WIP: Collaborating to Introduce Second-Life Battery Technology Research in an Informal STEM Learning Environment

Hope Whiteside
Alabama Transportation Institute
The University of Alabama
Tuscaloosa, AL, USA
hope.whiteside@ua.edu
0009-0001-0827-4212

Joni M. Lakin
Department of Educational Studies
The University of Alabama
Tuscaloosa, AL, USA
0000-0002-0546-0554

Dominic Combs
Department of Educational Studies
The University of Alabama
Tuscaloosa, AL, USA
0009-0000-5820-6114

Shannon Davidson
Department of Curriculum & Instruction
The University of Alabama
Tuscaloosa, AL, USA
0000-0003-3583-4147

Bernadette Forrest
Department of Educational Leadership
The University of Alabama
Tuscaloosa, AL, USA
0009-0005-5247-0965

Jaber Abu Qahouq
Department of Electrical and Computer Engineering
The University of Alabama
Tuscaloosa, AL, USA
0000-0002-8974-3112

Abstract— **This work in progress, innovative practice, paper outlines an interdisciplinary collaborative model utilized by a team of educational researchers, and engineers to design a series of community-centered, place-based learning activities suitable for a middle or high school informal STEM learning environment. Based on the potential applications and benefits of Second-Life Electric Vehicle Batteries, the activities connect cutting-edge STEM research with multidimensional real-world challenges within their communities related to climate change, renewable energy integration and storage, intelligent transportation systems, and optimized energy management, that empowers students to think critically about the role they can play in shaping a more resilient, environmentally sustainable community.**

Keywords—inclusivity, middle school, sustainability, social cognitive career theory

I. Introduction

Despite STEM's direct impact on our daily lives, underrepresented minority (URM) students in rural areas frequently struggle to see the relevance of science, mathematics, and other STEM-related subjects taught in formal classrooms to their personal lives and future careers. This issue is compounded by rural areas often being STEM deserts, lacking opportunities such as summer camps and museums for students to explore STEM programming. Subsequently, the disconnect results in a lack of engagement, self-efficacy, and interest in STEM subjects, all of which are essential for developing a strong STEM identity. According to the principles of Social Cognitive Career Theory, students' personal characteristics—such as interests, values, and self-efficacy—are shaped by their learning experiences and the broader sociocultural influences that impact their career development [1]. Informal STEM learning environments, which provide hands-on, experiential learning opportunities in a flexible and engaging manner, can help address this issue [2]. These environments can ignite interest, boost self-efficacy, enhance understanding, and demonstrate the relevance of STEM concepts, thus bridging the knowledge gaps that exist. Consequently, these informal settings are essential for supplementing student learning and development outside the formal classroom [2].

To tackle this issue, our collaborative team adopted a community-centered, place-based approach that brought together a public university, K-12 institutions and community partners with a shared goal of fostering STEM identity, career aspirations and long-term engagement with STEM disciplines among URM students in grades 6-8. By offering hands-on, experiential STEM learning experiences, promoting student-led research initiatives, and providing advocacy platforms grounded in the latest research on the potential applications and benefits of Second-Life Electric Vehicle Batteries occurring in the students' communities, we aim to provide the resources and support URM students need to improve engagement, self-efficacy, and interest in STEM subjects. Ultimately, this approach aspires to inspire the next generation of URM STEM professionals.

The collaborative team places focus on making community and culturally relevant connections when designing the STEM learning activities highlighted in this study. Emphasizing community relevance is expected to foster STEM identity in line with the principles of culturally responsive pedagogy, Social Cognitive Career Theory and community-centered, place-based education. Place-based education provides meaning and relevance to learning experiences aimed at inspiring students, deepening their understanding of STEM concepts, and fostering a sense of responsibility towards their communities and the environment [3] (p. 3). Moreover, by grounding learning activities in the framework of their immediate community and surroundings, students can explore the natural links between STEM principles and its significance in their everyday environment. A 2016 research synthesis revealed that culturally affirming teaching methods such as Culturally Responsive

This material is based upon work supported in part by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Vehicle Technologies Program Award Number DE-EE0010402. The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

Pedagogy in subjects like math and science, boosted students' understanding and involvement [4]. A conscious effort was made to recognize and incorporate diverse cultural perspectives into the curriculum, ensuring students can see themselves reflected in the content, which fosters a sense of belonging and identity in STEM fields. Specifically, we included opportunities for students to engage with a diverse group of local STEM professionals and highlighted minority pioneers in U.S. engineering and power sectors. Building connections with local STEM professionals and acknowledging the achievements of engineering pioneers helps students and teachers realize that science and engineering are carried out by 'real people' from their communities who come from diverse backgrounds and experiences [5]. This exposure enables students to see individuals like themselves in STEM careers, fostering the development of a STEM identity for all students, particularly those from URM populations.

To this end, community-centered energy and sustainability concerns has been an essential feature of the project. The decision to focus the curriculum on energy and sustainability was intentional, given that this rural area, with a predominantly Black population, lacks access to green and sustainable energy options. This has led to significant energy, and environmental challenges, including higher exposure to toxic pollutants and the resulting health issues. The engineering research already occurring in the region provides the context for engaging engineering curriculum as well as student-initiated research projects. By partnering middle school teachers and students with educational researchers and engineers in the Alabama Black Belt region, this work aims to act as a ‘proof of concept’ for the deep STEM learning possible through the development of multi-stakeholder, community-centered, place-based STEM learning activities that prioritize the values, interests, and cultural needs of students and their communities.

II. INNOVATION

The collaborative team created a series of community-centered, place-based STEM learning activities designed for informal STEM learning environment at middle school in a rural, predominantly Black (98%), and low-income (93%) area aimed at fostering STEM identity, career aspirations and long-term engagement with STEM disciplines. Educational researchers, and engineers from nearby universities and community organizations serve as support facilitators with teachers and provide context for the hands-on activities. Such interactions between students, teachers, and university researchers and engineers from the community can humanize researchers—allowing them to share their passion and expertise, and to show how their highly technical work can directly impact students’ communities (Allen et al., 2015).

In this case, the learning activities are used in combination with the curriculum provided by the Future City program as well as hands-on activities developed by our collaborative team of teachers, university-based engineers, and educational researchers. The Future City Competition is a program for the middle grades where students are challenged to design a city with cutting edge technology and social solutions. The competition involves an essay, physical model, and interviews about the city designs. It is one of several competitions drawing on project-based learning methods to promote student learning about engineering and a variety of 21st century learning skills, such as teamwork, collaboration, and creativity [6], [7]. The theme of the 2023-24 competition, “Electrify Your Future,” challenged students to design a sustainable city focused on ensuring the safety and health of its citizens. This theme created a strong connection to the work of our engineering collaborators.

To prepare for the competition, students spent 3 to 4 months working collaboratively as a team, immersing themselves in engineering concepts. Throughout this period, they applied these concepts to identify and address several critical issues impacting their community. These included a lack of public transportation, frequent power outages caused by weather-related crises, and significant air pollution.

As they developed their model, students proposed innovative solutions to these problems, which were then simulated in their city design. The solutions focused on creating a 100% energy-independent infrastructure, highlighting the implementation of a stand-alone microgrid system. In their competition essay and presentation, students emphasized the cultural and social significance of their design, underscoring how a self-sustaining city powered entirely by green energy could serve as a model for resilience and sustainability in their community.

The students also recognized the importance of interdisciplinary collaboration in engineering. They explained how the successful design of their sustainable city required the combined expertise of various engineering disciplines, reflecting the real-world necessity of teamwork in tackling complex challenges.

Additionally, students discussed the anticipated positive impact of their design on the community, such as reduced carbon emissions, improved air quality, and a more reliable power supply. They also addressed the challenges they encountered during the project, including difficulties in calculating the fractional scale of their model, managing team decision-making, and balancing time effectively.

To overcome these challenges, students sought assistance from their math teacher to ensure accurate scaling, practiced compromise to reach collective decisions, and strategically assigned tasks to optimize time management. This experience not only enhanced their problem-solving skills but also deepened their understanding of the collaborative nature of engineering work.

The activities in Table 1 were used in conjunction with the Future City program to deepen the students understanding of engineering concepts such as renewable energy and electrification, to expose them to a diverse group of STEM professionals and highlight minority pioneers in engineering. These aspects are important due to the disparities in STEM programming faced by URM students in rural communities. These activities (Table 1) can be combined in different ways for informal learning opportunities. All units have been used in an informal STEM learning environment and individual components were used as demonstrations at a community STEM night event.

Energy and sustainability lessons occurred one day each week during the program (with other days focusing on other

STEM topics). In Fall 2023 we provided five lessons on renewable energy sources adapted from the Snap Circuit Green Energy Kit and five lessons on sustainability developed specifically for a Department Of Energy (DOE) project (Award # DE-EE0010402) on Adaptive Second-Use Battery Utilization.

Daily exit surveys, pre- and post-surveys of students' STEM identity (using the Role Identity Survey [RIS-STEM] [8]), and qualitative interviews helped explore the effects of these lessons on students' STEM identity formation.

TABLE I. CURRICULUM TOPICS

Unit	***Topic***	***Activities***
Renewable Energy	Introduction to Renewable Energy	Renewable energy expert introduces students to the concept of renewable energy and its environmental benefits. A showcase of renewable energy technologies, including solar panels, wind turbines, and hydroelectric models was provided for students to explore and interact with renewable energy technologies Highlighted: Minority Engineering Pioneer
	Harnessing Solar Power & Wind Energy	SnapCircuit Kit Activity: Solar Panels / Wind Turbines to introduce how solar panels and wind turbines produce energy, Design Challenge: Build a Wind Turbine Research and Present on: Diverse cultures traditional practices, such as solar calendars
	Understanding Hydroelectric Power	SnapCircuit Kit Activity: Hydroelectric Power to understand the process of converting water flow into electricity, Design Challenge: Build Miniature Hydroelectric Models, Research and Present on: Cultural Water Rituals
Electric Vehicles & Batteries	Introduction to Electric Vehicles & Batteries	Minority electrical engineer specializing in energy storage systems introduces several topics related to Electric Vehicles (EVs), such as how batteries are made, battery module/pack construction, and how electric motors work, *Hands-On Activities*: Make a simple battery cell and measure voltage, Construct battery modules and packs, Build a simple electric motor Highlighted: Minority Engineering Pioneer
Second-Life EV Batteries	Exploring Battery Repurposing	Electrical engineer specializing in energy storage systems introduces the concept of using batteries that are retired from EVs in other less demanding second-use applications such as community microgrids or off-grid power systems, to give them a second-life before the battery material is recycled. *Hands-On Activities*: Battery Reconditioning Workshop, Design Challenge: Battery-Powered Devices
	Renewable Energy Integration	Electrical engineer specializing in energy storage systems introduces the concept of how batteries can be charged from renewable energy sources such as solar energy and wind energy. *Hands-On Activities*: Solar + Storage Simulation, Design Challenge: Build a Wind Turbine w/ Battery Backup
	Community Applications of Second-Life EV Batteries	Students conduct mock needs assessment within the community to identify potential applications of second-life EV batteries in addressing local energy needs.
	Project Implementation	*Prototype Development* - In teams, students design and build prototypes of renewable energy projects incorporating a simulation of second-life EV battery technology, such as community microgrids or off-grid power systems. *Future City Competition* - Students present their projects to engineering professionals highlighting the cultural and environmental benefits of using second-life EV batteries in renewable energy systems.

III. Methods

The informal program serves students in grades 6-8 who are enrolled in a rural, under-resourced school that has a 98% African American population. Our mixed methods research explores the impact of community-centered STEM activities on students' STEM identity formation. Our central data focuses on pre- and post-program surveys of STEM identity (using the Role Identity Survey for STEM [RIS-STEM] [8]) as well as qualitative interviews.

We conducted two focus groups with 3-4 students each. One group was highly involved in the future city competition, one group was consistently involved in afterschool but not as involved in the program while the competition was underway. Some of the questions included:

1) What have been some of your favorite activities or projects in STEM club? What do you hope we learn more about in STEM Club in the future?
2) When you think about the Future City project - What did you like about working on Future City? What did you feel like you were learning?
3) How are the activities you've been doing each week in STEM club connected to your community and/or home?
4) What kinds of careers do you know about that are related to STEM or use ideas and skills related to STEM?

IV. Evaluation & Findings

The preliminary results of the pilot study are positive, suggesting that students are exploring STEM interests through the initial learning activities. In addition to renewable energy, the focus of these lessons was on understanding electrical grids and how their reliability and security can be improved through new technology. Students used the concept of a "microgrid" in their Future City model to demonstrate community's sustainability through its 100% energy-independent infrastructure as depicted in Figure 1. This feature contributed to the team receiving the special award, "Best Use of Sustainable Infrastructure" at the state competition.

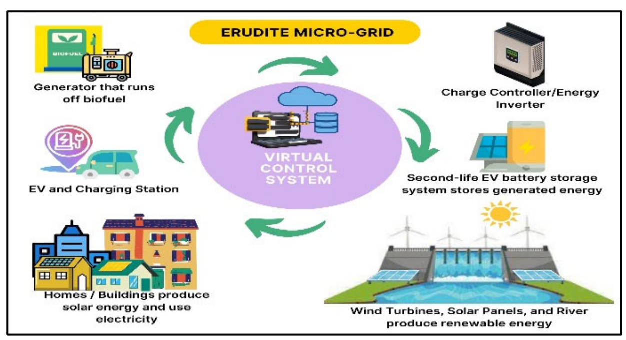

Fig 1. Future City model for energy-independent infrastructure

Another highly successful lesson was the "Introduction to Electric Vehicles & Batteries." Students were excited to learn about anything related to electric vehicles and learned that the greatest negative environmental impact of electric vehicles is their batteries and that extending the useful life of those batteries would increase the sustainability of EVs.

Figure 3 shows the model built by the Erudite Society (the name chosen by the students for their club and competition name). Students included an rural agricultural region similar to their community (to the left of the model) which produces not only fresh food but also biofuels (from plant material and animal waste). A mag-lev highway (public transportation) connects this area to the residential/commercial area (to the right of the model) where homes have integrated solar panels, EV charging stations, and a microgrid that protects their community from disruptions in other grids in the area. The whole community is powered by energy collected through solar panels, hydroelectricity, and wind turbines. The model incorporates components from the SnapCircuit Kit, demonstrating how energy generated from various sources can be stored in second-life batteries and converted into usable energy to power a functioning fan.

Fig 2. The Erudite Society's Future City Model

A. Teacher Ratings

The Future City program sent a formal evaluation survey to teachers who participated with students. We asked the teachers to provide us their ratings to those questions for our internal review. All four teachers provided ratings, which are reported here. We also selected a subset of questions and simplified the rating scale for use with students. Seven students completed the survey and we calculated percent agreement to equalize student and teacher rating scales. This allows us to compare the reactions that both students and teachers had to the FC experience. See Figures 3 and 4.

The teachers believed Future City increased their students' confidence for STEM activities, interest in STEM, and preparation to use the engineering design process. They were also confident that students learned how engineering solves real world problems as well as strengthening their math and science skills. Students most agreed that it increased their confidence to do STEM activities and that it strengthened their math and science skills. In terms of specific skills, teachers felt most strongly that Future City increased students' problem solving and teamwork skills. Students were less confident their teamwork skills increased, but rated problem solving, time management, and public speaking as other areas most impacted by the experience.

B. Students' STEM Identity

We used pre- and post-program surveys to look at students' changes in STEM identity as a result of the afterschool program (of which Future City and associated lessons were one component). Nine students completed the pre-unit survey and 10 completed the post- survey. Only five were matched and the rest were from other regular attendees who happened to miss or one the other date. The table below shows an independent samples analysis (n=18).

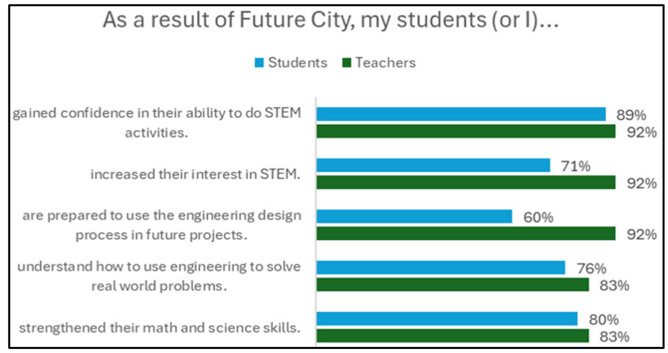

Fig 3. Teacher and student perceptions of benefits to student beliefs and skills

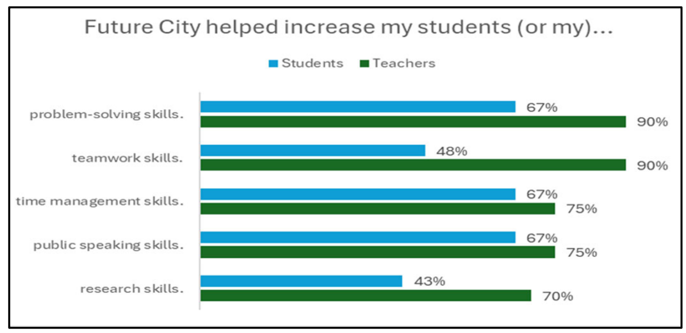

Fig. 4 Teacher and student perceptions of benefits to student skills

TABLE II. CHANGES IN STUDENT STEM IDENTITY USING RIS-STEM

	Pre		*Post*		*t-test (17)*
	M	SD	M	SD	sig.
Efficacy	3.2	0.3	3.8	0.3	0.03
Interest	3.6	0.4	3.6	0.5	0.62
Self-recognition	3.0	0.5	3.2	0.1	0.63
Others' recognition	3.0	0.4	3.5	0.5	0.15

The gain in self-efficacy was significant while the other changes were not. These results agree with the Future City survey results above, where students rated their gains in confidence among the largest benefits from the experience.

C. Focus Group Findings

When asked what they learned from Future City, the main responses included teamwork and collaboration skills as well as how to communicate ideas to others through writing and public speaking. The FC competition requires an essay describing their city model and design choices. Two of these students also presented the model and answered the judges' questions.

When asked about their favorite experience during the school program, one student named Future City. This student saw direct connections to community in terms of sustainability and the need for recycling of EV batteries. This student recalled that EV batteries could be used to set up microgrids that run off of second-life EV batteries to power homes. This student was eager to advocate for these solutions, stating that "[Hometown] & Alabama should use our ideas". Additional findings from focus groups suggest:

- **Understanding STEM:** For these students, STEM embodies a program that encompasses science, technology, engineering, and math, offering opportunities to innovate, build for the future, and acquire new skills.
- **Engagement and Feelings:** Participating in STEM activities elicited feelings of excitement, involvement, and learning. However, encountering challenges also led to feelings of being both challenged and frustrated, providing opportunities for learning and growth.
- **Career Knowledge:** Their exposure to STEM activities broadened their awareness of potential career paths, including scientists, architects, engineers, computer scientists, and accountants. Personal connections to family members in engineering fields further reinforced their understanding of the impact of STEM in everyday life.
- **Community Connections:** Students recognized the relevance of STEM in their communities, citing examples such as their father's role as a handyman with engineering skills, influencing their perception of engineering's impact on everyday life.
- **Suggestions for Improvement:** While overall satisfied with the program, students suggested improvements such as inviting more professionals from relevant fields, providing background information on projects, and incorporating newer technologies for enhanced precision.
- **Future Learning:** Students expressed interest in learning more about future cities, technology, electronics, coding, and various STEM-related topics, indicating a desire for continued exploration and expansion of their STEM knowledge.
- **Future City Project Reflections:** The Future City Project provided valuable learning experiences in teamwork, electricity, sustainability, and innovation, empowering students to envision and advocate for innovative solutions within their communities.
- **Motivation to Join Afterschool Program:** Students expressed various motivations for joining the afterschool STEM program, including a genuine interest in science and technology, seeing peers enjoying the program, the fun aspect of engaging in different projects, and parental influence. While some students were encouraged by specific educators, one male student mentioned being compelled to join by his mother.

V. Conclusions

In this work, we have outlined an innovative interdisciplinary collaborative model aimed at addressing the critical need to foster STEM identity, career aspirations, and long-term engagement with STEM disciplines among URM students in grades 6-8. By adopting a community-centered, place-based approach, our team endeavors to bridge the gap between formal STEM education and the lived experiences of students in rural areas, particularly those in STEM deserts. Through a series of hands-on, experiential STEM learning activities, grounded in the context of their immediate communities, we have sought to empower students to critically engage with real-world challenges related to energy, sustainability, and environmental resilience. By leveraging the potential applications and benefits of Second-Life Electric Vehicle Batteries, we aim to inspire students to envision themselves as active participants in shaping a more sustainable future for their communities.

Our approach is underpinned by principles of culturally responsive pedagogy, Social Cognitive Career Theory, and community-centered, place-based education, which emphasize the importance of relevance, inclusivity, and cultural affirmation in STEM learning experiences. By intentionally integrating diverse cultural perspectives and providing opportunities for students to engage with local STEM professionals, we strive to create a learning environment that fosters a sense of belonging and identity in STEM fields, particularly for URM students. Preliminary evaluation findings suggest that our efforts have had a positive impact on students' STEM identity formation, with notable gains in self-efficacy and confidence in STEM activities. Furthermore, feedback from both teachers and students highlights the value of project-based learning experiences, such as the Future City competition, in enhancing students' problem-solving skills, teamwork, and preparedness for using the engineering design process.

We recognize the importance of ongoing assessment and refinement of our approach to ensure its continued effectiveness and relevance. By continuing to collaborate with stakeholders and leveraging community resources, we aim to further strengthen the connection between STEM education and the aspirations of our students, ultimately empowering them to become the next generation of STEM leaders and innovators in their communities and beyond.

References

[1] R. W. Lent and S. D. Brown, "Social cognitive career theory at 25: Empirical status of the interest, choice, and performance models," *Journal of Vocational Behavior*, vol. 115, p. 103316, 2019.

[2] C. Maiorca *et al.*, "Informal learning environments and impact on interest in STEM careers," *International Journal of Science and Mathematics Education*, vol. 19, pp. 45–64, 2021.

[3] L. Nadelson, A. Seifert, and M. McKinney, "Place-Based STEM: Leveraging Local Resources to Engage K-12 Teachers in Teaching Integrated STEM and for Addressing the Local STEM Pipeline," in *2014 ASEE Annual Conference & Exposition Proceedings*, Indianapolis, Indiana: ASEE Conferences, Jun. 2014, p. 24.983.1-24.983.21. doi: 10.18260/1-2--22916.

[4] M. Will and I. Najarro, "What is culturally responsive teaching," *Education Week*, vol. 41, no. 33, pp. 16–18, 2022.

[5] S. G. Davidson, L. Z. Jaber, and S. A. Southerland, "Cultivating Science Teachers' Understandings of Science as a Discipline," *Sci & Educ*, vol. 31, no. 3, pp. 657–683, Jun. 2022, doi: 10.1007/s11191-021-00276-1.

[6] K. M. Gardiner, "The future city competition-A successful STEM experience for middle school students," in *Proceedings, ASEE New England Section Conference, Univ. of Rhode Island*, 2007.

[7] K. M. Gardiner, "Virtual and collaborative project-based learning," in *ASEE Northeast section conference*, Citeseer, 2012. Accessed: May 20, 2024. [Online]. Available: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=bf3eb8f575bf076c4271acb1222375290a0fe0d9

[8] K. M. Paul, A. V. Maltese, and D. Svetina Valdivia, "Development and validation of the role identity surveys in engineering (RIS-E) and STEM (RIS-STEM) for elementary students," *IJ STEM Ed*, vol. 7, no. 1, p. 45, Dec. 2020, doi: 10.1186/s40594-020-00243-2.