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Research Experiences for Teachers Summer Program in Biologically-inspired Computing Systems

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Abstract

Funded by the NSF Division of Computer and Network Systems, this grant establishes a new Research Experiences for Teachers (RET) Site at the University of South Alabama (USA). In the summer of 2021, eight middle school and high school teachers from two local public-school districts spent six weeks engaged with research activities on biologically-inspired computing systems. They worked on discovery-based research projects and obtained transdisciplinary research experience on biologically-inspired computing systems spanning application (cancer detection), algorithm (Spiking Neural Networks), architecture and circuit (synaptic memory design), and device (memristor). The USA faculty mentors, curriculum development specialist from school districts, Instructional Coach from Science/Mathematics faculty at USA coached participants as they designed standards-compliant curriculum modules and conducted professional development activities. The implementation details of the summer program and the evaluation results are presented in this paper.

Introduction

Science, technology, engineering, and mathematics (STEM) and computing-related jobs are growing fast in Alabama. Thirty-four of Alabama's 40 Hot Demand Occupations require secondary and postsecondary STEM education [1]. Between 2017 and 2027, STEM jobs will grow by 9% in Alabama, while non-STEM jobs will only grow by 5% [2]. Furthermore, the STEM and computing-related jobs along the gulf coast are a lifeline to Alabama. Labor market projections indicate a growing gap in the supply of qualified employees in the STEM fields, such as computer technology and advanced manufacturing [3].

Although a number of engineering and computing curriculum integrations are offered in K-12 schools nationwide, Alabama, particularly areas surrounding Alabama Gulf Coast, is lagging behind. According to the statistics offered by code.org, Alabama had only 614 computer science graduates in 2017. In Alabama, only 27% of all public high schools teach computer science. Up to 2016, Alabama higher education institutions have not graduated a single new teacher who was ready to teach computing courses. In 2019, the state of Alabama initialized a three-year state plan [4]: (i) 2020-2021: each public high school shall offer at least one authentic computer science course; (ii) 2021-2022: each middle school shall offer instruction in computer science courses; and (iii) 2022-2023: each elementary school shall offer instruction on the basics of computational thinking.

In order to promote the computing and engineering education in the state of Alabama, this RET site at the University of South Alabama (USA) offers a research-intensive program in biologically-inspired computing systems for middle and high school STEM teachers, Biologically-inspired computing systems, also referred to neuromorphic computing, which has been recently voted as one of the top ten emerging technologies by the World Economic Forum [5]. It uniquely integrates the research strength and expertise of a team of faculty members at

USA. The research projects were highly-structured and transdisciplinary, spanning application, algorithm, architecture and circuit, and device to enable future computing systems.

Research and Curriculum Development Activities for Teachers

Today, machine learning is transforming many modern artificial intelligence (AI) applications. However, the AI's superior performance comes at the cost of extremely high computational complexity associated with large datasets. Particularly, modern computers, which are based on von Neumann architecture, are extremely inefficient in carrying on the AI tasks [6]. Inspired by the working mechanism of mammalian brains, biologically-inspired computing systems have the potential to perform machine learning algorithms faster and consume less power than traditional von Neumann architectures. In this RET summer program, eight participating teachers were guided by an interdisciplinary group of faculty from the University of South Alabama on discovery-based research projects in the area of biologically-inspired systems to support machine learning applications. Among them, 6 were female, and 2 were male teachers. Five taught high-school math, 1 taught middle-school math, and 2 taught high-school science. One teacher was African American. All of the teachers were from Title I schools. Six teachers were from schools where at least 97% students were from the underrepresented minority group, and 1 teacher's school had more than 70% students from the underrepresented minority group.

Before the Summer Program

The RET site directors - Drs. Na Gong and Shenghua Zha - worked with school districts, research mentors, and advisory board members on the participant recruitment and selection. After participating teachers were identified, the team conducted a pre-assessment. An online survey was sent to them and asked them questions related to their demographics, prior knowledge in computing and engineering, and STEM teaching experiences. The team analyzed the survey responses, identified participants' existing knowledge/skills, and conducted training for faculty mentors & graduate students (GAs).

Orientation

The six-week summer program began with an orientation day for all RET participants. Ice-breaking activities were conducted to help participants, PIs, faculty mentors, and GAs know each other. Drs. Na Gong and Shenghua Zha gave an overview of the program and addressed logistics issues, such as lab access, pandemic policy, and parking permits, as well. Orientation also included seminars on Research Methodology and Ethics, and Safety Training. Four faculty mentors introduced their specific research projects. At the end of the orientation, four cohorts were formed, and each cohort had two teachers. Teachers from different STEM areas were assigned into cohorts with the relevant focus.

Preparatory Learning Module

A four-day preparatory learning module was implemented for four cohorts following the orientation, which was led by faculty mentors and GAs. The preparatory learning module provided the participants opportunities to learn the necessary skills that are needed to conduct

authentic research in the summer research program. The learning was embedded in the discovery-based research method that would be utilized in this and the following five weeks of the program [7]. All participants were required to participate in this learning module. Teachers were trained to become familiar with the needed programming language, design tools, and equipment/facility, so that teachers were able to conduct basic platform operations at the beginning of the research project. Although the lab experiments were conducted in cohorts, discussions and reflections were hosted at the class level. This was to ensure all participants' access and equity when getting ready for the research in the following weeks.

Authentic Projects in Summer Program

After Week 1, each teacher cohort worked with mentors and GAs to conduct research on their specific research projects. For each research project, the teachers' research experience was designed following the engineering design process, which has been emphasized by Next Generation Science Standards (NGSS) and Alabama Course of Study Standards to promote K-12 engineering education. Specifically, teacher cohorts worked on four discovery-based research projects and obtained transdisciplinary research experience on biologically-inspired computing systems spanning application, algorithm, architecture and circuit, and device: (i) Application – Excitation-Scanning Hyperspectral Imaging of Tissues for Cancer: The cohort worked with advanced hyperspectral imaging techniques for early detection of pathological processes in the lung, colon, and other tissues; (ii) Algorithm – Implementation of Spiking Neural Networks (SNNs) for Cancer Detection: The cohort designed and evaluated the effectiveness of SNNs; (iii) Architecture and Circuit – Power-Efficient Synaptic Memory: The cohort designed a low-power memory to effectively store data in machine learning systems; and (iv) Device – Mitigating Device Variations of Memristors to Enable Biologically-Inspired computing systems: The cohort analyzed and mitigated the device variations in memristor-based biologically-inspired computing systems. At the end of the summer program, each cohort gave a final research presentation and submitted a project report.

Curriculum Development

This RET summer program also provided the teachers a holistic ground for developing creative curricula modules and materials in mathematics, physics, biology, chemistry, engineering, and technology that align well with Next Generation Science Standard (NGSS) and Alabama Course of Study Standards. Based on their research experience, the RET teachers designed standards-compliant curriculum modules which they will implement in their classrooms during the academic year. In addition, the program offered workshops, seminars, and paired work for teachers to develop their lesson and curriculum ideas. This project has developed a lasting relationship between the university, the K-12 schools, and the surrounding community that can help to build a strong educational foundation in the schools supported by the university and the other partners.

Program Evaluation

The team delivered a pre-survey before and a post-survey after the summer program. All eight teachers responded to the surveys. Results showed an improvement in teachers' technological

pedagogical content knowledge (TPACK) at the end of the six-week summer program (N=8, $Mean_{pre}$=3.98, $Mean_{post}$=4.32).

The team asked teachers to define biological-inspired computing in the pre- and post-surveys. In the pre-survey, two teachers acknowledged that they did not know what that was. Six teachers gave the wrong interpretations. One teacher used the term AI but did not explain it, but later that teacher gave an accurate explanation of AI and biologically inspired computing in the post-survey. Only one teacher gave the right answer in the pre- and post-surveys. The other seven teachers provided a detailed explanation of biologically inspired computing in the post-survey, e.g., "*The goal of biological-inspired computing is to mimic biological systems in order to improve the efficiency of our current technology. The example I have learned this summer is the mimicry of the operation of a nerve cell in the process of machine learning.*" (answer provided on July 22, 2021).

We also asked teachers to describe instructional strategies to help their students learn biologically inspired computing. Teachers in the pre-survey described general strategies, such as hands-on learning and visualization, e.g., "Crossover/Cross curriculum learning, project based learning, incidental/accidental learning". One teacher said that he/she hoped to learn in the summer program. In the post-survey, the strategies that teachers described were contextualized; they were able to offer concrete examples to describe the strategies, e.g., "*Using technology to teach new science concepts by performing discovery-based hands-on activities in the classroom. Afterwards, taking that knowledge and applying it to real world issues/problems. This year, I will be using a flipped classroom in my Anatomy class in order to be able to fit more hands-on activities in the school year.*"

When answering how the summer program affected their development of classroom pedagogy, all eight teachers offered positive examples, e.g., "1) *I learned a lot in the research section. The group discussion was helpful* 2) *I especially liked the trying of the mirco-bits and other tools we could use in the class room*". Another example is "*The discovery-based and group discussion based sessions really helped me better understand how technology and science work together to produce results. I regularly use discovery-based instruction as well as groups in my classroom, but now since I have gone through those steps myself, it has given me a better idea of where to look for problems as the students are learning. The instructional strategy workshops were also very beneficial. All professors provided me with tools that I plan to use in my classroom.*".

Overall, teachers had a positive experience with the six-week summer program. Their average rate is 3.72, ranging from 3 to 4. 3 means agreeing and 4 means strongly agreeing that they enjoyed and were satisfied with the program. They thought it was a good experience.

Conclusion

The program evaluation results suggested that this RET project was successful in achieving the outcomes for the teachers. All teachers successfully finished the implementation of curriculum modules in Fall 2021. The team also conducted the follow-up activities in Fall 2021. Currently, the team is working with all teachers on the implementation in Spring 2022.

Acknowledgments

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