with machine learning, which enables systems to learn from data than from explicit programming. All these experiences align strongly with the ISTE standard of Teacher as Learner.

Teachers learned to value and provide design challenges and more real-life context and problems in their curriculum. In turn, this enabled teachers to realize more fully the vision of the framework for required academic standards, such as computational thinking and engineering practices. Teachers' developed curriculum, based on their intense computer science training in the boot camp and applied in the research experiences, created learning opportunities that challenged their students to use a design process and computational thinking to solve problems and craft explanations. These qualities align with the ISTE standard of Teacher as Facilitator.

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