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Integrating Data Science into the Pipeline Building Toward a Diversified Workforce in Nuclear Energy and Security

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Abstract

A workforce equipped with essential data analytics skills is crucial to maintaining the United States' economic growth and security, especially for nuclear energy industries and non-proliferation. Data analytics skills are in high demand in order to generate data-driven, robust solutions to solve global challenges and support decision-making for stakeholders in nuclear energy and security areas. This paper presents the technical approach that facilitates the integration of fundamental data analytics skills into pipeline building toward a diversified workforce through a suite of well-designed, comprehensive summer enrichment programs for high school, undergraduate and graduate students. The summer programs incorporated lectures, hands-on labs, group projects and/or national lab intern experience. In the last three-year's implementation, the student assessment and project completion result all showed the effectiveness of the approach in enhancing students' ability to understand the science foundation, identify real-world problems, analyze data and develop data-driven solutions in nuclear energy and security areas. The feedback from student surveys is also satisfactory and positive. This research is sponsored by Department of Energy/NNSA and intends to share the project team's experience and lessons learned with the STEM education community.

Keywords

Data Science, Workforce Development, STEM Education, Nuclear Energy and Security

Introduction

Data analytics is the process of inspecting, cleaning, transforming, and visualizing data with the goal of discovering insightful and critical information for decision making [1]. The integration of data analytics in STEM education has had a profound impact on the advancement in every sector of industries, government, and academia today. A workforce equipped with essential data analytics skills is crucial to maintaining the growth and security in nuclear energy area. Research shows that data analytics skills are in high demand in order to generate data-driven, robust solutions to solving the challenges that our society is facing today [2][3]. As major nuclear science and engineering problems rely on predictive computational modeling and simulation, understanding and use of nuclear data is extremely important. Nuclear data "impacts design, efficiency and operation of advanced reactors and security applications" [4]. Data analytics plays a crucial role in increasing safety, reliability, and economic viability [4][5].

However, the current K-12 and higher education curricula are lacking in data analytics especially for nuclear energy and security. Hence, there is an urgent need to explore innovative approaches in order to integrate data analytics skills into pipeline building to strengthen the future workforce in those areas.

In this paper, a pilot study that includes the strategies and practice to integrate data analytics into summer enrichment programs in nuclear energy and security hosted at Alabama A&M University is presented. The findings and lessons learned from this study are also presented with the intention to share our experience with the instructors and administrators to advance data science education at MSIs/HBCUs.

Related Work

In the past decade, educators and researchers realized the importance of data analytics in transforming STEM education. It was shown by Maier-Hein et al. [6] that incorporating data analytics and exposing students to real-world datasets improved their critical thinking. More impressively, data science education encourages students to explore STEM careers and also provides a strong foundation for further education and future employment opportunities as studied by Marques et al. [7].

Data Analytics in STEM Education

Brown et al. [8] integrated data analytics in engineering education to address technical requirements from a multicomplex environment perspective concept using data analytics tools such as IBM Watson Analytics. The results obtained from a multi-complex environment have aided students and improved their decision approach to quantify data accuracy and project requirements. The integration of analytics tools fostered the engineering students the ability to forecast requirements and create new methods critical to their engineering design.

Data analytics was also added to a core course on product manufacturing in the industrial engineering curriculum [9]. The pedagogical method was developed by first analyzing and comparing product manufacturing processes and data analytics techniques. Then the result of this analogy was used to develop a teaching and learning method for data analytics. For implementation and validation purposes, a Project Based Learning (ProjBL) approach was adopted, in which students used the methodology to complete real-world data analytics projects. Data from students' grades shows that this approach improved their performance [9].

Recently, Bonfert-Taylor et al. [10] developed multiple data science modules for various engineering and social science courses using R and MATLAB tools. In addition, they offered data science internships and interdisciplinary data science projects as experiential learning opportunities. A student survey tool was developed to measure the student attitude toward data science in four aspects: Interest, Value, Career, and Self-Efficacy.

However, learning fundamentals of data analytics is a form of complex learning, as many concepts and theory are abstract, counterintuitive, and challenging to understand, thus not accessible to learners, especially in minority communities due to instructional resource constraints. Therefore, our pipeline-building summer enrichment programs are motivated to address this gap.

Project-Based Learning (ProjBL)

Active learning pedagogies have been widely touted as beneficial to student learning [11] retention [12] and engagement. Also, learning outcomes are better when students are active participants in the learning process [13-14], especially for underrepresented students [15].

Teaching is an art of encouraging students to become active learners and awakening their enthusiasm to explore and absorb new knowledge and skills. On the other hand, learning is a dynamic process in which both the teacher and students should actively participate, exchange views, and ask/answer questions in an engaging atmosphere [16]. Student engagement has been shown to be a key factor in student retention in the STEM fields [17]. It has been abundantly demonstrated that pedagogical methods that promote conceptual understanding through interactive engagement of students are far more effective than traditional didactic instructional methods. Almost all of the newly developed methods on teaching and learning have concentrated on student-centered, inquiry-based approaches [18].

One of the successful evidence-based designs for teaching science and engineering courses is **Project-Based Learning (ProjBL)**[19]. ProjBL is an instructional methodology that encourages students to learn and apply knowledge and skills through an engaging experience. It provides students the opportunities for deeper learning and for the development of important non-cognitive skills for college and career readiness. Students drive their learning by inquires, research and collaboration toward the completion of the projects. The role of the instructor shifts from a content-deliverer to a facilitator and mentor. In ProjBL, students form a group and work more independently to complete the projects with the instructor providing support only when needed. Students are encouraged to make their own decisions about the project topics and how to complete. One of the main goals of ProjBL is to engage students in deep learning throughout the full project life cycle [19].

Our Approaches

The key objective of our project is to leverage active learning in conjunction with data analytics skills to increase students' exposure and interests and help them build up problem solving skills in nuclear energy and security areas. To achieve this, a team of faculty members in computer science, mechanical engineering and electrical engineering at Alabama A&M University diligently designed and implemented the summer enrichment programs by integrating data analytics skills into nuclear energy and security projects. This pilot study has focused on: (1) designing the summer programs by adding data analytics components; (2) incorporating ProjBL that promotes active student interaction, critical thinking, and problem-solving; and (3) conducting assessment and surveys to gather feedback from students. This section mainly describes the details of this pilot study.

The team has followed the logic model in Figure 1 that has been established in year one in this project. First, the team plans and designs the major components surrounding our project objective after thoroughly considering the deficiency area in K-12, undergraduate and graduate curricula in local schools and HBCUs. The length of each enrichment program is also decided: Two weeks for high school enrichment and ten weeks for undergraduate- and graduate enrichment. Learning outcomes are established to guide the lectures, labs and team projects.

This suite of well-designed, comprehensive summer enrichment programs for high school, undergraduate and graduate students have been implemented in the last three years. The summer programs incorporated lectures, hands-on labs, group projects and/or national lab intern experience as shown in Figure 2.

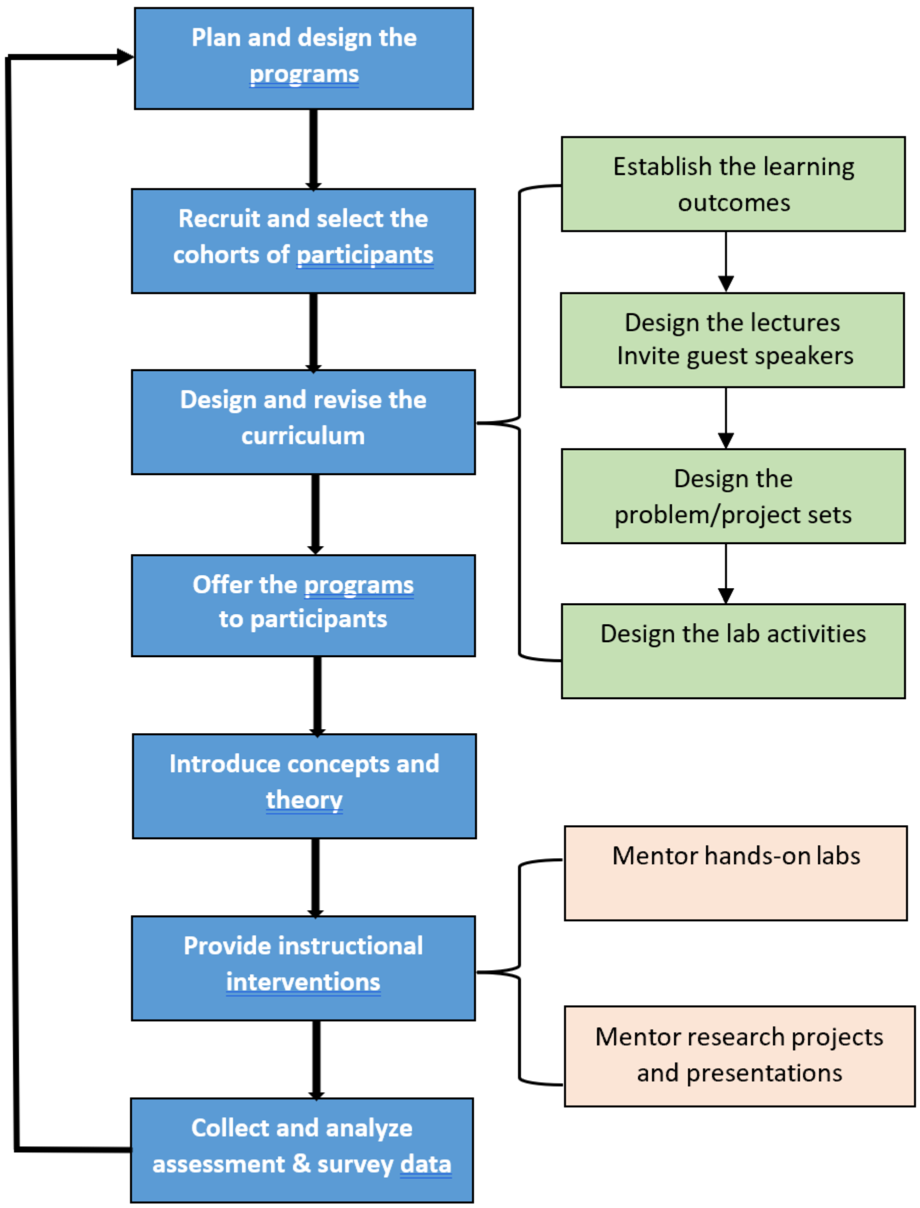

Figure 1. The Logic Model

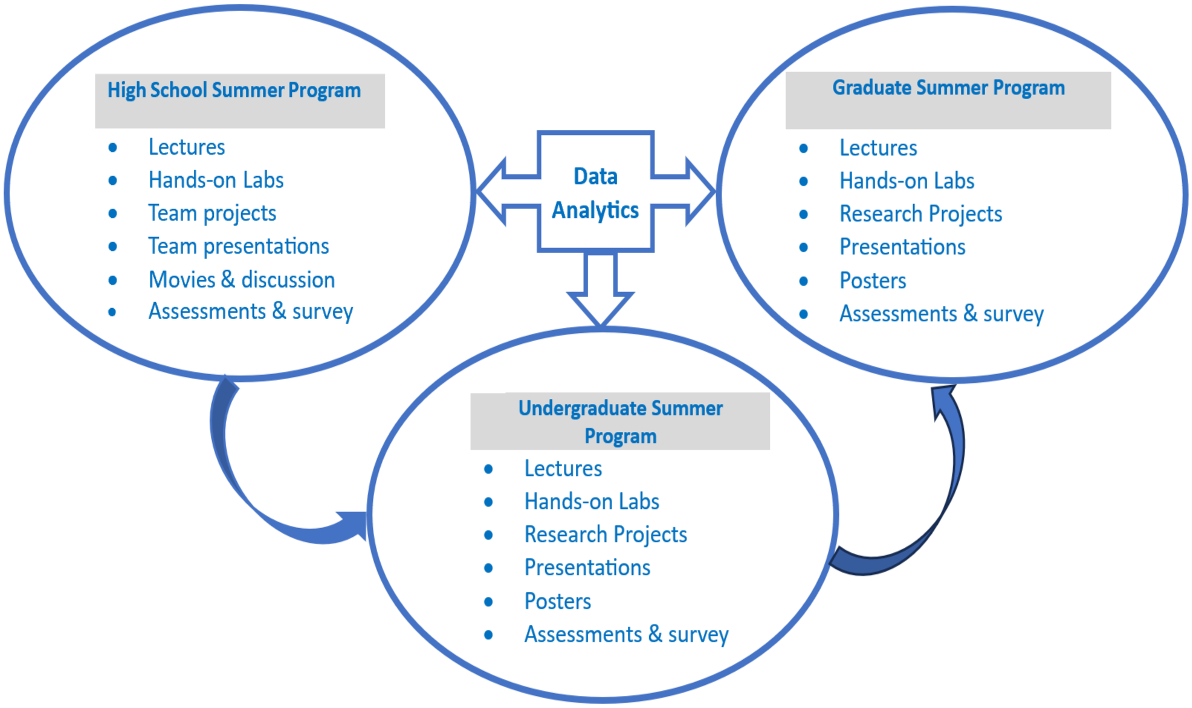

Figure 2. Components of Summer Enrichment Programs

Table 1 includes the data analytics related learning outcomes for the summer programs. Using the summer high school program as an example, lectures are given by full-time faculty members and experienced guest speakers at national labs for instructional quality, focusing on concepts, theory, emerging topics and technical challenges in data science, physics, nuclear energy, nuclear security, microelectronics, etc. Handson labs are added to reinforce the learning. Then students are given the opportunity to form teams and select a research topic to work on independently. Faculty members serve as the mentors, answering questions and guiding students when needed, but not giving solutions. At the end of the programs, students present their solutions via PPT presentations, posters and/or reports. An exit survey is conducted to gather feedback from students for further improvement in the next round. Three years (2021-2023) of implementation of the enrichment programs have been finished. Another two years (2024-2025) will continue as planned.

Table 1 Learning Outcomes, Activities and Assessments

Learning Outcomes	Activities	Assessments
Understand the basic concepts in data science	Lectures, labs/projects	Pre-test, post-test, Project presentation/poster
Understand the fundamental skills in data analytics	Lectures, labs/projects	Pre-test, post-test, Project presentation/poster
Understand the basic concepts in nuclear energy and security	Lectures, projects	Project presentation/poster
Be able to apply data analytics skills in problem solving in nuclear energy and/or security	Lectures, projects	Project presentation/poster

Since both undergraduate and graduate summer programs are ten-week long, students are offered the opportunity to work on research projects with the mentors at national labs. Students learned to use the lab equipment to collect data, and then used the computer tools to analyze and visualize the data. Figure 3 includes an example of the student project that tackles the technical challenges in room-temperature radiation detectors.

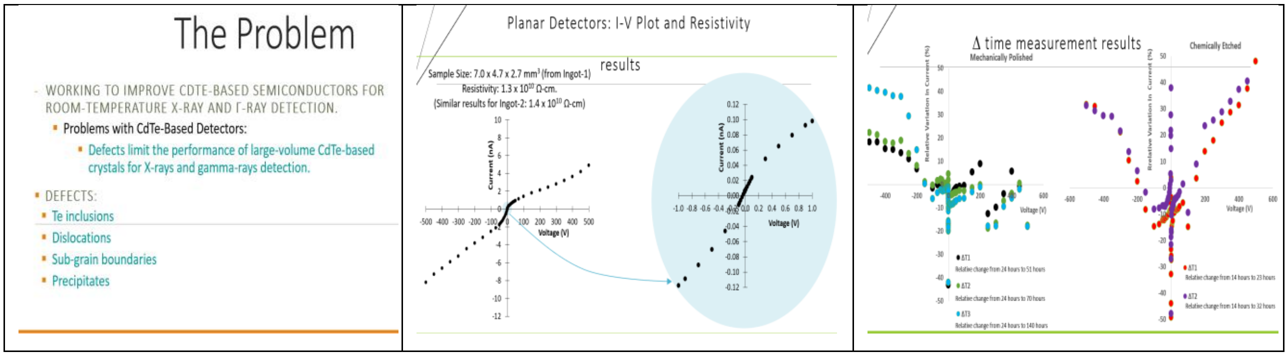

Figure 3. An example of student project: Problem Description(left); Examples of the data visualization results (middle and right)

In summary, the typical ProjBL activities follow a three-phase pedagogical approach: 1) Conceptual Phase (Learning): the students are first introduced to data analytics fundamentals, including concepts and theory. Then the students are exposed to the computing environment and software tools. 2) Experimentation Phase (Practice): The students are given the opportunity to implement and/or employ one data analytic method to process one sample dataset. The students are required to vary the parameters and observe the results. 3) Application Phase (Evaluation): The students are asked to employ various data analytic methods to process multiple datasets in the team project. The students then use the accuracy metrics and collect the results for comparison for different parameters. Students formed project teams and made their own decisions about how to split the work, when to meet, and how to complete the project tasks. The instructor provided support mostly during the Conceptual Phase and Experimentation Phase, then monitored the progress during the Application Phase.

Results and Discussion

This section summarizes the data and results obtained from the summer enrichment programs in the last three years.

The number of students in each cohort is included in Table 2. The student participants and minority students rates were relatively low in 2021 due to covid-19 disruption and remote learning/working in schools and universities, but were increased quickly in 2022-2023 with the team's recruiting effort and when the communities were back to normal operations, as shown in Figure 3.

Table 1. Student Participants in Each Cohort

Year	Number of Students			Minority Students Rate		
	High School	Undergraduate	Graduate	High School	Undergraduate	Graduate
2021	8	11	7	50%	100%	100%
2022	10	12	5	60%	100%	100%
2023	22	14	7	77%	100%	100%

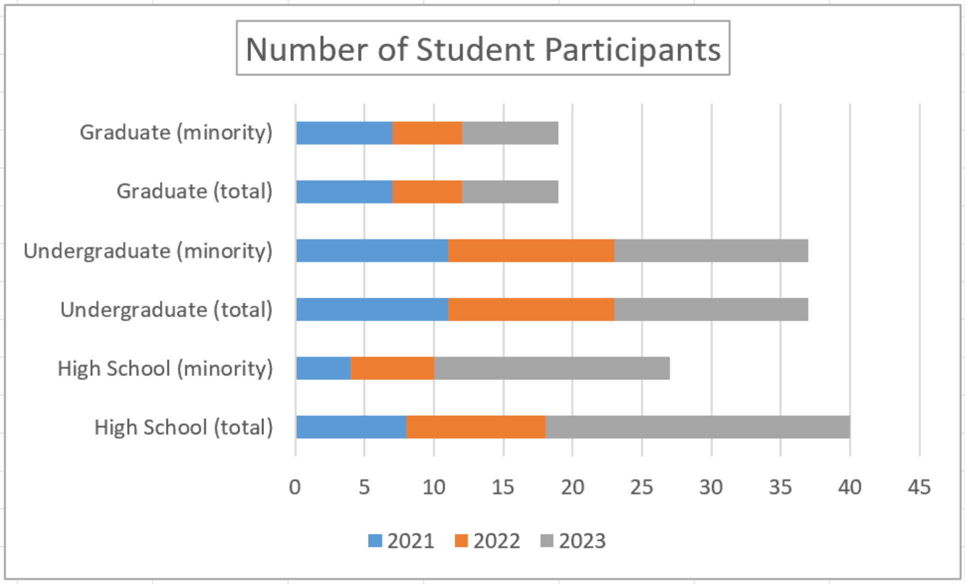

Figure 3. Student Participants Data

It is encouraging that the project completion rates are constantly high in the last three years as shown in Table 2, thanks to the tremendous efforts from the mentors and diligent work from the students. Similar satisfactory results can be found from the assessment data obtained from pre-tests and post-tests in Table 3.

Table 2. Project Completion Rate in Each Cohort

Year	Project Successful Completion Rate		
	High School	Undergraduate	Graduate
2021	100%	91%	100
2022	100%	92%	100
2023	100%	93%	100

Table 3. Assessment Data in High School Enrichment Program:
Percentage of students who get the correct answer to each question

Question	Year 1		Year 2		Year 3	
	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
Q1 on Python	50 %	100%	40 %	100%	45%	100%
Q2 on Regression	50 %	100%	30 %	100%	45%	100%
Q3 on Analytics 1	50 %	100%	40 %	100%	45%	100%
Q4 on Analytics 2	50 %	100%	40 %	100%	45%	100%
Q5 Analytics&Nuclear	25 %	100%	40 %	100%	45%	95%

In addition to the assessment, student surveys have been conducted to provide the evaluation and feedback. Table 4 summarizes the sample student survey results from 20 responses, which indicated positive feedback and favorable attitudes from students toward our program programs.

Table 4. Student Exit Survey Summary

Survey Questions	**Feedback**				
	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
The schedule and length of the program is appropriate.	75%	20%	0%	5%	0%
The topics covered in the program is helpful.	75%	25%	0%	0%	0%
The research project helped you gain the experience in data analytics and problem solving.	75%	25%	0%	0%	0%
This program inspired you toward your future career path or interest.	80%	20%	0%	0%	0%
Some suggestions to help improve this program	Add more advance topics; Add more hands-on activities; Add field trips; Add one more week; love this program, no need to change now; I really want to thank all spins team members and sponsors for this opportunity to be part of this summer camp. Specially, I wish to thanks for inviting to high school teachers and students to learn many important thing in science and technology.				

In addition to the positive turnouts in the last three years, there are also some lessons learned as the team observed. Firstly, due to the diversity of student background regarding school preparation, resources, and family support, it is a challenging task to equip students with data analytics skills and nuclear related knowledge in a short summer program for high schoolers. Our programs attempted to focus on the fundamental skills and increase the exposure and interests to the fields. Secondly, the workload for instructors and managing staff is heavy due to limited resources. Our endeavor is a pilot study and will seek the resources and personnel for sustainability purpose in the future.

Conclusion and Future Work

This paper presents the logic model and technical approach that facilitates the integration of fundamental data analytics skills into pipeline building toward a diversified workforce through a suite of well-designed, comprehensive summer enrichment programs for high school, undergraduate and graduate students. The summer programs incorporated lectures, hands-on labs, group projects and/or national lab intern experience. In the last three-year's implementation, the data obtained from assessment and the student projects all showed the effectiveness of the approach in enhancing students' ability to understand the science foundation, identify real-world problems, analyze data and develop data-driven solutions in nuclear energy and security areas. The feedback from student surveys is also satisfactory and positive. Lessons learned from our study include the challenges to accommodate the diverse school preparation and student needs, and how to deal with the workload due to resource and personnel constraints. Future study will continuously apply the same approach to integrating data analytics into ProjBL for workforce development in nuclear energy and security. Continuous data collection will be conducted as well to further verify the effectiveness. Findings will be shared with the STEM education community.

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