

Linking Engineering to Life: Expanding Gender Diversity in STEM Through an Afterschool Program

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Amber Doiron is an Assistant Professor in the Department of Electrical and Biomedical Engineering at the University of Vermont. She received her B.S. in Chemistry from Colorado State University in 2003, and she was an NSF-IGERT fellow while earning an M.S. and Ph.D. in Biomedical Engineering from the University of Texas at Austin. She was the T. Chen Fong Postdoctoral Fellow in Medical Imaging in the Departments of Radiology and Chemical Engineering at the University of Calgary. Dr. Doiron also served as the chief scientific officer at NanoPulse Biosciences LLC for four years.

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Nicole is deeply committed to ensuring equal access to third space programming for all Vermont youth. After serving as Vermont Afterschool's assistant director for nearly three years, focused on strengthening programs, statewide quality efforts, and the interconnectedness of the VTA team, Nicole was hired as the organization's executive director. In this role, she spearheads the organization's work in ways that build partnerships, support programs, empower youth, and transform communities so that all of Vermont's children and youth have opportunities to be active, engaged, connected, and heard. She is responsible for managing our dynamic team professional staff, developing strategy, and implementing programs that make youth-serving organizations and communities stronger for Vermont's children, youth, and families. Nicole is also responsible for securing grants and funding opportunities, building ongoing relationships with funders and partners, and leading on our statewide policy efforts. She has more than 16 years of experience in afterschool programming and youth development, serving 10 years as a program director of a rural afterschool program in northeastern Vermont, and five years in providing professional development workshops for other afterschool professionals. She has a BA in Elementary Education from Johnson State College and believes that all youth should have access to high-quality and engaging afterschool programs. In 2014, Nicole was chosen as a Next Generation Leader by the National AfterSchool Association.

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Background

The vitality and diversity of the Science, Technology, Engineering, and Math (STEM) workforce is a significant concern in the US, according to the 2022 US National Science and Engineering Indicators, in part due to the “missing millions” of workers from the underrepresentation of women and historically marginalized communities [1]. The need for skilled workers in STEM continues to grow, yet women make up only 1/3rd of the STEM workforce [1]. This issue is even more pronounced when considering the field of engineering where women hold only 16% the jobs. Furthermore, students in high-poverty populations score significantly worse on mathematics and science assessments in 4th and 8th grade, and classroom teachers with less experience in STEM are more prevalent at schools with high-minority or high-poverty populations [1]. The pandemic exacerbated disparities, with isolation and limited opportunities for formal and informal educational engagement. K-12 education in mathematics and science are the foundation for entry into most STEM-related occupations, and interventions in early education are seen as a promising avenue to move girls towards careers in engineering.

Compared to classroom teaching, afterschool programs are unique in their ability to offer more time-flexible, hands-on activities that advance student-centered learning, which is crucial in STEM education [2] - [4]. Linking Engineering to Life (LEL) is an afterschool, experiential engineering curriculum launched in the fall of 2020 by Vermont Afterschool, a statewide nonprofit dedicated to strengthening programs, empowering youth, and expanding access to afterschool and summer programs so that all Vermont youth are active, engaged, connected, and heard. LEL’s goal is to overcome barriers of access and affordability in engineering education for Vermont girls and non-binary middle school-aged youth. While the challenges facing women in engineering do not overlap completely with those facing non-binary engineers, our program mentors these youths as we continue to learn about these differences. LEL was created in spring 2020 in response to The Million Girls Moonshot, an initiative of the STEM Next Opportunity Fund, which seeks to re-imagine who can engineer, build, and create by engaging one million more girls in afterschool and summer STEM learning programs. LEL Basics introduces the engineering design process through ten weeks of engineering challenges while elevating female and non-binary success in STEM. Trained undergraduate engineering Mentors and afterschool staff facilitate LEL. LEL now also offers a biomedical engineering (BME) curriculum created in partnership with Northern Vermont Area Health Education Centers (NVTACHEC), a non-profit entity for health career exploration and training. LEL has recruited 69 Mentors who led both virtual and in-person curricula for 214 youth. LEL afterschool site recruitment in 2020 (Year 1) was a statewide opportunity launched during the initial months of the pandemic with a majority of sites participating from low income, rural and urban program sites. In subsequent years, attention has been paid to returning LEL sites and programs who have 50% or more youth living at or below the poverty level.

Curriculum Development

The LEL program operates through interactions between learners who identify as girls or non-binary youth, college-age Mentors who oversee and help lead the weekly design activities in coordination with the on-site afterschool staff, and management provided by Vermont

Afterschool who coach and train Mentors, oversee curricular implementation, and assess the program. Youth learn to use the engineering design process as a tool for solving a weekly engineering challenge (Table 1) and gain knowledge about different engineering fields. They identify a problem, determine a goal, test material properties, and design a prototype within set criteria and constraints. Each engineering challenge is relevant to youth, aligns to real-world problems, uses accessible and affordable materials, and is age-appropriate in complexity.

Table 1. Example Modules from LEL Basics and LEL BME

Module	Challenge
Water Filter	To design a filtration system to produce a half cup of clean water from one cup of “dirty water” made from coffee grounds, dry beans, food coloring and vegetable oil.
Human Survival in Cars	To design safety features to protect a “passenger” (raw egg) in a small cardboard car that would roll down a ramp and collide with a brick wall.
Catch That Toad	To design a trap that would catch an invasive species (toy toad) that must be activated at least 4 feet away from the trap.
Wind Powered Water Pump	To design a wind turbine connected to a water pump that would pump water from a container using only the force of air from a fan.
Protecting the Pill	To design a coating for a “pill” (Skittle candy) that would not be bigger than a dime and would not bleed any candy color when submerged in clear soda.
Clearing a Pathway to the Heart	To design a mechanical solution to expand an “artery” made by packing 2 inches of Playdoh inside a 6” section of PVC pipe with a pencil pushed through to represent the level of blockage.
A Better Bandage	To design a bandage by experimenting and incorporating hydrogels into traditional bandaging materials. The design must stop the 3 oz of “bleeding” on an “injured” arm
Prosthetics Prototypes	To design a prosthetic hand and/or leg that meets the needs of the client: comfort, stability, durability and function.

An essential element of the LEL program curricular design is the recruitment, training, and support of college-aged women and non-binary people as Mentors. Engineering students from the University of Vermont were provided support by (1) in-person and/or virtual training, (2) ongoing Mentor team check-ins by the LEL Leaders, (3) LEL Informational Videos to guide each session, (4) an LEL Guidebook with session outlines and content links, (5) a materials kit, and (6) a series of *Women in STEM* Inspirational Videos. During training, Mentors test each LEL engineering challenge while Vermont Afterschool trainers model STEM facilitation skills. With training and experience, Mentors become proficient at asking purposeful questions that encourage youth to share their thinking, to persist in redesigns, and recognize what is expected of an engineer. While the principal recipients of education are the students in LEL afterschool programs, Vermont Afterschool envisions this program as a strong career

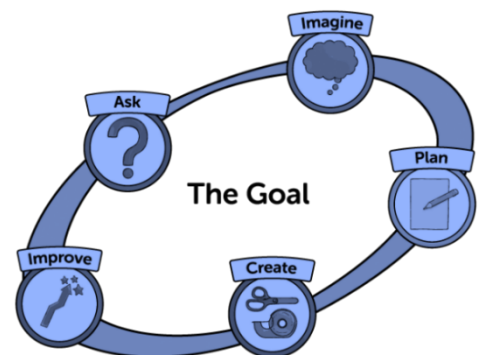


Figure 1. Engineering Design Process, www.eie.org

development opportunity for Mentors who gain experience communicating science and engineering to lay audiences, learn to teach, and solidify their own understanding of the engineering design process through practice.

Over the course of the LEL program, Mentors teach and reinforce the use of a five-step engineering design process (Figure 1) created by the Museum of Science, Boston Engineering is Elementary©. This educational paradigm requires youth to consider the goal, ask questions, determine the criteria and constraints, independently imagine solutions, sketch ideas, manipulate materials to collect data on their properties, and then begin to create a prototype. The youth are taught that using the engineering design process is a foundational skill set that results in better success and less frustration than trial and error. To solidify these skills, Mentors are encouraged to acknowledge aloud when they observe youth using the engineering design process, or to redirect them to Figure 1 to place themselves in the process. Additionally, Mentors positively reinforce students demonstrating inclusiveness, acceptance of new ideas, and awareness of their own emerging “STEM identity”, meaning their enjoyment of and capability in engineering. An increase in self-perception is recognized as one of the most impactful outcomes of afterschool programs [5], [6].

Finally, the LEL *Women in STEM* Inspirational Videos are played weekly at the start of the design challenge to elevate female and non-binary success stories in STEM careers. Mentors reflect on the messages shared by those featured in the videos and to ask youth questions about what they perceived as barriers to women, especially women of color, women with disabilities, and women with minimal financial means. The videos create a platform for girls and non-binary youth to share their perspectives about diversity through the lens of a STEM learning experience.

Implementation

In the pilot year, LEL delivered bins of engineering materials for up to 12 youth at each of the 10 pilot sites around Vermont.

Afterschool program staff chose either to distribute materials for individual youth to participate from home or to supervise in-person group work while being virtually connected to the LEL Mentors. In either case, the need for reliable internet in the rural communities was important for video communication – a factor that emerged as a barrier for some sites that ultimately required adjustments to scheduling and site location.

In the fall of 2021, the pandemic intensity lessened, and in-person school resumed as did many afterschool programs, and the LEL program was revised. A new partnership was established for Year 2 with NVT AHEC that expanded the content to allow for two afterschool LEL program options: LEL Basics and LEL Biomedical (LEL BME). New afterschool sites were encouraged to recruit youth for LEL Basics, and returning sites could repeat LEL Basics

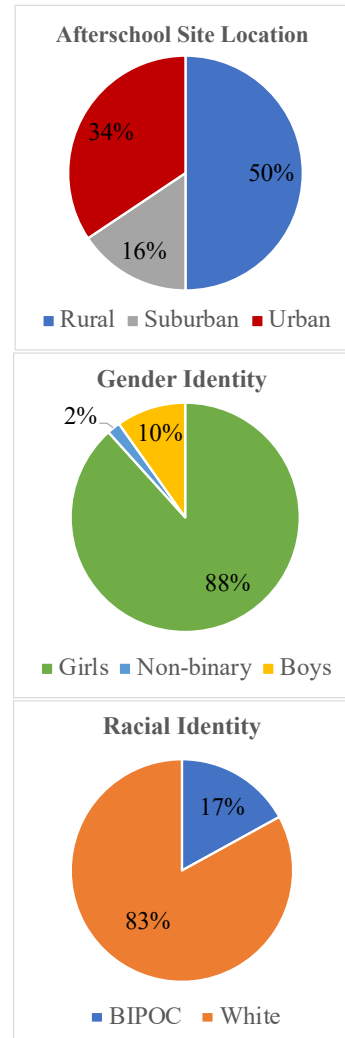


Figure 2. Demographics of LEL youth across VT.

(ostensibly with new youth), or explore BME with new challenges involving innovations for health and medicine. Local women engineers and members of the University of Vermont faculty were added to the *Women in STEM* Inspirational Videos so that youth could better relate to those featured. A schedule revision resulted in offering two sessions of LEL (Fall 2021 and Spring 2022), each of which ran ten weeks to better align with college and afterschool semester calendars.

Assessment

Through 2020-2023, four sessions of LEL including 2020 Basics, 2021 Basics, 2022 BME, and 2022 Basics have been completed; while 2023 LEL BME is currently running. To date, 32 afterschool sites across Vermont, serving 70 towns, have participated in LEL. Sites varied in community type, with 34% of sites being urban, 50% rural, and 16% suburban, as shown in Figure 2. In part due to geographic spread, 47% of Mentors were in-person, 47% were virtual, and 6% have been hybrid, meaning the Mentors held virtual sessions some weeks and in-person sessions other weeks. While nearly half of Mentors were virtual, 89% of youth were in-person, with 11% joining sessions virtually, and all youth are now in-person.

From 2020-2022, a total of 214 youth participated, with at least 23 youth returning for multiple semesters. While LEL is intended primarily for girls, participation restriction cannot be applied at some afterschool sites, so 88% of youth identified as girls and 2% as non-binary, and 17% identified as Black, indigenous, or person of color (BIPOC) and 83% as white. These racial demographics are similar to Vermont demographics where the non-Hispanic white population is 92.2% [6]. Three percent of youth identified as LGBTQ+.

At the conclusion of the LEL programs, youth received a survey of 13 questions pertaining to connectedness, sense of belonging, diversity and inclusion, and program content with a rating of 1-3, where 1 indicates disagreement with the given statement, 2 indicates partial agreement, and 3 strong agreement. Figure 3 shows that the average rating throughout the 3 years varied little, and the average overall rating from youth throughout all of LEL seasons is 2.6. For all questions considered together, 95% of youth fully or partially agree, and 5% indicate disagreement, with insignificant changes between sessions. Figure 4 shows these survey data based on individual questions from the survey over the four sessions combined. Open-ended comments were also solicited on the survey and a few direct quotes are shown below, ranging from loving science

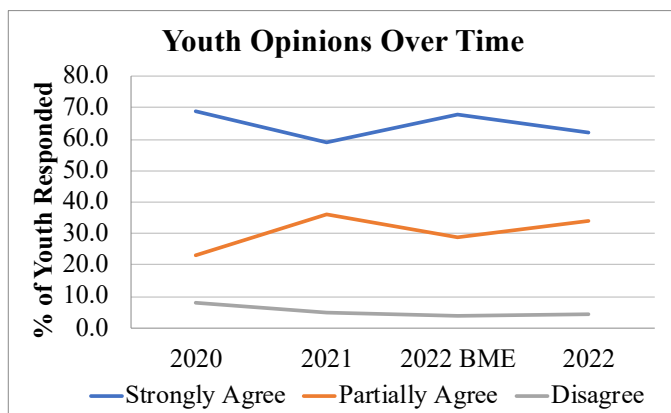


Figure 3. Average ratings from youth survey responses as percent of agree/disagree responses.

and wanting LEL to be longer, to feeling included and making friends, to wanting more food and materials. One student stated, *“I really enjoyed how every activity we did brought us together. We all worked as part of a team,”* while another responded, *“Everyone was open to hear other people’s ideas and ... no one was judged of their opinions,”* and *“What I like about the LEL program is it got more girls to like science including me.”* Furthermore, feedback directly pertaining to programming included, *“I liked the activities. It helped me better understand*

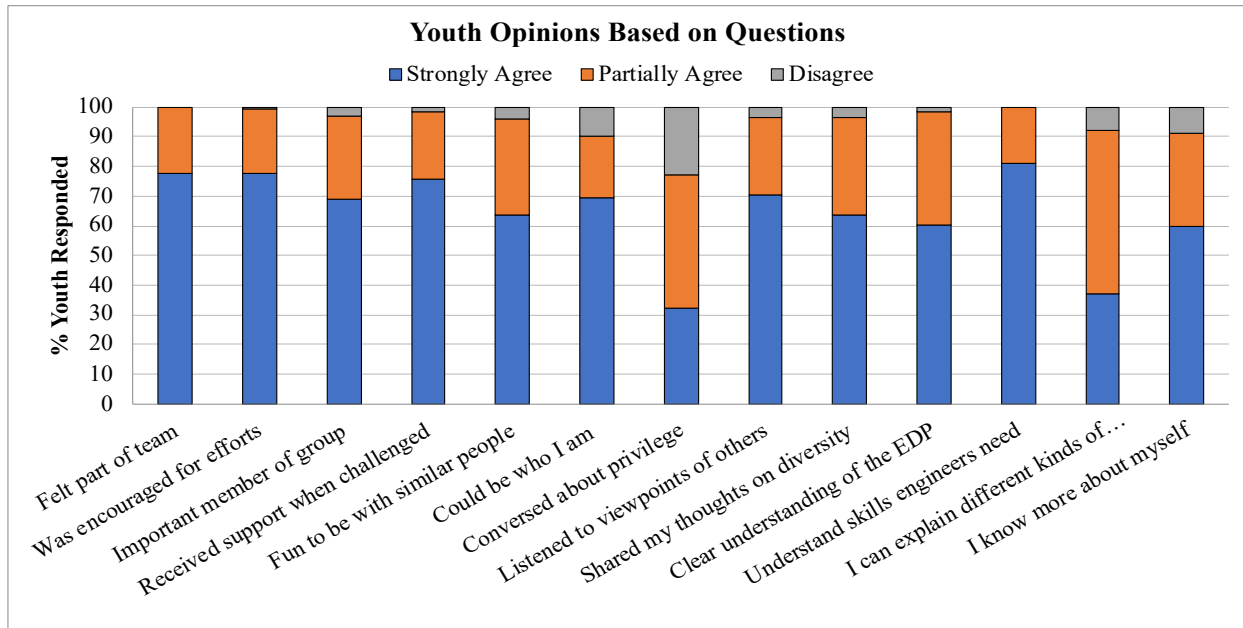


Figure 4. Percentage of youth that said strongly agree, partially agree, and disagree to each question from the survey over the 4 different sessions of LEL.

engineering and how it works. I also loved doing hands on engineering activities” and “I liked learning new things about engineering design process and engineers.”

From 2020 to present, LEL has had 69 Mentors from the University of Vermont, all of which have been female or non-binary, with the exception of one male. Table 2 shows the percentage of returning Mentors that participate in LEL again. Most notably, the present session (Spring 2023) has 10 out of 11 Mentors repeating from Fall 2022. One mentor has been involved with every LEL Basics semester since the pilot in 2020 and participated in a multi-state STEM conference in March discussing how to work around staff shortages in afterschool programs. Figure 5 shows survey questions and responses from Mentors and staff, who almost universally agree that the program has a positive impact and is a valuable experience that they would recommend to others. Vermont Afterschool recently added a question to the survey about whether they will use what they learned in the program in other areas of their life, and 90% strongly agree and 10% agree. They also 100% agree that the Engineering Design Process and the Engineering Mindset are valuable for youth, and they referenced them throughout the sessions. Both Figures 4 and 5 indicate that conversations about equity, racism, and inclusion are the weakest points of the program, and the continuing work will focus on improving these areas. Encouragingly, Mentors commented that *“We referenced [the Engineering Design Process] every single session and by the end of the ten weeks, the [youth] had grown accustomed to the process and understood why we approached problems in a certain way.”* Another mentor mentioned, *“I loved hearing what the youth felt their role in engineering in the future might*

Table 2. Mentor retention rates across all semesters.

		2021	2022 BME	2022 Basics	2023 BME
Repeats	From 2020	23%	20%	8%	0%
	From 2021		20%	8%	18%
	From 2022 BME			8%	27%
	From 2022 Basics				45%
New		77%	60%	75%	9%

be.” Proper assessment of afterschool programs are often complex given students of multiple ages, different levels of engagement, less rigorous requirements on attentiveness than during classroom learning, and lack of state or national standards [2], [3], [7]. The plan is to continue to iterate surveys and assess learning more thoroughly as the program grows.

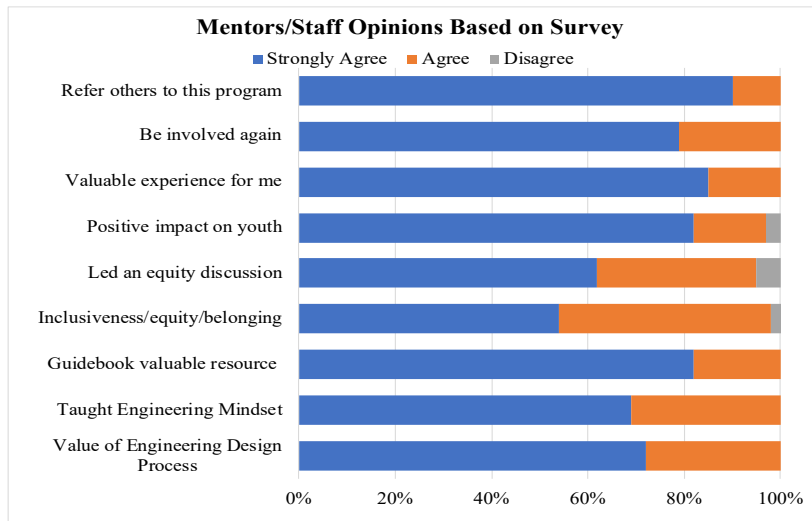


Figure 5. Mentor and staff survey results, from across 4 sessions.

Conclusions and Future Work
 Over the last four sessions, LEL has adapted to meet youth and Mentor needs based on feedback from participants and shifts in STEM education, including accommodations related to COVID-19. LEL started early in the pandemic, with virtual sessions and adaptability for sites, Mentors, and youth. As time has passed, LEL has transitioned to more in-person sessions, and all youth have been in-person for the last year. However, the model of virtual Mentors continues to be integral to the program’s ability to provide LEL to rural sites. One example of LEL response to feedback is that participants wanted more relatable inspirational videos, so more female engineers in Vermont were asked to create a “if you can see it, you can become it” video series. Mentor feedback indicated that it was challenging for them to have meaningful conversations about equity, diversity, and inclusion with the youth, so Vermont Afterschool arranged for guest speakers to discuss the challenges they have encountered in the STEM field. Some guest speakers have stayed to do the engineering activity, allowing the Mentors to see an example of a female engineer in practice. Youth also went on a field trip at the end of last semester to Beta Technologies, an aerospace company in Burlington, Vermont where the youth and Mentors experienced real life engineering. Over several sessions, Vermont Afterschool has learned that some Mentors need more support in communicating engineering in a simpler way for youth and afterschool staff with limited STEM experiences to understand. To support the Mentors more in these efforts, the plan is to create seminars for the Mentors to cover topics like science communication across audiences, teaching in an inclusive manner, and collaborating with adults and youth.

As of this writing, LEL’s 2022 – 2023 program year is enjoying a new resurgence of afterschool sites investing in engineering education. Plans for future years include offering LEL Basics exclusively in the fall and LEL Biomedical in the spring as a logical progression of the two content focus areas. Mentors, too, are encouraged to participate for a full year – many of whom will benefit from engaging in the field of BME for the first time. As LEL continues to build momentum, Vermont Afterschool will continue to seek funding, track data on participation, learn from outcomes experienced by both youth and Mentors, and perhaps consider new partnerships that elevate girls and non-binary youth in their exploration of the broad range of opportunities for a career in engineering.

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