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CULTIVATING A STRONG STEM COMMUNITY THROUGH INNOVATIVE EDUCATION

HIGHLIGHTS:

- Sounding the Right Note: Integrating Music and STEM Teaching
- Recognition's Role in STEM Identity Development
- Training a New Generation of Skilled Environmental Scientists
- Humanitarian Engineering: Training Engineers to Best Serve Communities

EXCLUSIVES:

- The National Association of Biology Teachers
- The Association for Women in Science

Issue: #135

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WELCOME...

Scientists, engineers, medical professionals and statisticians are all at the forefront of our battle against COVID-19. As a result, the fields of science, technology, engineering and mathematics (STEM) have perhaps never seemed so important.

In addition to eradicating this devastating disease, many other challenges facing society, such as climate change and biodiversity loss, can only be addressed by a strong and diverse STEM workforce. Building a robust STEM community is dependent upon innovative and inclusive education, from primary school to university and beyond. Therefore, this issue showcases an inspiring collection of projects, each seeking to enhance STEM education worldwide.

Our first section of the edition focuses on the development and application of innovative teaching methods. Through providing immersive educational experiences, facilitating student collaboration and harnessing technology, the initiatives featured here are ensuring better academic outcomes for students, towards building a strong STEM community.

Next, we feature a range of programs that aim to increase diversity in STEM, by inspiring young people from diverse backgrounds to pursue STEM subjects, and supporting underrepresented students on their journeys to successful careers. By enhancing diversity amongst graduates, these initiatives will ultimately lead to a stronger STEM community with greater potential for generating new ideas, and a better ability to take on humanity's greatest challenges.

Each initiative featured in our final section is designed to address a specific societal need – from teaching engineering students how to devise solutions that are socially responsible, to cultivating a new generation of environmental scientists that can tackle climate change, pollution and biodiversity loss.

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INNOVATION IN TEACHING

EMPLOYING INNOVATION TO ADVANCE STEM EDUCATION

In the age of COVID-19, the fields of science, technology, engineering and mathematics (STEM) have perhaps never seemed so important, as STEM professionals bear the responsibility of eradicating the virus. For instance, the development of multiple successful vaccines has resulted from countless hours of hard work by teams of innovative scientists. Meanwhile, skilled engineers are behind the large-scale manufacture of these vaccines, while the manner in which they are deployed is based on the work of statisticians.

In addition to tackling COVID-19, many of humanity's other great challenges, such as climate change, biodiversity loss and the energy crisis, can only be addressed by a robust STEM workforce. Ensuring a strong workforce into the future will depend upon innovative and inclusive education, from school to university and beyond.

Nevertheless, many educational institutions still use outdated teaching methods, many of which rely on students simply memorising information and recalling it later in an exam. Although this form of tuition can be useful in certain situations, it often fails to develop students' critical thinking, problem solving and decision-making skills, which are all essential attributes for being a competent scientist.

Scientific enquiry follows a pattern where researchers use evidence and collaborate with one another to construct explanations for observed phenomena. Similarly, students must be allowed to 'figure things out' and share ideas with their peers in order to develop a rich understanding of scientific concepts. However, teachers often have minimal experience encouraging students to engage in active discussion and scientific knowledge generation.

Therefore, researchers from Florida State University and Georgia State University are finding ways to enhance teachers' development in such ambitious instruction. In the first article of this section, we showcase their project, 'Learning through Collaborative Design – Professional Development' (or 'LCD-PD'), which investigates how collaborative lesson design can help science teachers to develop the skills needed to facilitate active discussion and provide high-quality instruction.

Our second article also presents methods to deeply engage students with scientific concepts through innovative teaching – this time focusing on outdoor, place-based learning. Here, we meet educators and researchers at the University of Hawai'i at Mānoa, who have developed a unique academic program called Teaching Change. Through immersive, outdoor field courses for local middle- and high-school students, and curriculum development courses for teachers, the program aims to encourage Hawaii's youth to become the next generation of natural resource scientists and managers.

In collaboration with high-school teachers, physicist Dr Charles Smith at the University of New Hampshire

is also providing local students with innovative educational opportunities, by engaging them in an exciting research project. Here, we highlight the Space Weather Underground (SWUG) project, in which each participating school builds a magnetometer that can measure ionic currents in the Earth's atmosphere. By recruiting students and teachers from schools across northern New England, the project will ultimately culminate in an extensive network of these magnetometers, which together will offer important insights into the ever-changing dynamics of Earth's upper atmosphere.

Next, we meet Dr Tennille Presley at Winston-Salem State University in North Carolina, who has also found an innovative way to engage students with both physics and biology. To make these subjects exciting and relatable, her program combines them with an art that is central to many students' social lives: music. From using bells and glasses of water to explore the physical properties of sound, to studying the effects of different genres of music on cellular growth and viability, the program has been successful in engaging high-school and university students and showing them that science is involved in everything.

From here, we shift our focus to enhancing engineering instruction, and feature the work of Dr Diana Bairaktarova at Virginia Tech, whose team is developing innovative learning tools to prepare engineering students to tackle the complex challenges they will face in their future careers. The team suggests that engineering courses could recreate practical situations more reliably using virtual objects, or 'vObjects' – simulated 2D and 3D objects including boilers, fans, turbines, and condensers, whose behaviours and functions all mimic their real-world counterparts. If their approach becomes widely adopted, it could transform how engineering students learn to apply their skills to complex, often unpredictable scenarios.

To close this section, we introduce the National Association of Biology Teachers (NABT), a US-based organisation that supports learning methods based on scientific principles and advocates for biology within society. Here, we feature an exclusive interview both the Executive Director and President of NABT, who discuss the varied ways in which the Association empowers educators to provide the best possible biology and life science education for all students, even in the midst of the COVID-19 pandemic.

ENHANCING TEACHER LEARNING OF AMBITIOUS INSTRUCTION THROUGH COLLABORATIVE DESIGN

Efforts to reform science education in the US emphasise the importance of engaging in the development of explanations of natural phenomena in students' learning. Discussing and evaluating ideas is a vital component of this process. Thus, teaching practices that enhance student sensemaking through talk are central to improved science education; this is a marked shift from traditional teaching, where the teacher lectures about science explanations and then students do a lab to confirm what they have been told. Researchers from Florida State University and Georgia State University are investigating how teachers can be supported to develop the skills they need to adopt these instructional practices, in their research and professional development project: Learning through Collaborative Design.

Learning Science by Talking Science

In science, scientific enquiry is propelled by the need to answer questions – and this process follows a pattern where scientists use evidence gathered from the natural world to construct explanations for observed phenomena. Similarly, students must be given opportunities to 'figure things out' in science if they are to develop a rich understanding of scientific concepts. In the classroom, this can be achieved through negotiations between peers, joint attention, and shared engagement aimed at constructing and critiquing ideas about an interesting or vexing topic.

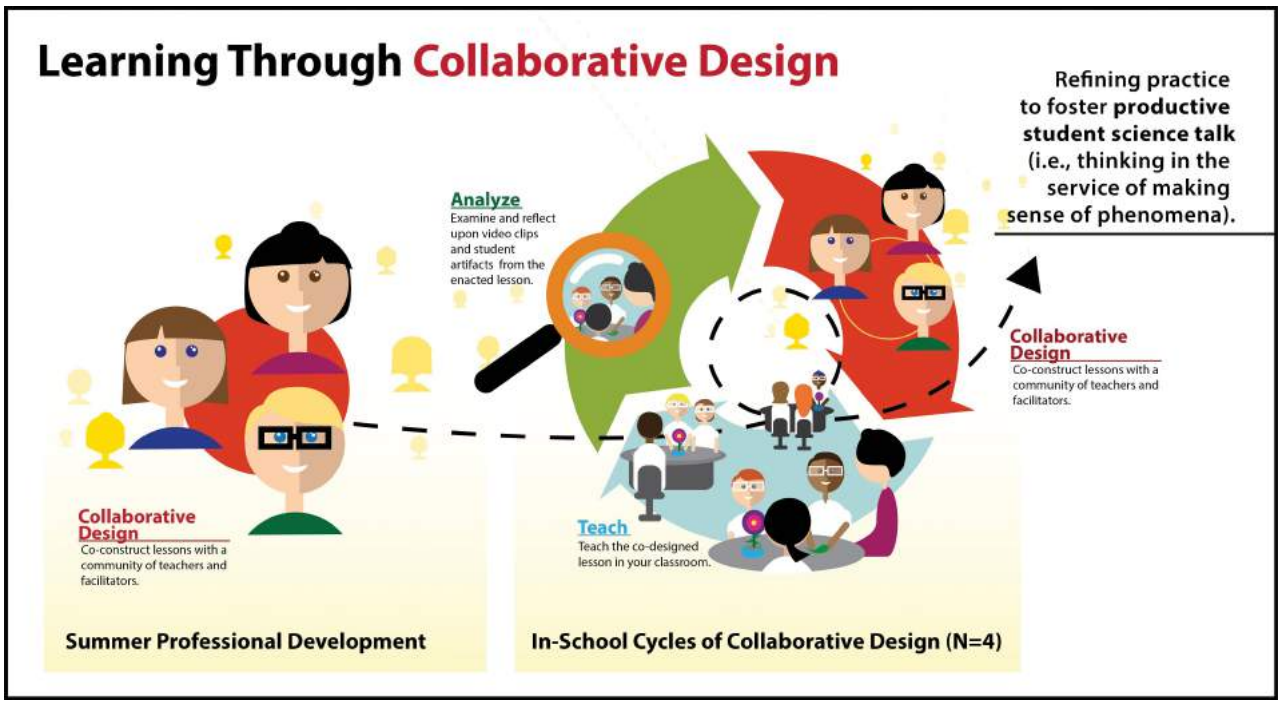
Imagine a classroom where students in small groups are engaging in a lesson on natural and sexual selection and the interplay between how these mechanisms shape population traits. As you enter the room you observe students' wonderment, frustration, joy, and even nervousness, as they explore a dataset to develop an evidence-based claim about what is happening and, most importantly, why it is happening. These emotions arise because students are actively discussing and grappling with one another's ideas about what causes colour variation in Venezuelan Guppies (a type of fish). Such sensemaking discussions demonstrate how framing lessons as a space for students to 'figure things out' can lead to deeper engagement with scientific concepts.

This process is emphasised in the National Research Council's Framework for K-12 Science Education, developed in 2012 to reform science education in the US from kindergarten to 12th grade. Based on this framework, the Next Generation Science Standards (NGSS) provide performance expectations that integrate three dimensions of science learning.

The first of these dimensions involves 'disciplinary core ideas' – the key ideas in each of the disciplinary areas of science. The second encompasses 'crosscutting concepts' – which help students explore connections across the multiple disciplines within the physical sciences, life sciences, Earth and space sciences, and engineering. The final dimension is 'scientific practices', which allow students to engage with the processes scientists use to investigate the natural world. Exploring these dimensions through sensemaking discourse can help students build a robust and cohesive understanding of science over time. By shifting the focus of science education from reaching the 'one correct answer' towards the *process* used to generate and evaluate ideas, students also develop transferable skills, such as critical thinking.

But teachers often have minimal experience supporting students to engage in 'productive talk' – that is discussions centred on scientific knowledge generation and evaluation. Further, many find it difficult to design instruction focused on productive talk. If the goals of the NGSS are to be achieved, teachers must be provided with the skills and tools they need to achieve this ambitious science instruction. For many teachers, this necessitates a fundamental shift in their thinking and practice.

How to enhance teachers' development in ambitious science instruction is a topic being tackled by a team of science education researchers and professional development experts from Florida State University and Georgia State University. Their National Science Foundation funded project, 'Learning through Collaborative Design – Professional Development' (LCD-PD), aims to investigate how a specific kind of professional development activity – collaborative design – can support teachers' professional growth and provide them with the skills and tools required to facilitate productive talk in their science classrooms.



'If students are to understand science as a sensemaking activity in which core ideas, scientific practices, and crosscutting concepts are used in concert, the field must go beyond simply providing new curricula for teachers,' explains Project Manager Dr Jennifer Schellinger. 'Instead, new approaches to professional development – approaches that promote teachers' learning about and enactment of productive talk – are needed.'

Collaborative Design as an Active Learning Tool

Well-designed professional development that supports teacher learning is especially important when the instructional practices they need to adopt are challenging and complex, as is the case with the NGSS. To optimise their progress, the LCD-PD team build on established principles of engaging teachers in active learning. In particular, evidence highlights the importance of involving teachers in the development of curricular materials. 'Collaborative design is situated in real-world teaching contexts and positions teachers as active content and pedagogical learners within the context of their classrooms,' says Team Leader Dr Sherry Southerland.

Previous research has predominantly focused on the modifications that teachers make to the curricula. Relatively little research has investigated how these curriculum design activities, when occurring in collaboration with others, contribute to changes in the knowledge, beliefs, and practices of the participating teachers themselves. The team aims to address this knowledge gap through the research component of the LCD-PD project. 'We aim to understand if and how teachers' engagement in collaborative design of science lessons shapes their learning and enactment of those lessons,' explains Dr Southerland.

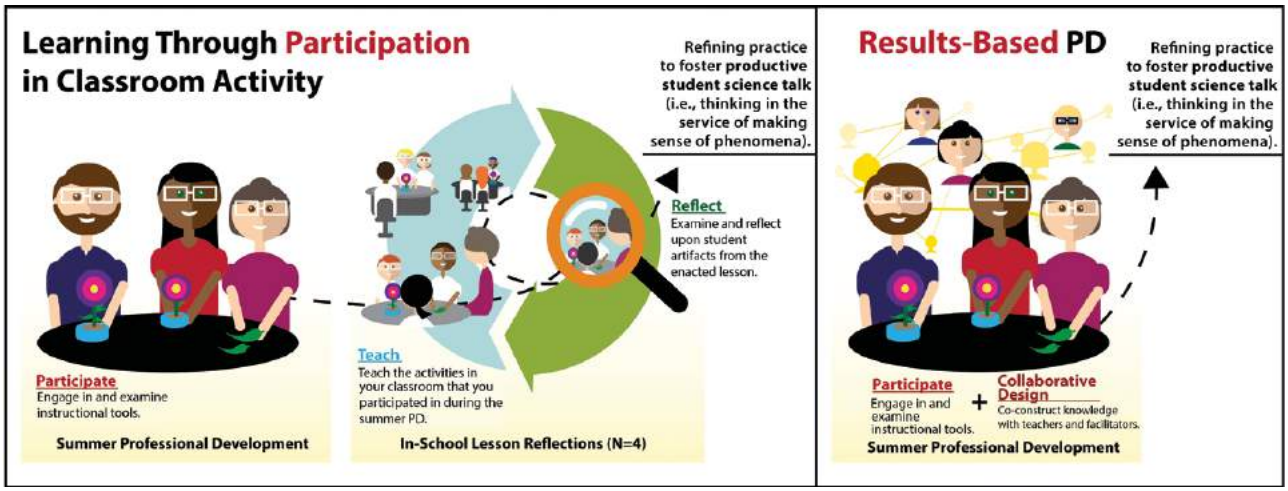
The lessons designed by teachers participating in LCD-PD are structured around strategies that position students to actively engage with challenging questions about the natural world. Additionally, teachers are introduced to the importance of embedding this strategy in their instructional practices. Dr Southerland says, 'The lesson design and instructional practices revolve around the idea of using vexing questions about natural phenomena to get students to deeply engage in "figuring things out" through productive talk in the classroom, and in that process, they learn the role evidence plays in knowledge construction in science.'

The Project

During the first phase of the LCD-PD project, the team designed, implemented, and refined the professional development in two school districts across the academic years of 2018/19 and 2019/20.

Teachers initially took part in a six-day professional development course during the summer, where they collaborated with a community of teachers and LCD-PD facilitators to explore the role of productive talk in science learning, to examine strategies that support this kind of discourse in science classrooms, and to design science lessons centred around these strategies. Subsequently, teachers participated in multiple cycles of designing, implementing, and evaluating lessons across the school year. The structure of each cycle aimed to provide teachers with sufficient time to practice their new skills and tools, examine their teaching practices closely, and reflect on their development.

The core focus of the design sessions is to help teachers ensure that lessons move beyond superficial skills and activities, and instead, effectively engage students with productive talk and



scientific sensemaking. In post-teaching analysis sessions, teachers were given the opportunity to contrast different strategies to support student discourse and reflect on factors contributing to productive talk in classrooms.

Findings from the first phase of the project identified effective design principles for professional development that help teachers refine their practice. These principles included attending to the kinds of activities that make up the professional development, streamlining these activities, modelling best practices, and providing balance between the doing and reflecting on practice. Indeed, when teachers were positioned as 'content learners' before they reflected on activities as 'teacher learners', their level of engagement increased.

Further, the LCD-PD team examined participating teachers' classroom instruction around lessons they had collaboratively designed during the professional development. They identified key components that maintain high-level student thinking and sensemaking throughout the trajectory of a science lesson. These components require that the lesson begin with a rigorous task and that the teacher continually presses students to provide contributions across the arc of the lesson.

Critically, a rigorous task alone is not enough – the alignment of a teacher's practice and pedagogical views with reform instruction has a considerable influence on classroom learning opportunities. For instance, even when curricular materials have the potential to engage students with concepts, ideas, and practices to encourage productive discussions, small instructional moves rooted in a teacher's views on teaching have the power to position students' understanding of science away from a sensemaking endeavour and towards the accumulation of previously-developed knowledge. These findings demonstrate how shifts in teacher practice as well as their thinking are central to effective educational reforms.

The teachers participating in the first phase of LCD-PD continue to be supported into the second and third years of the project. 'This follow-up will provide the teachers with extended support and will contribute empirical insights regarding the value of long-term professional development support on teachers' adoption of and developing expertise around fostering productive talk in science classrooms,' says Dr Schellinger.

Next Stages: The Field Study

The next phase of LCD-PD, a field study, will compare the LCD-PD model developed during the first phase of the project with two other treatments. One of these treatments is a Learning through Participation in Classroom Activity professional development (LPCA-PD) model and the second is a Results-Based professional development model, which will function as the control group. All models support teachers' learning of the skills and knowledge necessary to implement the NGSS.

The LCD-PD group emphasises collaborative design and revision of curricular materials, while the LPCA-PD group engages in cycles of teaching and analysing without modification to the materials or engaging in collaborative lesson design with peers. Otherwise, the structure and content of the professional development provided to the groups will be kept consistent. Because both professional developments focus on promoting effective productive talk, the inclusion of a control group will allow the researchers to better understand the influence of collaborative design on teachers' learning and practices. The Results-Based control group will not receive any professional development associated with the project until the field study is complete, and instead their normal teaching around the lesson topics covered by the LCD-PD and LPCA-PD groups will be evaluated.

Although the final phase of the LCD-PD project has been delayed due to COVID-19, the researchers have already contributed valuable information to the science education community through presentations, papers, and academic posters. Ultimately, the professional development strategies devised as part of their LCD-PD project could help teachers across the US gain the skills and knowledge they need to keep up with science education reforms and provide high-quality instruction to their students.

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TEACHING CHANGE: BIOCULTURALLY GROUNDED, PLACE-BASED ENVIRONMENTAL EDUCATION IN HAWAI‘I

With ongoing climate change, land use change, and changing disturbance regimes that negatively impact Earth's ecosystems, it is critical that educators convey the importance of safeguarding the natural environment to younger generations to prepare them to face current and future environmental challenges. *Teaching Change* comprises a collection of innovative programs aimed at strengthening the relationship between youth and nature in Hawai‘i while also inspiring Hawaii's youth to become the next generation of natural resource scientists and managers. *Teaching Change* addresses this mission through immersive, place-based, outdoor Field Courses for local students, and Teacher Training Workshops for local teachers.

Understanding Environmental Challenges

Although we live in an era that places great emphasis on industrial and technological advances, enlightened stewardship of Earth's natural resources is an enormous priority if we are to mitigate the environmental challenges affecting our planet. It is, thus, important to teach younger generations to value and safeguard the planet while also inspiring them and teaching them how to become environmental leaders.

With this in mind, educators and researchers at the University of Hawai‘i at Mānoa, the USDA Forest Service and the Akaka Foundation for Tropical Forests have created a collection of innovative academic programs called *Teaching Change*. Led by Drs Creighton M. Litton, Christian P. Giardina and Ming Wei Koh, the program aims to strengthen students' relationships with nature, broaden their knowledge of environmental issues and create opportunities for students to engage in career-connected learning.

Teaching Change

Teaching Change was initiated in 2012 with Field Courses based at the Hakalau Forest National Wildlife Refuge and the Pu‘uwa‘awa‘a unit of the Hawaii Experimental Tropical Forest. Over the past seven years, *Teaching Change* has expanded to offer outdoor education opportunities throughout the Island of Hawai‘i to students and teachers from across the state. *Teaching Change* offers students the opportunity to participate in day long and overnight Field Courses, as well as Teacher Training Workshops for local middle- and high-school teachers focused on how to develop and implement curricula that emphasizes outdoor, place-based learning.

‘*Teaching Change* began as an effort to provide outdoor, immersive, place-based educational opportunities

on Hawaiian forest ecology and climate change science to local, underrepresented youth from Hawai‘i Island,' explains Dr Litton. These outdoor educational activities are designed to inspire a sense of environmental stewardship and broaden students' knowledge about Hawaiian native forest ecosystems, the threats they face due to climate change and other forms of environmental degradation, and solutions that could help to manage these threats.

'*Teaching Change* began as an effort to provide outdoor, immersive, place-based educational opportunities on Hawaiian forest ecology and climate change science to local, underrepresented youth from Hawai'i Island.'

The programs led by *Teaching Change* staff seek to inspire at least some of the student participants to pursue careers in natural resource management in Hawai'i. This is achieved by introducing students to local careers in conservation and to college education pathways that prepare students for careers in environmental protection, conservation and natural resource management.

Immersive Learning Experiences

Teaching Change comprises several different Field Course programs, organised events and Teacher Training Workshops – all designed to provide transformative outdoor learning experiences to local youth and educators in Hawai'i. Over the past seven years, *Teaching Change* has offered a variety of opportunities to middle- and high-school students by taking them on Field Courses where they learn about native forest ecosystems and have first-hand experiences with the natural environment on their island home. During these courses, students learn about important STEM topics relating to natural resource management while being informed about career pathways in wildlife biology, conservation, forest ecology, and restoration ecology.

The programs offered by *Teaching Change* emphasize 'phenology' – the study of cyclic and seasonal natural phenomena – specifically focusing on climate and endemic forest plants and birds. For instance, overnight Field Courses expose students to the importance of greenhouses where threatened, rare and endangered native plants are propagated for the critical work of confronting habitat degradation through restoration of native biodiversity.

'Over time, we have built strong relationships with land managers and scientists in places such as Hakalau Forest National Wildlife Refuge and the Pu'uwa'awa'a unit of the Hawai'i Experimental Tropical Forest, which allow us to take local youth on day and overnight Field Courses to study native forests using observations of phenology as a central organizing and learning mechanism,' says Dr Litton.

Teaching Change Field Courses are intensive and the staff has a strong commitment to creating opportunities for active, place-based learning in premier montane wet and lowland dry native forest environments. The program provides these remarkable overnight learning experiences during 10-12 overnight Field Courses each year that serve ~200 students.

Training Teachers

Because of very high demand for Field Courses and to reach a wider audience, *Teaching Change* began offering Teacher Training Workshops in 2015 that are designed to broaden local teachers' knowledge of outdoor, place-based education. Participating teachers apply what they learn during these workshops to their classrooms, introduce new learning activities based in natural environments and align activities and curricula with next generation science standards while gaining professional development credits that support their career development. This program greatly expands the impact and reach of *Teaching Change* in Hawai'i schools, creating a ripple effect that reaches dozens of classrooms and hundreds of students every year.

The Teacher Training Workshops are offered to 20–30 teachers each year who are recruited from public schools throughout Hawai'i with a focus on teachers and schools serving underrepresented and underserved students. During these workshops teachers are trained how to teach core STEM concepts in natural settings in a way that meets next generation science standards. To accomplish this, *Teaching Change* focuses on teaching diverse concepts including phenology, climate change, invasive species, land-use change, forest ecology, and biocultural resource management.

Each Teacher Training Workshop operates over the course of a semester. First, teachers attend a three-day intensive learning session to experience the overnight Field Course that students in the program participate in. They then engage in collaborative learning opportunities focused on next generation science standards and developing new outdoor, place-based and immersive curricula and course content, which they then apply inside and outside of their classrooms. To support teachers in their efforts to create new, placed-based learning, participating educators meet regularly with *Teaching Change* staff at their schools. Teachers complete the program by meeting again at the end of the semester to share their curriculum experiences with other participating peers.

'Local teachers, based on the lessons learned in these workshops, create outdoor curricula that make sense for their students and their place,' Dr Litton adds. 'The results have been truly impressive in terms of the curricula developed and implemented for local youth state-wide, and we never cease to be amazed with what these teachers develop and put into place for their students based on our workshops.'

Key Achievements

Since it was first established in 2012, *Teaching Change* has offered overnight, science-based Field Courses to over 1,100 middle- and high-school students in Hawai'i, day long Field Courses to over 450 elementary school students, and led four Teacher Training Workshops that have been attended by 75 teachers from schools across Hawai'i. To evaluate the program's outcomes and accomplishments, the program leaders ask participants to complete surveys before and after they attend courses, workshops or events.

The feedback collected from these surveys has helped the researchers to identify the strengths and weaknesses of *Teaching Change*'s programs. In the future, Drs Litton, Giardina and Koh also plan to track the academic and professional development of students who have taken part in *Teaching Change* programs to, for instance, explore how many students the program has inspired to enter into educational pathways and careers in environmental protection, conservation or natural resource management.

'The building of teams has been one of the most important achievements, as it has allowed *Teaching Change* to flourish since its inception in 2012,' adds Dr Litton. 'This includes the team of current principal investigators, the team of staff from the University of Hawai'i at Mānoa, the Institute of Pacific Islands Forestry and the Akaka Foundation for Tropical Forests, and the various land management agencies that we partner with who provide access to their sites, as well as the teams of teachers that organically become a support network during and after the Teacher Training Workshops.'

A further accomplishment of the program has been the recruitment of experienced teachers who have taken part in Teacher Training Workshops as peer-mentors for participating teachers, educational leaders who the program leaders refer to as Master Eco-Literacy Teachers (METs). Typically, 2–3 METs take part in each Teacher Training Workshop, supporting new teachers by showcasing examples of the curricula they developed in previous years while helping participating teachers design programs that they will apply to their schools and students. These experienced METs are an invaluable source of knowledge, support and inspiration for new teacher participants.

Inspiring Future Generations

As Earth continues to face daunting environmental challenges, initiatives such as *Teaching Change* will become increasingly important as a source of inspiration for the next generation of conservationists and managers. *Teaching Change* strengthens local students' appreciation of nature, while also inspiring teachers to introduce more outdoor and nature-based learning activities.

In the future, *Teaching Change* can serve as a model for other institutions and universities seeking to introduce programs aimed at bringing middle- and high-school students outside of the classroom and into natural settings. Such initiatives not only strengthen students' scientific understanding of climate change and environmental science by learning how to carefully observe the world around them, but also help students gain a deeper appreciation of nature and become inspired to take better care of our planet.

Meet the researchers

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SPACE WEATHER UNDERGROUND: A MAGNETOMETER ARRAY WITH EDUCATIONAL OPPORTUNITIES

The complex processes of Earth's ionosphere may occur far above the planet's surface, but when monitored from numerous locations at sufficient distances, they can be measured using inexpensive equipment on the ground. **Dr Charles Smith** at the University of New Hampshire has assembled an extensive team to do just that, with participants ranging from space scientists with decades of experience, to high school students considering futures in science and engineering. Named Space Weather Underground, the project could soon make extensive data on ionosphere dynamics available to scientists and the public alike.

Earth's Ionosphere

With its lower edge situated around 60 kilometres above our heads, the ionosphere contains an abundance of atoms and molecules that have been ionised by the Sun's powerful radiation. Just as the atmosphere closer to Earth's surface displays the vibrant weather patterns that we witness every day, the ionosphere is also in a constant state of change – although its motions are driven by entirely different processes. Rather than factors such as temperature and pressure, they are driven by the fact that streams of moving charged particles – known as currents – generate their own magnetic fields, and can also be generated by external magnetic fields.

Since the charged particles in the ionosphere are intrinsically connected to the Earth's magnetic field, they can be driven to form currents by processes that disrupt the field, such as high-energy bursts of plasma thrown out by the Sun. Once set in motion, these currents then generate magnetic fields of their own, which can be measured from the ground.

One particularly important aspect of these fields is that they can distort the radio waves that satellite systems use to communicate. Therefore, by understanding precisely how these currents flow, researchers can gain important insights into the complex 'weather' of interplanetary space, while also finding ways to mitigate potential disruptions to our communications and navigation systems.

Measuring Ionic Currents

To detect currents in the ionosphere, the magnetic fields they create must first be picked up by devices called magnetometers, which can measure the strength and direction of the field, and register any changes in these values over time. Perhaps the most well-known example of a magnetometer is a compass, which aligns its needle with Earth's magnetic field; though more accurate devices are required to pick up the subtle fields created by ionospheric currents.

Since these charged particle motions play out on scales of hundreds of kilometres, researchers can only measure them by spreading out numerous magnetometers over large distances. This is most effective if the devices are incorporated into expansive networks, or 'arrays', which transmit their measurements to central data centres.

So far, such measurements have typically involved cutting-edge instruments that are extremely sensitive, capable of detecting incredibly subtle changes in magnetic field strengths and directions. However, such sophisticated apparatus is by no means essential. According to Dr Charles Smith at the University of New Hampshire, there are numerous advantages to using simpler, far less expensive magnetometers.

Possibilities with Simpler Instruments

Rather than high degrees of accuracy, Dr Smith believes that measurements of ionospheric currents should benefit more from a higher number of measurements, taken using larger arrays. With this in mind, he is now building an extensive magnetometer array using the 3-Axis Simple Aurora Monitor (SAM-III) – a semi-professional device manufactured by Reeve Electronics in Alaska. Often used by hobbyists, such as radio amateurs and photographers of the Aurora Borealis, these magnetometers can be purchased as kits costing just $500.

As well as their low cost, the circuitry of a SAM-III device is easy to assemble, with step-by-step instructions appearing on a graphical interface as the user progresses. For Dr Smith's team, this presents a further advantage: that their project can accommodate the skills of young people who are considering careers in science and engineering. Together, these advantages mean that while SAM-III magnetometers are ideal tools for monitoring currents in Earth's ionosphere, their assembly, deployment, and monitoring provides a unique educational opportunity for local high school students.

Deploying for Measurement

The efforts of Dr Smith's team to deploy an extensive array of SAM-III magnetometers have now culminated in the Space Weather Underground (SWUG) project – a collaboration between his colleagues at the University of New Hampshire (UNH), and high schools across northern New England. To guide the project, Dr Smith has drawn out precise guidelines for schools to build their own magnetometers.

Once they have been assembled by students, the SAM-III devices need to be mounted into 'trees' made from PVC plastic, which enable their sensors to be precisely oriented parallel to Earth's magnetic field. Then, they must be placed in watertight tubes, which are buried vertically in the ground to prevent their contents from freezing or overheating in the long term. An extension of the tube above the ground then houses all of the necessary electronics.

As data is collected, it is transmitted through radio antenna to a Raspberry-Pi computer at the school, from which it flows into a central data centre, located at UNH. Finally, a solar panel mounted on a post next to the tube provides power to each setup, while a battery pack stores the excess power it generates for night-time operation.

Taking Precautions

Before a magnetometer in the SWUG array can begin operation, a number of precautions need to be taken to maximise the quality of its measurements. In order to avoid any measurement disturbances from magnetic fields associated with human activity, such as electrical currents, Dr Smith advises that they should be deployed in a remote location about a quarter of a mile from each school. Furthermore, since the clocks that SAM-III magnetometers use to time their measurements can drift by up to a second each day, each school must attach a GPS chip to their system, to ensure the measurements of all devices in the array are synchronised with each other.

Finally, Dr Smith instructs that the devices should take one magnetic field measurement every two seconds. This is slower than SAM-III's maximum measurement speed, but enables the device to operate more reliably, while still allowing it to detect any important events.

Since first drawing out detailed plans for the project in 2019, the SWUG team has needed to navigate the numerous challenges presented by Covid-19. However, having fully assembled and demonstrated the setup at UNH, Dr Smith hopes that the project will progress rapidly once schools reopen. Furthermore, earlier results, presented in December 2019, reveal a promising potential future for the project.

Encouraging Early Results

In October 2019, several ionosphere monitors in eastern Canada – which borders New Hampshire – picked up the key signs of an ionospheric current passing through Earth's mid-latitudes. For Dr Smith's team, this presented an ideal opportunity for testing the early SWUG array. Just as they hoped, SAM-III magnetometers in Exeter and Durham – home to the UNH campus – also clearly detected the signal, which endured for around one hour in the early morning. 'We presented these early results at the 2019 Fall American Geophysical Union conference, where we brought two high school students to aid in the presentation,' says Dr Smith.

Since the two devices were spaced less than 20 kilometres apart, their combined measurements could not be used to determine the large-scale, time-varying properties of the ionospheric current responsible for the signal. However, the results were a key demonstration that each of the devices was able to reliably carry out its role, and could be used to gather useful data if incorporated into a larger network.

'The goal is that with multiple sites running accurate clocks, we can time the passage of a magnetic disturbance across the surface of the Earth, determine its speed and direction, and relate it to other ionospheric activities as measured by spacecraft,' explains Dr Smith.

Plans for Expansion

To reach this point, Dr Smith's team now hopes to expand the SWUG array across northern New England, and even further afield within the US – with two magnetometers now under construction at high schools in the Midwest. As the network expands, the team will be able to triangulate the time-varying positions of ionospheric currents increasingly accurately, allowing for observations with a similar quality to those made by expensive, well-established ionosphere monitors.

Dr Smith and his colleagues will now continue to work towards this goal by building relationships with high school students and their teachers, allowing student-built magnetometers to be deployed across numerous locations. They will also expand the data centre at UNH to handle an increasing flow of incoming information, as more magnetometers are incorporated. Furthermore, they plan to expand the online presence of the SWUG project through a website. These measures will allow the team to achieve their overall goal of detecting activity in the Earth's upper atmosphere, and associating it with activity in the global ionosphere.

New Opportunities

When the SWUG array becomes fully operational, Dr Smith and his colleagues will aim to make the data it produces completely free to access – open not only to members of the public who are interested in the project, but also to real scientists conducting their own research.

Alongside this advantage, the project represents a highly unique way to introduce high school students to an active field of research, before they even begin university. Ultimately, the project soon promises to offer important new insights into the diverse and ever-changing dynamics of the Earth's ionosphere, and the communications systems they affect.

Meet the researcher

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Dr Smith completed his PhD in Physics at the College of William and Mary in 1981, after which he worked at numerous prestigious institutes, including the University of New Hampshire and the University of Delaware. Since 2003, he has worked as a Research Professor at the University of New Hampshire, where his research interests include space plasma physics, interplanetary magnetic fields and their interaction with Earth, and the interpretation of spacecraft data. Dr Smith has been involved with a variety of NASA spacecraft missions throughout his career, including the Advanced Composition Explorer (ACE) Magnetometer Experiment, and the EMFISIS Instrument Suite aboard the Van Allen Probes. He now coordinates the Space Weather Underground (SWUG) collaboration, which is enhancing educational opportunities for high school students in New England.

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Marc Lessard, University of New Hampshire – expert in the field who is making connections to established science
Michael Routhier, University of New Hampshire – professor leading the development of the SWUG Data Center
John Blackwell, Phillips-Exeter Academy – first high-school teacher to have a magnetometer up and running
Rich Levergood, Londonderry High School – high-school teacher (now retired) whose students have built more magnetometers than any other school
Scott Goelzer, Coe-Brown Academy – high-school teacher whose students have set up the latest deployment, and who is central to the 'summer ballooning program', in which high-school students build magnetometers and fly them to 100,000 feet
Carol Young, CONVAL Peterborough High School – high-school teacher and Dr Smith's initial contact at CONVAL
Andria Johnson, CONVAL Peterborough High School – high-school teacher who has a working magnetometer awaiting indoor deployment once schools reopen
Dave McKenney, Plymouth High School – high-school teacher whose students have finished their initial build, to be deployed once schools reopen
Julie Burton, The Bromfield School, Harvard – high-school teacher whose magnetometer will be the most southern in the array
Elizabeth England, Winnesquam High School – high-school teacher whose build will resume once schools reopen
Andwar Heliovore, Hillsboro-Deering High School – high-school teacher whose build will resume once schools reopen
Sara Cathey, Oyster River High School – high-school teacher whose build will resume once schools reopen
Stephen Zaffke, Austin High School, Minnesota – high-school teacher whose students are building one of two magnetometers in the Midwest, as the UNH team works to seed a new array there
Nick Goeldi, Ripon High School, Wisconsin – high-school teacher whose students are building the second Midwestern seed

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SOUNDING THE RIGHT NOTE: INTEGRATING MUSIC AND STEM TEACHING

Young people can often be discouraged from engaging with STEM subjects because they seem to have little obvious connection to their everyday lives. At Winston-Salem State University in North Carolina, an innovative program led by **Dr Tennille D. Presley**, is seeking to engage students by combining physics and biology with an art that is central to many students' social lives: music. Early results from the program suggest that it has been successful in making science exciting and showing students that physics is involved in everything.

Connecting Physics with Everyday Life

Physics has long been regarded as a highly prestigious academic discipline, often talked about in terms of complex theories such as quantum mechanics and represented by exotic technology such as CERN's Large Hadron Collider. For students, however, this picture can be intimidating: not only can they find physics difficult to relate to other disciplines, but it can also seem disconnected from the reality of their own lives, leading them to feel that physics is not for them.

Dr Tennille D. Presley, a physics professor based at Winston-Salem State University (WSSU), is leading a radical new interdisciplinary program that challenges such perceptions by engaging young people with physics and biology through creative teaching methods – ranging from making music with household objects to studying the physics of baking a cake. Dr Presley's academic background makes her well suited to lead an interdisciplinary project: she is a bio-physicist whose research is concerned with the influence of factors such as diet, exercise, free radicals and heat treatment on diabetes.

Dr Presley's collaborators on the program are music professor Dr Myron Brown, education professor Dr Denise Johnson, and biology professor Dr Mesia Steed. Together, this team has developed novel methods to integrate the teaching of physics, music and biology in ways that engage and excite students of all ages.

Inside the Classroom

Dr Presley's team redesigned an existing undergraduate course at WSSU, entitled *Music Physics/Acoustics*, to include a much broader curriculum under the name of *Biophysics of Music*. In the new course, students learn physics, biology and music, integrated through teaching methods that focus on active learning. The team trialled these methods in two workshops, one in October 2018 and again the following year, in association with Girls Empowered by Mathematics and Science (GEMS) – an organisation for female middle-school students directed by Dr Johnson. Each workshop attracted over 50 participants – a promising start that led to the introduction of the new program in the Spring 2019 semester.

The program included both a Lecture course and an Investigation and Research course. During the Lecture course, students were introduced to key concepts of the three disciplines involved. Dr Presley taught the fundamentals of physics including Newton's laws of motion, alongside elements of energy, waves and sound mechanics. Dr Steed taught students about the physiology of the ear and the role of neurophysiology in the perception of music, while Dr Brown not only taught the fundamental concepts of music, including pitch, dynamics, tempo and timbre, but introduced students to the physics and measurement of these qualities. To bridge any gaps in understanding within the course, Zakiyah Henry served as a teaching assistant and provided help for students during classroom activities and outside the classroom.

In the Investigation and Research course, students learned about

'The major accomplishment of the program has been students identifying that physics is involved in everything.'

research methods, and developed their own research protocols incorporating physics, biology and music. For instance, the physics, biology and music involved in the process of baking a cake was explored. After designing and conducting their own experiments, the class presented their findings, orally and through a poster presentation, at WSSU's annual Scholarship Day.

The group involved in this experiment found that from the perspective of physics, baking a cake involved the conversion of energy into heat, power and work. From a biological viewpoint, the consistency and structure of the cake were products of the molecular characteristics of the ingredients, whilst from the perspective of music, the students found that the baker's choice of music resulted in different beats per minute in the mixing process, which could significantly change the texture of the cake. Although for most, it was the first time they had ever presented publicly, the students in the course won the prize for Most Creative Poster Presentation.

The program was run again in 2020. Whereas in 2019, most students had a background in biology, the 2020 program attracted a more diverse group: 40% were majoring in biology, 40% in music, and 20% in education. Moreover, the student body included two drum majors in the university's marching band, a member of the university's gospel choir and an experienced musical engineer – each of whom was able to contribute their own experience and insights to the course. For most students, physics was the most challenging part of the course, so the team focused on enhancing knowledge of physics whilst relating it to music and biology.

Experiments and Research Projects

Dr Presley and her colleagues used a variety of innovative teaching methods to capture the interest of students and demonstrate the ways that physics permeated their lives. For example, students learned about the characteristics of sound by striking glasses filled with varying amounts of warm or cold water. The experiment showed that loudness, intensity, pitch and frequency were all affected by the quantity of water in the glass and its temperature. In another activity, hand bells were used to demonstrate the phenomenon of resonance: when a bell of a particular frequency was rung, it generated resonance in other bells whose frequencies were part of the same harmonic series. The team employed computer technology to demonstrate the effects of frequency, amplitude and the Doppler Effect on sound through simulations visually represented on screen.

The students also engaged in a cycling class using the university's recreation centre. The goal was to investigate the effects of listening to different genres of music on cycling performance – with measurements including revolutions, time, distance and power generated. The experiment was a huge success, as the university chancellor visited and the students gained significant knowledge in the intersection of physics, music and biology in cycling and exercise.

On the research side of the program, students conducted laboratory research in Dr Presley's lab. Performed by computer engineering major, Brandon Daughtry, the effects of different genres of music on participants at rest and in motion were explored using the Python data analytics tool. By measuring blood pressure, heart rate and power output when stationary and while climbing a staircase, Python was able to predict which types of music would be most effective in different circumstances. Through the experiment, Brandon found that when at rest, classical music, jazz and rap all had measurable effects on the body, but when in motion, only rap music significantly altered heart rate response. This work resulted in a presentation award at the 2019 Annual Biomedical Research Conference for Minority Students.

In another research project, biology major Shaheera Drummond examined the effects of varying musical genres on cellular growth and viability, by exposing human embryonic kidney cells to different musical genres at room temperature

for 30 minutes each day. From her data, she concluded that music has a positive effect on cell viability and cell growth, with gospel music having the most pronounced effect. Furthermore, varying the musical genre also altered cellular behavior. Recently, two additional students have joined the research team exploring the impact of music on skin conductivity.

In all of these experiments, students engaged in everyday activities and applied mathematical formulas in order to scientifically understand the processes behind them. 'The major accomplishment of the program has been students identifying that physics is involved in everything,' says Dr Presley.

During the 2020 program, students followed their own interests in developing projects to explore four new topics: music as treatment for coronavirus; the biology and physics of music engineering; music therapy as treatment for pain; and the biophysics of synaesthesia.

Crossing Disciplinary Boundaries

To further demonstrate inter-relationships between science and art, the program team gave guest lectures in music, physics and biology courses. Dr Steed took the opportunity to introduce a new topic to her *Cell Biology* course, entitled *Music and the Cell*. This led to the *Cell Biology* and *Biophysics of Music* courses being brought together for two weeks, in which biology students benefited from the broader perspectives of students enrolled in the *Biophysics of Music* course. Similarly, Drs Brown and Presley teamed up to integrate biophysics and music into a *Fundamentals of Music* course and *College Physics* course. Lastly, Dr Johnson introduced the students to educational research, and effective STEM pedagogy and integrative learning strategies.

Beyond the three disciplines at the heart of the program, the projects that students conducted also exposed them to the fields of exercise science, chemistry, psychology and art. Each faculty member in the program assessed each of their respective courses, and found that students had a greater appreciation for the interrelationships of the arts and sciences, and a deeper understanding of physics, music and biology.

School Outreach

The program established a link with a local high school, enabling university students to go into the school, present their knowledge and engage in hands-on activities with high-school students. Because Dr Johnson is an education professor, she provided training for the WSSU students on effective methods to engage and interact with the high school students. The students from WSSU also served as mentors for high-school students, and were able to give them insights into college life. This encouraged a number of the high-school students to apply to WSSU.

In July of 2020, the team expanded their interactions by implementing an interactive online program called the Biophysics of Music Virtual Summer Program. During this four-week program, middle school, high school and college students spent two days a week watching live speakers and taking part in interactive activities, focusing on topics including mechanics, sound, forces and electricity. Two additional days in the week were dedicated to the students having one-on-one educational sessions with their teaching assistants, and preparatory assignments for the live sessions.

The goal of the program was to highlight atypical STEM careers that relate to physics, music and biology, while exploring activities that complement those respective careers. The live speakers included a dancer, sound engineer, US Naval Captain, and a cardiologist. Overall, the students established a greater appreciation for interdisciplinary learning, recognising that physics is universal.

Bringing in STEM Talent from Under-represented Groups

WSSU is a historically black university in a country in which black people remain significantly under-represented in STEM disciplines. The innovative interdisciplinary program has been successful in engaging black students, as well as women, who are also under-represented in the STEM community.

Going forward, the team seeks to increase the numbers of students taking the course by engaging in freshman activities and continuing their collaboration with the GEMS project in order to attract female high-school students. The kind of collaborative integration of arts and sciences being pioneered under Dr Presley's leadership may serve as a model for other universities trying to reach under-represented groups in a range of global contexts.

Meet the researcher

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Dr Tennille D. Presley earned her PhD in Biophysics from Ohio State University. She subsequently undertook postdoctoral training in Physics and Translational Science at Wake Forest University, where she remains a Faculty Affiliate. Appointed to Winston-Salem State University in 2010, she also serves as a Visiting Faculty member at the Brookhaven National Laboratory. Dr Presley has published extensively on her research in free-radicals and has received a significant range of awards and honours. These include US Delegate for the 6th IUPAP International Conference on Women in Physics, Best Student Research Achievement at Ohio State University in 2007 and the Buckeyes Under-40 award received in 2016: the same year her book, *Biophysics of the Senses* was published. Dr Presley has a keen interest in equality issues and has participated in a number of programs aimed at enhancing the position of women and people of colour within STEM.

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vObjects: A VIRTUAL TOOL FOR GRASPING ENGINEERING CONCEPTS

Engineering students can benefit greatly from interacting with physical objects whose attributes mimic those of real-world systems. So far, however, objects that do this effectively have proven to be extremely difficult to create. To solve the problem, **Dr Diana Bairaktarova** at Virginia Tech suggests that taught engineering courses could recreate practical situations more reliably using virtual objects, or 'vObjects'. If her approach becomes widely adopted, it could transform how engineering students learn to apply their skills to complex, often unpredictable scenarios.

Preparing Engineering Students

From civil to electrical, the broad field of engineering encompasses a diverse variety of different areas, each of which presents its own unique set of challenges. As students come to grasp the founding principles of their chosen field, many factors of the education process are critical in ensuring success in their future careers.

Acknowledging this, Dr Diana Bairaktarova and her colleagues at Virginia Tech are identifying effective ways to prepare engineering students to tackle the complex, real-world challenges they will face in their future careers. 'Through my research, I am building and strengthening our understanding of the professional formation of engineers by contributing to the knowledge of how the engineering learner develops professional skills, knowledge, and abilities,' she explains.

Perhaps one of the most significant challenges faced by Dr Bairaktarova and others in her field is the difficulty presented by translating the abstract ideas taught in lectures into skills for guiding real-world situations. Problems that students work on in their studies tend to have well-defined parameters and rigid, pre-set solutions, but everyday problems faced by real engineers are usually far more complex and ambiguous. In order to prepare students for these realities, Dr Bairaktarova advocates the need for a more hands-on approach to engineering education. However, this poses its own further challenges.

Solutions with Physical Objects

In any science-related teaching course, students can benefit greatly from physical demonstrations of the concepts they learn in their lectures – particularly through projects and experiments that they carry out themselves. This holds particularly true for engineering students, as regardless of their specialisation, they will almost certainly need to deal with tangible objects in some form in their future careers. Yet despite these advantages, incorporating such objects into learning programs is no easy task, for a number of reasons.

As they overcome obstacles, it is critical for real engineers to consider how the physical objects they interact with are influenced by a variety of different factors, and how their decisions can have widely varied outcomes. This makes it particularly difficult for students to translate the attributes of physical objects into useful knowledge about such abstract real-world problems. In addition, physical objects will often need to be large and complex, and may even risk safety. Overall, these issues call for more innovative approaches to how demonstrations can be made in engineering courses.

‘I am engaging in research with undergraduate and graduate students, educators and practitioners at the intersection of mechanical engineering, learning sciences, cognitive psychology, and engineering education, with the overarching goal of graduating ethical, empathic and creative professionals.’

Introducing vObjects

In the face of these challenges, Dr Bairaktarova proposes that engineering students’ education could be enhanced through interactions with virtual objects, whose attributes accurately translate to real-world effects.

Through efforts to realise this goal, she and her colleagues have now created a tool for building ‘vObjects’ – simulated 2D and 3D objects including boilers, fans, drains, turbines, generators and condensers, whose behaviours, shapes and functions all mimic their real-world counterparts. Furthermore, the team has incorporated vObjects into a ‘Virtual Learning Environment’, which also includes features such as equations and datasets. This virtual tool enables students to account for the impact of their engineering decisions on the physical, economic, social and political environments of the different geographical regions where their engineered system can be applied.

This virtual tool gives students access to reliable simulations of real physical components, enabling them to study and design systems in the mindset of a real engineer. ‘Our vObjects learning environment contributes to the situated perspective on learning by closely mapping the learner experience to a real-life scenario,’ Dr Bairaktarova says. ‘It adds value in traditional education as well as in a variety of energy science and fundamental engineering courses by bringing back the laboratory experience to courses that traditionally apply lecture-based instruction.’

Translating to Real-world Situations

Having developed vObjects and the Virtual Learning Environment, the team’s next goal is to determine how effective they are at enabling engineering students to truly grasp the concepts they learn in lectures.

To quantify the effectiveness of vObjects, Dr Bairaktarova and her colleagues are now considering how they could be used to solve problems posed by thermodynamics: the physical field describing how heat and temperature relate to factors including energy, radiation, and the properties of matter.

For engineers, the equations conveying the founding principles of thermodynamics are particularly abstract, making it one of the most notoriously difficult theories to apply to their work. For vObjects to succeed in this case, students would need to be able to use the Virtual Learning Environment to visualise how such abstract concepts apply to the real world, and then, to apply their skills to design effective systems.

Designing Virtual Power Plants

To test the true capabilities of vObjects and the Virtual Learning Environment, Dr Bairaktarova and her colleagues have now designed an experimental task, which tests the skills of undergraduate mechanical engineering students.

The task involves assuming the role of a global project manager proposing a design for a power plant in one of three developing countries – either Jamaica, Panama, or Rwanda. Since each of these nations struggle with persistent energy problems, such a project would require an in-depth understanding of the influence of thermodynamics on

real-world systems, and also requires students to account for a wide variety of factors that are not usually considered in the engineering classroom.

The students will likely be well accustomed to considering the actual design aspects of their power stations, which are strongly tied to the principles of thermodynamics. These include the total power the plant requires, the energy generated by its turbines, inputs from pumps and compressors, steam and gas flow rates, and the plant's overall efficiency. As well as these considerations, however, the students will need to tailor their designs, and their application of thermodynamics, to the specific requirements of Jamaica, Panama and Rwanda in an energy generation context.

Among these factors are economic aspects such as GDP, inflation and the value of imports and exports; geographic aspects including population, land and water area, and average temperature; and energy-related aspects including a nation's consumption and production, and the proportion of its population without electricity.

Assessing Student Interactions with vObjects

In their research, Dr Bairaktarova and her colleagues asked a group of undergraduate students, enrolled in an engineering thermodynamics course, to complete the task over a 12-week project. Afterwards, the students delivered their results in a written proposal. Then, in the second year of the study, students completed the task using vObjects and the Virtual Learning Environment – and supplemented their written proposal with 3D models of their power stations, designed using vObjects.

Practicing engineers in the energy field are currently evaluating the students' projects from both groups. The engineers are blind to the group conditions. At the end of the study, Dr Bairaktarova's team will ask the students about four different aspects of their approach to the project. Firstly, the researchers will ascertain whether the students found that vObjects enhanced their learning of the difficult and abstract engineering concepts involved in the project. Secondly, they will ask the students whether the digital environment of vObjects supported their methods for solving the problems involved, which did not have any pre-set parameters or solutions.

Third, they will determine which of the characteristics of the Virtual Learning Environment, including its incorporated equations, testing capabilities, and vObject manipulation, made it easier for the students to solve these less-rigid problems. Finally, they will quantify whether differences in skill and demographic between individual students influenced how they interacted with vObjects.

Transforming Engineering Education

If the students respond positively to vObjects and the Virtual Learning Environment, Dr Bairaktarova hopes that she will be in a strong position to promote their wider integration into many more engineering-related courses in the long term. Ultimately, she envisages that vObjects and the Virtual Learning Environment will become an ingrained aspect of engineering courses worldwide and could greatly improve many students' career prospects.

'I am engaging in research with undergraduate and graduate students, educators and practitioners at the intersection of mechanical engineering, learning sciences, cognitive psychology, and engineering education, with the overarching goal of graduating ethical, empathic and creative professionals,' she concludes.

Dr Bairaktarova now hopes that further advances in technology will allow vObjects to simulate real-world situations even more reliably, while becoming even more accessible to students across many different disciplines. If achieved, this could allow vObjects to equip a new generation of engineers to thrive under the challenges they will face in an increasingly complex modern world.

Meet the researcher

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Dr Diana Bairaktarova completed her PhD in Engineering Education at Purdue University in 2013, after more than 15 years of experience as a Design and Manufacturing Engineer. She joined Virginia Tech as assistant professor in 2015, and is now driven to use innovative technologies to study novel user interfaces, virtual and augmented learning and working environments that encompass human aspects at the cognitive, eye-tracking and sensory-motor levels. Her current projects include the development of learning environments, investigating the role of individual aptitudes and abilities in performing and learning engineering through psychometric instruments and experimental interventions. Dr Bairaktarova is particularly dedicated to the education of engineering students, and promotes the importance of equipping them for the complex, real-world challenges they will inevitably face in their future careers.

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Dr Scott Huxtable is an Associate Professor of Mechanical Engineering at Virginia Tech. He received his BS in Mechanical Engineering from Bucknell University and his MS and PhD also in Mechanical Engineering from the University of California at Berkeley. His research interests include nanoscale thermal transport, energy harvesting, phase change materials, and engineering education.

Mr Sathyanarayanan Subramanian
Graduate research assistant working on the project
Mr Sathyanarayanan Subramanian recently graduated with master's degree from the Department of Mechanical Engineering at Virginia Tech. Mr Subramanian was the developer of vObjects and his involvement in the research was instrumental for the study. Mr Subramanian is now employed by Kosh Industries working as CFD Engineer.

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THE NATIONAL ASSOCIATION OF BIOLOGY TEACHERS

Founded in 1938, the National Association of Biology Teachers (NABT) is an organisation of educators that promotes biology teaching, supports learning methods based on scientific principles and advocates for biology within society. In this exclusive interview, we have had the pleasure of speaking with NABT's Executive Director, **Jaclyn (Jacki) Reeves-Pepin**, and President, **Sharon Gusky**, who discuss the varied ways in which the Association empowers educators to provide the best possible biology and life science education for all students, even in the midst of the COVID-19 pandemic.

To start, please give us a brief history of The National Association of Biology Teachers (NABT). Who established the Association, and why?

Jacki: In the years following the Scopes trial, prominent scientists and scientific organisations like AAAS were starting to publicly voice concerns that secondary science teachers were not teaching 'organic evolution' in their classrooms. Surveys of teachers also indicated that they weren't teaching conservation or photosynthesis either.

On July 1, 1938, 18 biologists convened in New York City, and according to an announcement in the *New York Times*, they met with the express purpose to form an association 'to encourage scientific thinking and the utilisation of the scientific method through the teaching of biology, provide a national journal, facilitate the dissemination of the biological knowledge which is most vitalising and useful to the public every day and aid biology teachers generally.'

NABT was established by biology teachers to support biology teachers, something we have been doing for the last 82 years.

NABT's mission is to empower educators to provide the best possible biology and life science education for all students. Discuss some of the ways that the Association achieves this.

Jacki: Empowered teachers are life-long learners, so it is imperative that NABT provide opportunities to help teachers constantly reflect and improve on their own practice. We do this by providing avenues for teachers to share best-practices, innovative ideas, and research-based methods through our peer-reviewed journal, *The American Biology Teacher* and the NABT Professional Development Conference.

Sharon: The conference features over 100 member-referred sessions that highlight effective resources and pedagogies. Often, manuscripts lead to conference presentations and vice-versa, helping improve dissemination and adoption of the ideas.

Jacki: We also work with partners to offer workshops and seminars that help educators successfully implement current research and learner-centred teaching practices.

Another way NABT empowers educators is by celebrating their contributions to our profession through the *NABT Awards Program*. With the help of our generous sponsors, NABT is able to offer 12 teaching awards, five student awards, one scholarship for an educator attending graduate school, and one travel award. In addition, the NABT Outstanding Biology Teacher Award (OBTA) attempts to recognise an exceptional biology teacher in each of the 50 states, Washington DC, Canada, Puerto Rico, and overseas territories.

Sharon: Some of our most important efforts are focused on advocating for our members by being vocal supporters of science research, education, and literacy. NABT provides a number of formal position statements to help give a strong, unified voice to biology and life science educators. The statements use clear language to help articulate our views on subjects that are often

‘We believe science education should mirror how science is done. It should be evidence-based, grounded in research, iterative, and collaborative. And the ultimate goal should always be to improve understanding for learners’ – Jaclyn Reeves-Pepin

viewed as controversial by society – like evolution and climate change – but are not scientifically controversial. Educators use these guiding statements to support their teaching of important topics. And the statements provide teachers backing by a nationally recognised organisation should they encounter conflicts with administrators, parents and legislators.

Jacki: There are so many resources and opportunities that NABT provides as an organisation to empower the ‘individual’ educator. But the most gratifying way we achieve NABT’s mission is by nurturing a supportive community. The leaders of NABT work to ensure the association embodies our values. We believe that improving yourself professionally is always easier if you’re doing it with a friend.

Last November, you hosted the 2019 Professional Development Conference in Chicago. How does this annual conference help NABT to fulfil its mission?

Jacki: The Professional Development Conference is immensely important to our community. As the name implies, the design of the conference is focused on professional development and learning. We look to our community of biology and life science educators to tell us what they want or need to learn about. Then our challenge is to accommodate as many high-quality sessions, workshops, speakers, posters, social events, and exhibits into a four-day timeframe as possible.

The conference is incredibly popular and attendees are recommending our event to their colleagues. As a result, the conference has experienced steady growth in attendance for the last five years. When people attend the NABT Conference, they really understand what the NABT community is all about, and how we can support them as educators.

Sharon: Because of that strong sense of community, teachers are willing to share the newest, most innovative, and often cutting-edge techniques they are using in their classrooms. They know that they will receive both supportive and honest feedback from their peers.

Jacki: Embracing the opportunity to get supportive, honest feedback is part of our culture so the NABT conference is also when our leaders and members gather to take a long, hard look at areas in need of improvement within the association.

Sharon: One of the major outcomes of the 2019 Conference is that the leaders of NABT committed to undergoing a strategic planning initiative with the express intent to improve diversity, equity, and inclusion at every level of our organisation.

The Association strongly advocates the use of evidence-based educational techniques and learner-centred approaches to teaching. Please describe an example or two of such cutting-edge techniques, and explain how you encourage biology teachers to adopt educational methods that are most effective for their classrooms and students.

Jacki: We believe science education should mirror how science is done. It should be evidence-based, grounded in research, iterative, and collaborative. And the ultimate goal should always be to improve understanding for learners.

Sharon: NABT supports the recommendations of guiding documents like the NGSS for K-12 and Vision & Change in Undergraduate Education. These tell us the 'what', which is content-focused, but we also need to help educators with the 'how'. One of the best ways we can do that is by demonstrating methods that work. This could be by promoting active learning techniques and flipped classrooms. Or showing how to effectively implement CURES (course-based undergraduate research experiences) or story-lining into a curriculum.

Jacki: One of our biggest initiatives is NABT's Introductory Biology Experience (IBEx). High school biology or introductory biology at the undergraduate level is often a student's only exposure to STEM. NABT's membership is 59% high school, 15% two-year college, and 18% four-year college and university. We have been working with leaders from these different levels to identify areas of overlap in content, skills, and relevance so that all students can be successful. This could mean college or career readiness for a high school student, foundational understanding for a STEM major, or improved science literacy for everyone.

What other resources do you have available for your members?

Jacki: In addition to the journal, conference, awards, and position statements mentioned above, NABT works with a diverse group of both for-profit and non-partners to create resources and opportunities for biology teachers. The life sciences advance so rapidly! The only way we can keep up is by collaborating with experts in the field.

How does NABT advocate for biology within American society?

Jacki: NABT is well-known for our commitment to science education. We have a number of formal position statements that address the 'hows', 'whats', and 'whys' of teaching biology and life science. Although the vast majority of NABT's time and efforts are focused on how best to teach biology and life science, we will actively oppose attempts to misrepresent or diminish science.

In May 2019, the California State Assembly considered a bill that 'would prohibit a pupil in any California private or public school in kindergarten and grades 1 through 12 from

As classes moved online, there was an 'all hands on deck' mentality in our community and we saw increased collaboration between educators at different academic levels. NABT has always tried to encourage these interactions, but the Covid-19 pandemic showed how access to a diverse group of fellow educators is such a great asset' – Sharon Gusky

performing dissection', NABT wrote a letter in opposition to the bill and also encouraged our California members to contact their representatives. Although NABT supports the ability of any student to opt-out of dissection, we felt the bill went too far. It not only used an overly broad definition of dissection to include food-grade products, it also threatened the agency of professional educators to design meaningful experiences for their students.

NABT also responds to efforts by local and state representatives who sponsor legislation to counter the teaching of 'controversial' topics like evolution and climate change by introducing language into state education standards that allows specific science concepts to be subjected to special consideration. The legislation seeks to permit discussions on 'strengths and weaknesses' or 'alternative explanations', and NABT's position is that concepts like evolution and climate change are not controversial. We will challenge any effort that allows non-scientific explanations to be used to describe observable, natural phenomena in science classrooms.

NABT believes that society is best served when students understand science the same way scientists understand it, meaning it is supported by experimentation, logical analysis, evidence-based revision, and reliance on detectable and measurable data.

How is the Association responding to the current global biodiversity crisis?

Jacki: Education is key here. Teachers and their students need to know about how the loss of biodiversity is personally affecting them. When we look at climate change and loss of habitat, the scale is so big it's hard to comprehend. But when you talk about biodiversity and extinction in less abstract terms, it can help people understand how urgent we need to address this looming crisis.

Biodiversity impacts not only sustainability of ecosystems – it has implications for access to food and clean water, pharmaceutical development, the incidence of infectious pathogens. By helping students understand what's happening and why, we hope we are giving them the tools to face this challenge head on.

In what ways have you been supporting your members throughout the COVID-19 pandemic?

Jacki: Biology teachers supporting biology teachers is very important during this challenging time. As our members moved their instruction online, it was critical that they could get just-in-time guidance and support from their peers. Some teachers only had a day to move their classes online, so they were making adjustments in real-time.

We encouraged both NABT members and non-members to join our Facebook group because of the ease of use and adoption of the forum. Members are sharing resources and setting up Zoom meet-ups, and partners and vendors are offering materials for free. NABT has made our entire journal archive free and we built a freely available resource table

to capture member recommendations so teachers can more easily find useful tools.

Going into 2020, NABT is hosting our Professional Development Conference completely online so we can help keep our community safe during the ongoing Covid-19 pandemic. We're excited by the opportunity to conduct professional learning in a new modality, and it also allows more teachers to participate in the NABT Conference from the comfort of their own homes.

More generally, what long-term changes will the COVID-19 pandemic bring to biology education?

Sharon: It is still too early in the pandemic to determine which changes will be longer term, and which will only last through the crisis. But as we approach the Fall, some changes are starting to emerge.

As classes moved online, there was an 'all hands on deck' mentality in our community and we saw increased collaboration between educators at different academic levels. NABT has always tried to encourage these interactions, but the Covid-19 pandemic showed how access to a diverse group of fellow educators is such a great asset.

Jacki: Recommendations for virtual tools prompted many of the early conversations, and we had high school teachers sharing the Weebly sites with university faculty, and two-year college instructors showing middle school teachers how to use Zoom more effectively. We had scientists and graduate students visit classrooms 'virtually'. Even as the discussions move away from tools, we continue to see cross-level collaborations that focus on improving the teaching and learning of biology in an online environment and across the K-12 to college continuum. Since Covid-19, Professional Learning Communities have taken on a whole new meaning.

Sharon: NABT recognises that biology and life science cannot be effectively taught with a lecture-only approach, and so much of learning biology is actually doing biology. While remote, online, and simulated labs cannot take the place of learning hands-on lab skills, they still provide a way to introduce students to scientific practices like asking questions, analysing data, and interpreting models. We expect to see more educators fully incorporate these tools not only in their online classes, but also use them in conjunction with face-to-face instruction when they return to their campus-based classrooms.

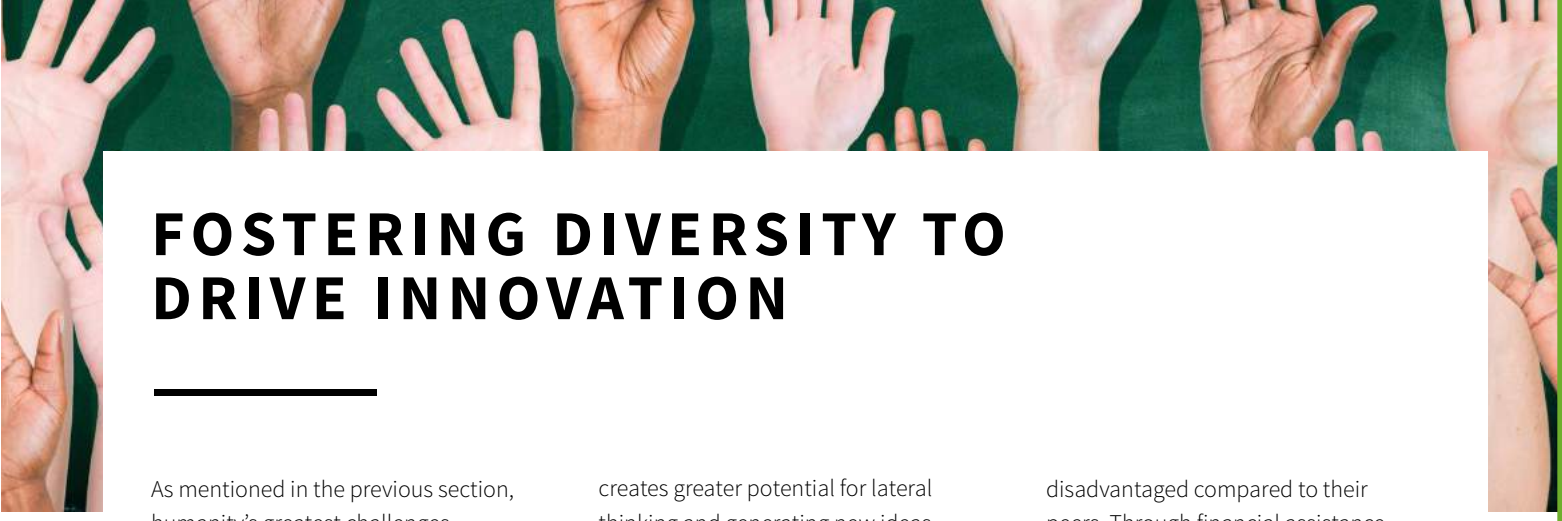
Jacki: Of course, we also expect the Covid-19 pandemic to increase overall interest in biology and the life sciences, and especially in disciplines like virology, immunology, epidemiology, public health. The list is endless.

Biology affects people's lives every day, not just during a pandemic, but every day. Biology teachers are here to help us make sense of this ever-changing world, and how we can stay healthy and happy in it.

www.nabt.org

NABT
National Association of Biology Teachers

FOSTERING DIVERSITY



FOSTERING DIVERSITY TO DRIVE INNOVATION

As mentioned in the previous section, humanity's greatest challenges, including the COVID-19 pandemic and climate change, can be most effectively tackled by a strong and diverse STEM workforce. However, the number of STEM students is not adequate to meet the growing demand for professionals in these fields.

There are many reasons why a young person might not consider a career in STEM. They may hold beliefs about the types of people who 'belong' in the STEM community, with many associating science and engineering with white, middle-class men. This perception results from a long history of women and minority groups being actively excluded from scientific disciplines. The current lack of diversity within STEM perpetuates this problem, as many young people have no relatable role models to inspire them to pursue these fields.

Then, when enrolled in a STEM degree, many underrepresented students experience bias and discrimination from their peers and mentors. Such bias can lead to feelings of isolation and low confidence, resulting in poor academic performance and even drop out. In addition to being profoundly unfair for those who ultimately miss out on rewarding STEM careers, the low numbers of women and people from diverse backgrounds mean that there are insufficient numbers of young people graduating with STEM degrees overall.

Furthermore, homogeneity within the scientific community stifles innovation. In contrast, by combining the widest possible range of backgrounds, perspectives and experiences, diversity creates greater potential for lateral thinking and generating new ideas, towards achieving true excellence in science. Therefore, this section highlights several fantastic initiatives, aimed at both inspiring young people from diverse backgrounds to pursue STEM subjects, and supporting underrepresented students on their journeys to successful STEM careers.

In the first article of this section, we introduce a project funded by the National Science Foundation (NSF) called SciGirls, which encompasses an educational television show, a website, and various outreach programs, all aimed at encouraging girls to pursue STEM fields. As part of an effort called SciGirls CONNECT, a research team at the National High Magnetic Field Laboratory has explored the impact of SciGirls outreach programs, such as after-school clubs and summer camps, on students' STEM identity, towards improving these programs further.

Another NSF-funded project that aims to increase diversity in STEM is called STEMWoW, which we feature next. Through a two-week STEM summer program and a series of follow-up family booster sessions, the project is designed to promote greater STEM interest among underserved middle school students predominantly from Hispanic/LatinX communities.

In the third article of this section, we meet Dr Ignatius Fomunung at the University of Tennessee Chattanooga, who has developed UTC ASSETS – a program that supports engineering students as they transfer from community colleges to university, recognising that they may be academically and financially disadvantaged compared to their peers. Through financial assistance, community building, summer boot camps and mentoring, UTC ASSETS aims to increase the graduation rates of transfer students, towards fostering greater diversity in engineering fields.

Mentoring is the focus of our next article, in which we introduce Dr Christine Pfund at the University of Wisconsin-Madison, who has been developing ways to optimise mentoring relationships within STEM. Her work is especially important for graduate students from minority groups, who typically receive poorer quality mentoring than their peers, reducing their motivation and productivity. The success of Dr Pfund's initiatives has resulted in the development of a network of mentors across the US.

Next, we showcase the HBCU-HDI Women in STEM Conference, which takes place every two years – alternating between South Africa and the US. The event aims to empower women in STEM, particularly women of colour, by bringing scientists and graduate students from these two countries together to openly discuss their experiences and achievements, while sharing the challenges they encountered throughout their professional journeys.

In the final article of this section, we meet Dr Susan Windham-Bannister, President of the Association for Women in Science (AWIS). In this exclusive interview, Dr Windham-Bannister describes the barriers that women face in the STEM workplace, and the many ways in which AWIS works towards eliminating inequality through systemic change.

RECOGNITION'S ROLE IN STEM IDENTITY DEVELOPMENT

SciGirls is an educational television show, website, and outreach program funded by the National Science Foundation (NSF), aimed at encouraging more girls to pursue science, technology, engineering and mathematics (STEM) fields. As part of a research effort called SciGirls CONNECT, **Roxanne Hughes**, **Kari Roberts** and **Jennifer Schellinger** at the National High Magnetic Field Laboratory have been investigating the impact that SciGirls outreach programs across the nation, such as after-school clubs and summer camps, have on students' STEM identity.

The Gender Gap

In 2013, a report by the US Department of Commerce revealed that women are significantly underrepresented in STEM disciplines, holding less than 30% of STEM jobs, despite making up approximately half of the global working population. These numbers tend to be even lower for minority women of colour, who typically represent one out of 10 employed engineers and scientists.

The gender gap within STEM fields can be traced back to childhood, when a majority of girls begin to move away from STEM disciplines and towards more humanistic fields while completing their middle school education. Early teens are a crucial time, because they are the years when girls start forming attitudes and interests towards specific subjects that shape their future career aspirations.

While many young girls have positive attitudes towards, interests in, and remarkable talents with STEM subjects during their early education, most never realise their potential because they tend to lose confidence in STEM subjects. This perpetuates a STEM workforce that is largely male dominated – one that misses out on a vast and rich talent pool of gifted women. Such homogenous workplaces, primarily made up of white men, also suffer from a lack of diversity in perspectives – hindering progress and innovation.

Aware of the current gender gap in STEM fields, universities and other organisations across the US have been developing a growing number of academic programs aimed at encouraging more females to engage in STEM disciplines from a young age. Motivating girls to pursue STEM-related careers involves helping them to build a 'STEM identity', by strengthening their interest, confidence and motivation in approaching STEM fields.

SciGirls CONNECT

To continue working towards reducing the gender gap in STEM fields, a team of US researchers and educators introduced a project called SciGirls, funded by the NSF. The project involved the creation of a television show

and later a website resource and an outreach program for girls between the ages of 8 and 13, aimed at strengthening their STEM identities.

Eventually, the project also fuelled the formation of SciGirls CONNECT, a network of 140 academic institutions and organisations across the US that all use teaching resources developed as part of the SciGirls project. These teaching resources include the SciGirls Strategies, a set of seven teaching strategies that help educators to increase the engagement of primary and middle school girls in STEM disciplines.

‘We define STEM identity as individuals’ sense of belonging and success in STEM domains and careers.’

Three STEM-education experts at the National High Magnetic Field Laboratory in Tallahassee, Florida – Roxanne Hughes, Kari Roberts and Jennifer Schellinger – are currently leading the research portion of the project. As part of this work, they have been exploring the impact of multiple SciGirls programs on the STEM identity of female students. Their ultimate goal is to use the data they collect to improve SciGirls teaching strategies and academic programs and to add to the larger conversation occurring in the STEM-education research community about gender equity and STEM identity.

‘We were able to collect two years of data on informal STEM education programs, including summer camps and after-school programs, for girls across the US to empirically understand the impact of these programs on middle school youths’ STEM identity,’ says Hughes. ‘We define STEM identity as individuals’ sense of belonging and success in STEM domains and careers.’

Evaluating Impact

The team’s work is guided by a conceptual framework for STEM identity that draws inspiration from the work of several researchers including Heidi Carlone, Angela Johnson and Angela Calabrese Barton. This framework suggests that to develop a stronger STEM identity, an individual has to develop STEM-related skills and engage in activities where they can perform these skills, so that they can be recognised for these skills by experts in the field.

‘This last portion is not well understood by science education researchers,’ explains Schellinger. ‘Our study supports the importance of external recognition through quantitative results. It also provides examples of what recognition looks like in an informal STEM education setting through examination of these observational data.’

To evaluate the impact of SciGirls programs, Hughes, Roberts and Schellinger collected survey responses from 148 young girls who took part in one of 11 SciGirls programs. The surveys measured youths’ self-efficacy and STEM identity both before they started a SciGirls program and after completing it.

‘The subscales for the STEM Self-Efficacy scale were: Self-Confidence, Openness to Challenge, and Willingness to Learn,’ says Roberts. ‘The subscales for STEM Identity were: Self-Perception, which involves seeing oneself as a STEM person or someone who is competent in STEM, and External Perception, which means believing that others see one as a STEM person or someone who is competent in STEM.’

In addition to analysing survey data, the researchers gathered observations at three locations that offered SciGirls programs, to examine how the programs influenced the STEM identities of participating girls. This data included the collection of video recordings and observation notes during each activity, as well as recordings of interviews with both educators and youth at each location.

Effect of SciGirls on STEM Identity

The team's research yielded a number of promising results. For instance, the researchers found that programs incorporating SciGirls teaching strategies strengthened the STEM identities of participating girls, often changing their perceptions about how others viewed them (for example, as a 'STEM person').

Interestingly, however, the girls' own perceptions of themselves did not always change, highlighting the need for more activities that can encourage a positive shift in self-perceptions, helping girls to recognise their potential in STEM disciplines.

Examination of the observational data gathered by the researchers during the three SciGirls programs also suggests that there was a growth in the participating girls' STEM identities. More specifically, these findings suggest that SciGirls programs created supportive and inclusive learning environments, where young girls could participate in learning activities that increased their engagement and competence in STEM subjects.

Face-to-face interviews with the educators delivering the programs, however, highlighted their difficulties in understanding the meaning of 'culturally responsive teaching', one of the essential constructs highlighted by the SciGirls project. Additionally, the educators expressed uncertainty about how to apply culturally responsive teaching in their programs. Their uncertainty was reflected in the observational data, as the researchers found that culturally responsive teaching strategies were rarely or never employed by educators in their respective SciGirls program.

The Future of SciGirls CONNECT

Overall, the findings of the research conducted by Hughes, Roberts and Schellinger indicate that informal education programs guided by SciGirls teaching strategies can support girls in exploring their STEM identities, helping them to recognise the value of STEM disciplines and empowering them to pursue STEM-related educational pathways and careers in the future.

The analyses carried out by the researchers also shed light on specific teaching strategies that could be improved or better conveyed to educators, such as culturally responsive teaching. As well, aspects of STEM identity that appeared to be unaffected by the programs need further examination, including the students' perception of themselves as potential STEM professionals.

The findings identified by Hughes, Roberts and Schellinger have the potential to help improve SciGirls teaching strategies and academic programs by highlighting specific areas that require further attention. The researchers are now working on disseminating their research at national and international conferences, while also presenting them in peer-reviewed STEM education journals.

'We also plan to follow-up with participants to examine how their STEM identities changed after participating in SciGirls CONNECT programs,' says Hughes. 'The goal of this follow-up is to understand how school, family, and out-of-school opportunities intersect to influence and change STEM identity.'

Meet the researchers

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Dr Roxanne Hughes holds a PhD in Educational Policy and Evaluation from Florida State University, as well as an MA in Secondary Education and a BA in Biology from LaSalle University. Currently, she is the Director of the Center for Integrating Research and Learning at the National High Magnetic Field Laboratory (MagLab). Dr Hughes has carried out extensive research investigating academic programs and policies that could increase the number of women and underrepresented minorities in STEM fields.

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Dr Jennifer Schellinger holds a PhD in Curriculum and Instruction and an MSc in Biology from Florida State University (FSU), along with a BSc In Earth Systems, Science & Policy from California State University, Monterey Bay. She is currently a postdoctoral researcher for an NSF-funded program called 'Learning Through Collaborative Design: Professional Development' in the School of Teacher Education at FSU. Dr Schellinger has conducted research exploring integrated STEM education to identify interdisciplinary approaches that improve learning and engagement in STEM discipline for *all* students.

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Kari Roberts holds a Master's of Science in Higher Education from Florida State University and a BA in French from the University of South Carolina. After completing her master's degree, she started working at MagLab's Center for Integrating Research and Learning. In addition to serving as the Center's internal evaluator and postdoc liaison, she conducts quantitative analyses focusing on the role of informal science education programs in forming STEM identities, enhancing students' self-efficacy, and strengthening the current STEM workforce.

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FLORIDA STATE UNIVERSITY
NATIONAL HIGH MAGNETIC FIELD LABORATORY

BUILDING THE STEM STUDENTS WE NEED

Despite recent efforts to promote diversity in STEM education and professional environments, some ethnic groups remain highly underrepresented in STEM fields, including the Hispanic/LatinX community. To tackle this underrepresentation, researchers at the University of San Diego have created a multi-dimensional program funded by the National Science Foundation called STEMWoW, which is designed to promote and sustain interest in STEM disciplines among middle school students from underserved communities.

Diversity in STEM

In this era marked by rapid scientific and technological advances, the United States must ensure that all available talent is recognized and cultivated. With this in mind, many researchers and academic institutions have been developing programs aimed at increasing diversity in STEM (Science, Technology, Engineering and Mathematics), by providing support and learning opportunities for underrepresented and minoritized communities.

Despite the potential shown by many of these initiatives, some communities remain widely underrepresented in STEM education and professions, including the Hispanic/LatinX community, which makes up only 7% of the US STEM workforce, despite being one of the youngest and most rapidly growing ethnic groups in the country.

In addition to being a serious equity issue, this underrepresentation means that the talent of countless young people is currently going to waste. To tackle the underrepresentation of Hispanic/LatinX individuals in STEM fields, a team of researchers at the University of San Diego has developed STEMWoW (Bridging the World of Work and Informal STEM Education), an academic program aimed at increasing young people's interest in science, technology, engineering, and mathematics.

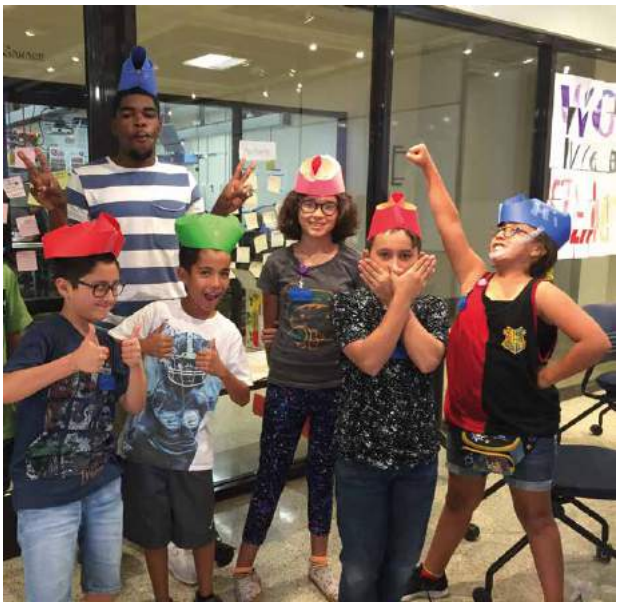
The STEMWoW program addresses the challenges of underrepresentation in STEM using an innovative and multi-layered approach. The investigators on the team are Dr. Odesma Dalrymple, Dr. Yaoran Li, Dr. Perla Myers, Dr. Vitaliy Popov and Dr. Joi Spencer. The researchers all have extensive experience in STEM academic settings and are actively working on a variety of projects designed to enhance learning experiences across the US and abroad.

The STEMWoW Project

The ultimate goal of Project STEMWoW is to promote greater STEM interest among underserved middle school students predominantly from Hispanic/LatinX communities. This is achieved through a two-week STEM summer enrichment program and a series of follow-up family booster sessions, which take place throughout the academic year.

The STEMWoW research project employs a mixture of different methods to better understand the factors that influence STEM learning and engagement, as well as variables that can encourage students to make STEM oriented academic and career choices. The project is funded by the Advancing Informal STEM Learning (AISL) grant program through the National Science Foundation (NSF). AISL is aimed at better understanding what enhances STEM learning in informal environments and updating teaching practices accordingly.

'Paramount to this work is the core focus on the city of San Diego's



Five Priority Workforce Sectors: Advanced Manufacturing, Information and Communications Technology, Clean Energy, Healthcare, and Biotech,' the researchers explain. 'Few, if any, existing projects in the Advancing Informal STEM learning portfolio have explored the potential connections between these five priority workforce sectors, informal STEM learning, and identity among predominantly Hispanic/LatinX youth and families engaged in a year-long, culturally responsive STEM learning and workforce focused program.'

First introduced in the summer of 2018, the STEMWoW program has so far predominantly involved students from the Hispanic/LatinX and underrepresented groups in STEM in the Chula Vista Community of San Diego who attend three local middle schools. So far, the program has had 40, 38 and 49 students for each of its three two-week summer sessions, respectively.

Students are recruited through their school district, with school administrators and teaching staff actively supporting potential candidates with their applications. Once a student is accepted into the program, this is then communicated to the child's family members, who are also invited to take part in some of the program's activities.

When recruiting 'pod leaders' to lead the program activities, the researchers sought a diverse pool of applicants by reaching out to candidates from communities that have been underrepresented in STEM, as well as to individuals who had participated in their previous initiatives. Ultimately, they hired a total of 18 pod leaders: six STEM undergraduate students, two graduate students, 1 STEM alumnus, 2 practicing teachers and 1 practicing school counselor.

During the two-week summer program, students take part in a variety of hands-on activities and projects, which often involve collaboration with their peers. Interestingly, some students who participated in the summer program asked if they could eventually become pod leaders. The researchers thus decided to also recruit some high school pod leaders who had previously participated in the program to support younger students in their learning.

Another key component of the STEMWoW program is the World of Work model. Pod leaders are coached on how to facilitate the development of the students' concept of self, by exploring their abilities, interests, and values, as well as by identifying ways in which these can be aligned with STEM fields and world of work opportunities in the San Diego region, nationally, and internationally.
During the STEMWoW workshops for pod leaders, pod leaders are also asked to participate in self-discovery, reflection, setting goals, meeting with professionals, and career exploration activities, in order to effectively guide students during World of Work activities.

STEM with Purpose

STEMWoW students are encouraged to consider how STEM can be employed as a tool for addressing societal issues and challenges. Drawing upon the United Nations Goals for Sustainable Development, participants create culminating tasks that incorporate coding, origami and scaling to address some of society's most pressing problems. For example, one group designed a working model windmill to address Sustainable Development Goal 7: Affordable and Clean Energy.

Dalrymple, Li, Myers, Popov and Spencer created the curriculum for both the summer course and follow-up booster activities. The program's activities range from complex workshops to simple tasks. For instance, students might be asked to go on scavenger hunts around the university campus, taking pictures or noting down the specific mathematical objects that they encounter.

Other hands-on activities include exploring mathematical concepts through paper folding, building chain reaction machines, solving unfamiliar visual problems, drawing and data collection. When explaining these activities to students, pod leaders associate them with real-life situations, so that students can understand their significance outside the classroom.

The program also includes career exploration sessions, in which students learn about STEM-related career paths. As part of this, STEM professionals come in to share their work. These sessions are designed to improve students' knowledge of STEM-related careers, while also encouraging them to pursue these careers in the future.

The Research

While it is a fun series of activities for students, STEMWoW is an active research study whose results could shed light on how best to meet the STEM learning needs of underserved and under-serviced students in STEM. The researchers are interested in three broad questions:

- What is the impact of the STEMWoW program on student engagement, STEM motivation, sustained interest in STEM, and academic performance outcomes?
- What are the factors that moderate student engagement, STEM motivation, sustained interest in STEM, and academic performance outcomes of the STEMWoW program?
- How does the WoW component influence students' personal goals/career plan and what links do students make between their STEM learning experiences and their personal goals and career plan?

Dr. Bernadette Chi, Keri Waller and Ashley Currin have served as external evaluators for the project. In this role, they collected feedback from pod leaders and participating students, and used it to assess the rigor and appropriateness of the program's design and implementation, as well as that of the parallel research study investigating its impact.

This evaluation process yielded very promising results, with the team concluding that the program is robust, well-designed and effectively implemented. In their feedback, many participating students said that they felt the program had strengthened their teamwork skills, their confidence in their abilities, and their levels of engagement in STEM-related disciplines.

'What I liked so far about STEMWoW is the activities we do, specifically the coding,' said one student. 'It's fun to learn how machines and technology work.' Another participating student said: 'I learned about myself and that I can actually do stuff. In school I usually partner up with students who come up with ideas for me. I usually think my own ideas are garbage. Today, I finally did something with my ideas in the chain reaction.'

The feedback collected from pod leaders was also positive, with many highlighting that the students particularly enjoyed the hands-on activities. 'The students really enjoyed the different activities, such as paper folding, circuits, chain reaction machines, etcetera,' said one pod leader. 'Many of them commented that these activities were way more fun and engaging than what they do in school.'

After the program's first two-week course was completed, pod leaders applied some changes that they later felt considerably improved the course's implementation. For instance, they learned to manage their time better, delivered presentations about their personal and professional background at the beginning of the course, and were given greater responsibilities in running course activities.

A More Diverse STEM Workforce

The STEMWoW project has so far proven to be a very effective and promising endeavor. The reactions of both students and pod leaders have been overwhelmingly positive, suggesting that both the summer course and follow-up sessions were successful in enhancing the interest and engagement in STEM disciplines.

The summer enrichment program developed by Dalrymple, Li, Myers, Popov and Spencer has been featured in several local and national media platforms. In the future, the researchers hope that it will become a template for other academic institutions, inspiring similar efforts and initiatives.

The team is still in the process of analyzing all the data they collected from students, parents, and pod leaders who were involved in the program. Once they are complete, these analyses could offer further insight into the impact of STEMWoW and its effects on the engagement, learning, attitudes, and skills of the participating students.

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Dr. Li attained an MA in statistics and a PhD in educational psychology from the University of Missouri Columbia. Currently, Dr. Li is a managing researcher in the School of Leadership and Education Sciences at the University of San Diego. She is particularly interested in leveraging data and empirical evidence to better understand and model complex learning processes, such as mathematical and socio-emotional learning. Before she started working at the University of San Diego, Dr. Li was part the statistical research team at ACT Inc.

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UTC ASSETS: SUPPORTING UNDERPRIVILEGED AND UNDERREPRESENTED ENGINEERING STUDENTS

When designing undergraduate engineering courses, educators typically assume that all new students will be academically prepared to begin higher education studies. The reality, however, is that not all students starting college are 'college ready', as some may have had fewer learning opportunities in the past. To help these students achieve their full potential, **Dr Ignatius Fomunung** and his colleagues at the University of Tennessee Chattanooga created ASSETS. This academic program is specifically designed to support engineering students that transfer to university from community colleges, who may be academically disadvantaged compared to their peers.

Obstacles Faced by Underprivileged Students

The curriculum and structure of higher education courses can play a crucial role in ensuring that students retain their motivation and commit to completing their studies. If students feel unsupported and isolated in their university course, they will be more inclined to drop out and pursue a different path.

Most existing higher education institutions implicitly assume that all students have the necessary background knowledge and academic preparation to begin the course they selected. However, many students who start college may not be 'college ready', as some may be less privileged and not as academically prepared as their peers. This includes students who have come from disadvantaged high schools, and those who are the first person in their family to pursue higher education.

In 2015, the state of Tennessee launched a program that allows high-school graduates to attend two-year community colleges without having to pay tuition fees. Because of the program's great success, the number of students who will transfer to universities upon completing these courses is expected to surge in the coming years.

Ensuring that all students transferring from community college courses receive the support they need to feel confident in their studies is thus of utmost importance, as it could ultimately improve student retention rates and increase the number of people graduating every year. This is particularly important within engineering disciplines, where a large number of highly skilled graduates are urgently needed to tackle some of humanity's greatest challenges, such as ensuring water security and developing sustainable energy technologies.

With this in mind, Dr Ignatius Fomunung and some of his colleagues at the University of Tennessee Chattanooga (UTC) introduced ASSETS – Academic Intervention, Social supports and Scholarships for Engineering Transfer Students. Funded by the National Science Foundation, this academic program is designed to improve the retention rates and reduce graduation times for engineering students who have transferred from community colleges.

2019 cohort of students on the ASSETS program

The ASSETS Program

Students who start attending an engineering course at UTC after completing a two-year community college course can sometimes take up to four years to graduate. Therefore, one of the goals of the ASSETS program is to reduce these graduation times, by providing students with the support they need to excel in their classes.

As part of the ASSETS program, UTC offers 80 scholarships to a total of 36 students majoring in chemical, civil, electrical or mechanical engineering who are talented but either financially disadvantaged or are insufficiently academically prepared. These provide students with much-needed financial support to enable them to complete their studies. Eight of these scholarships span over the course of three years and are specifically assigned to students who are most behind on prerequisite coursework, due to a misalignment between the topics covered at their previous college and the curriculum at UTC.

The ASSETS program tackles some of the issues typically faced by transfer students, including what is referred to as 'transfer shock'. Transfer shock typically results from curriculum differences between courses offered at UTC and those previously taken by students, as well as differences in teaching environments – where community colleges tend to have small classroom sizes with individualised attention from tutors, while universities are notorious for larger classes, and decreased attention from faculty. Along with other challenges faced by transfer students, transfer shock is addressed using several strategies that have previously proven to be effective for supporting students in higher education settings.

A Comprehensive Support System

As many transfer students are financially disadvantaged, they often cannot afford to live on campus with their peers and miss out on the opportunity of becoming part of a 'living learning community'. The ASSETS program offers students the possibility to join a 'transfer learning community' and share their experiences with other students attending courses at UTC.

Students participating in the ASSETS program are also supported throughout their studies by both peer and faculty mentors. The role of these mentors is to ensure that transfer students are on track with their academic work, and to provide them with course-related guidance and advice. Students are assigned a specific faculty mentor from UTC's College of Engineering & Computer Science, whom they meet with three times per semester. Alongside this, they also receive support from a peer mentor and can participate in tutoring sessions delivered by other students.

'This program was helpful in getting to know faculty, putting us in a group with peers who were like us, all having been to community college,' said one student. 'I got to meet civil and mechanical engineering students, expanding my group of who I knew. I also got to meet lots of faculty across the discipline areas.'

The ASSETS program also organises a summer boot camp, designed to strengthen new students' knowledge of the course material and increase their confidence in their academic abilities. The curriculum delivered in this summer camp is put together with the needs and strengths of the students in mind.

The final component of the ASSETS program focuses on the students' professional development. Every year, UTC organises several career development activities that can help disadvantaged students to gain a better understanding of the careers they are thinking of pursuing or preparing them for their professional endeavours.

These activities, organised in collaboration with different industry partners, include events where guest speakers talk about their professions, as well as industry tours, workshops, internships and collaborative research projects.

Impact of the ASSETS Program

The ASSETS program officially started running in Autumn 2018, so it is too early to evaluate its long-term effects on the students' academic and professional

2020 cohort of students on the ASSETS program

development. So far, Dr Fomunung and his colleagues have tried to determine the impact of the program by examining the participating students' sense of community, commitment to their chosen studies, and overall experience with the different activities they took part in.

Dr Fomunung's team analysed a variety of data, including the recorded participation of students in different activities and their responses to surveys completed at different times during the year. So far, a total of 23 students have participated in the program, many of whom are from disadvantaged backgrounds, were employed, or had attended disadvantaged high schools.

The first evaluation study carried out by Dr Fomunung and his colleagues suggests that students found most of the ASSETS program's activities useful for their academic development. In a survey completed at the end of their first year of college, all students said that they felt ASSETS had helped them to be 'better and more successful students'. Every student also highlighted the value of the financial support received from their scholarships.

In the surveys, students also reported that the support received from faculty mentors and the career development activities had been important for their academic development. On the other hand, peer mentoring, tutoring, the summer boot camp, and ASSETS seminar courses received mixed reviews and had lower attendance rates.

Dr Fomunung and his colleagues also organised four different focus groups, in which students who had participated in ASSETS shared their experiences and perceptions about the program. In the discussions that took place during these sessions, students reiterated that the financial support they had received, faculty mentoring, and career-related activities had been most beneficial for their academic development.

Supporting Students Throughout Their Academic Journey

'The ASSETS program has made inroads towards establishing a sense of community amongst transfer students,' said faculty member Dr Bradley Harris. 'This has been achieved through simple measures such as enrolment in shared seminar courses, participation in social messaging apps, and peer-to-peer mentoring, but the results have been profound. These students, who come from diverse backgrounds, levels of academic preparation, and life circumstances, now have a network they can depend on for advice, encouragement, and support.'

So far, ASSETS has allowed several transfer students from disadvantaged backgrounds to pursue high-quality undergraduate courses in engineering, facilitating their academic development and social integration. The program is running again in the 2020/2021 academic year, involving some of the previous participants and new students.

Dr Fomunung now plans to adapt some of the program's components based on the feedback his team received from participating students over the past few years. For instance, the summer bootcamp is likely to change significantly, as students were not fully satisfied with some of its original modules and activities.

The ASSETS program and other similar academic initiatives could play a crucial role in ensuring that disadvantaged students and those from underrepresented minority groups are offered the opportunity to pursue their desired careers, while also receiving the support they need to perform well in their education and gain greater confidence in their abilities. This could improve graduation rates in engineering and other STEM courses, as transfer students might feel less inclined to drop out of college due to financial reasons or because they feel isolated and unsupported in their university course.

Dr Fomunung and his colleagues hope that UTC ASSETS will serve as a national model for increasing the retention of transfer students and ensuring that they complete their studies over a shorter period of time. The ultimate goal of their work is to foster greater diversity in engineering and other STEM-related fields, and help to meet the urgent demands for skilled professionals in these disciplines.

Meet the researcher

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Dr Ignatius Fomunung is a professor of Civil and Chemical Engineering at the University of Tennessee at Chattanooga (UTC). He holds a PhD in Civil & Environmental Engineering, in addition to an MS in Civil Engineering from Georgia Institute of Technology, an MS in Physics from Clark Atlanta University and a BS in Civil Engineering from Nanjing Institute of Technology in China. Before he joined UTC, he worked as an assistant professor at several other universities in the US, including Clark Atlanta University, Spelman College. He is also a Visiting Professor in the International College at Changsha University of Science and Technology, Hunan, China. Dr Fomunung's areas of expertise include the application of Wavelet Theory in transportation analyses, transportation/air quality planning and analysis, the development of intelligent transportation systems, human factors and safety in transportation, and the use of smart materials in infrastructure health monitoring. Dr Fomunung is also the director of UTC's Center for Energy, Transportation and the Environment (CETE). In recent years, he has broadened the focus of his research to include topics related to STEM education, including devising strategies that enhance student engagement, confidence, and success in STEM-related disciplines.

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FURTHER READING

https://blog.utc.edu/magazine/from-oil-fields-to-scholarship/

THE UNIVERSITY OF TENNESSEE CHATTANOOGA
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IMPROVING MENTORING RELATIONSHIPS IN SCIENCE: MENTORS NEED MENTORS

Dr Christine Pfund is a researcher at the University of Wisconsin-Madison, USA. With a strong network of colleagues and collaborators, her work focuses on developing, implementing, documenting, and studying interventions to optimise research mentoring relationships across science, technology, engineering, mathematics, and medicine. Read on to discover how the success of these initiatives has resulted in the development of a national network of mentors in the USA.

Mentors in Science

Mentors play a critical role in developing the careers of junior scientists. A good mentor inspires, encourages, and supports their mentee. This commitment is especially important for those from traditionally underrepresented groups in science who typically receive poorer quality mentoring than their non-minority peers.

The benefits of mentoring are clear. Mentored graduate students are more likely to publish their research and report greater career satisfaction. Benefits have also been identified for mentors themselves, including increased productivity, sense of fulfilment, and refinement of leadership and other key skills, in addition to their existing subject-specific expertise.

Unfortunately, in some cases, the mentor-mentee relationship is unsuccessful, resulting in a detrimental impact on the happiness and motivation of both parties. This circumstance may be due to a lack of training and support offered to mentors; despite its critical importance, mentors typically learn by example, trial and error, and peer observation.

Dr Christine Pfund at the University of Wisconsin-Madison (UW), along with her colleagues and collaborators, places particular focus on optimising the mentoring relationships that occur in the research context. Currently, this team is leading several national programs based at the UW, including the National Research Mentoring Network (NRMN) and the Center for the Improvement of Mentored Experiences in Research (CIMER). By using evidence-based curricula and approaches to foster the persistence and success of a diverse group of trainers, mentors, and mentees, the team focuses on aligning expectations and strengthening communications for mentoring relationships.

The team has also developed a strong, collective scientific foundation for research mentor and mentee training that includes both face-to-face and online delivery across a variety of disciplines and career stages. Indeed, their work is supported by a convincing track record of success in creating, implementing, publishing, and rigorously investigating interventions for scholars from diverse groups and their mentors.

Dr Pfund leading a mentor training workshop'

Drs Pfund, Sorkness, Byars-Winston and colleagues at the University of Wisconsin-Madison

UW Madison as a National Mentor Training Hub

The National Institutes of Health (NIH) is supporting the Diversity Program Consortium (DPC) to develop new approaches to engage and support researchers from populations which are underrepresented in biomedical sciences. Due to the established

‘Mentoring is known to be a critical factor in the satisfaction, productivity, and advancement of researchers across career stages.’

Dr Pfund and two NRMN Master Faciliators discussing ways to improve mentor training curricula

national reputation of Dr Pfund and her colleagues in the field of mentorship, the University of Wisconsin-Madison (UW) became a national hub for research mentor and mentee training for the National Research Mentoring Network (NRMN), part of the DPC.

The NRMN aims to provide all researchers, regardless of their position or background, access to evidence-based mentorship, professional development, and networking opportunities. The main aims of the project in its first phase were to: 1) increase access to mentoring across career stages; 2) improve mentoring relationships through training; 3) increase access to research resources and career development, and 4) promote the value of mentoring. As a nationwide project, the overarching goal is to assist in the development and expansion of a diverse, high-quality biomedical workforce.

As one of the NRMN Principal Investigators, Dr Pfund and the NRMN team developed training materials for both mentors and mentees with a focus on attributes known to impact mentee persistence, including cultural awareness. The team also assembled a group of 32 Master Facilitators who have collectively trained over 6000 mentors across the country. Starting in July 2019, Dr Pfund will launch the NRMN Coordination Center, which will support eleven NRMN research projects and a resource center to catalyse long-term potential across the collective. Dr Pfund and colleagues have also been involved in building capacity for training beyond NRMN, teaching others to implement evidence-based mentor and mentee workshops, and to further extend the reach of the initial programme.

Additional Training for Mentors and Mentees

Dr Pfund and the team are actively involved with other training programs,

Dr Pfund and the NRMN Master Facilitators

both at UW and at other institutions, aimed to establish, foster, and promote effective mentoring relationships at a broader level. For example, at UW, they lead mentor and mentee training efforts at the Institute for Clinical and Translation Research and are part of efforts to optimise the mentorship training provisions for graduate students, post-doctoral trainees, and junior faculty for this and other programs. As part of their work, the team is also developing and testing new training modules and assessment tools.

Dr Pfund also directs the Center for Improvement of Mentored Experiences in Research (CIMER; www.cimerproject.org) at UW. Here, the focus is on the development, implementation, and evaluation of mentor and mentee training using theoretically grounded, evidence-based, and culturally-responsive training interventions and investigations. One element of this work involves making evidence-based curricula available to the public. Another element is the development of a platform which can be used to assess researchers' mentoring experiences both in mentor and/or mentee training as well as in their mentoring relationships.

As part of their national efforts through CIMER, Dr Pfund and colleagues are implementing and testing an integrated mentor-mentee training package in partnership with the Howard Hughes Medical Institute as part of the prestigious Gilliam Fellowships for Advanced Study. Gilliam scholars engage in an evidence-based session at their annual meetings to support effective and proactive navigation of their mentoring relationships. Mentors of the Gilliam scholars engage in a full year of culturally responsive mentor training which includes face-to-face meetings, online modules, and other resources, all with the aim of fostering an environment where mentors can learn and support their peers.

How and Why Do Mentoring Relationships Work?

It is important to understand how and why mentoring relationships work from a solid theoretical perspective. Dr Pfund and colleagues have investigated several frameworks to inform future practice. These conceptual frameworks consider, for example, what factors are associated with academic persistence and career attainment. They provide a means of understanding the relationships between these factors and experiences, such as mentoring. Social cognitive career theory is one framework that helps explain these factors as potential mechanisms underlying key factors in motivation to reach a specific career goal.

Other frameworks of importance to Dr Pfund and the team include science identity development and social negotiation. These frameworks aim to explain how an individual adopts his/her professional identity and social capital. However, to advance the science of mentorship and understand what works for whom and in what context, more research is needed to determine the most appropriate metrics for assessing mentors, mentees, and mentoring relationships. This question requires further research, and is one of the goals of the NIH Diversity Program Consortium.

Research is also needed to understand the process by which evidence-based approaches in mentoring, such as Entering Mentoring, are disseminated and implemented on a national scale. A recent article by the UW team, led by Kim Spencer and colleagues, describes the approach the team used for national scale-up. Using these approaches, the team has trained more than 600 facilitators nationwide. The majority of these facilitators went on to implement mentor training for more than 4000 other researchers.

It is important to also note that barriers still exist to implementing research-mentor training. These can include a lack of support and resources, including training materials, personnel for planning and organising training, dedicated time for training, and a lack of confidence in implementation. However, outcomes from facilitator training sessions have revealed that having attended, delegates report more confidence and preparedness, and also reported that the opportunity to develop connections with other delegates was invaluable.

Key Findings

When asked what the key findings of current and past projects were, Dr Pfund identified the following take-home messages:

1. Mentor and mentee training interventions can improve the knowledge and skills of both mentors and mentees, and improve the effectiveness of mentoring relationships.
2. Despite evidence supporting the importance of mentoring, it remains unclear which mentoring relationships have the most impact. What specific factors best account for key outcomes in mentoring success? Critically, mentoring relationships do not occur in isolation – they are inherently woven into the social and cultural contexts of individuals and their academic institutions.
3. Facilitator training/train-the-trainer workshops are a demonstrably effective means of national dissemination and capacity-building.
4. Critical factors, known to impact mentees persistence and development in their careers, can be incorporated into mentor and mentee training. In this way, mentors and mentees are better able to address these factors in their relationship(s).

We can clearly see how the work of Dr Pfund and her colleagues benefits all – mentors, mentees, and the scientific workforce more generally. As Dr Pfund notes, 'Mentoring is known to be a critical factor in the satisfaction, productivity, and advancement of researchers across career stages.'

By building, improving, and evaluating the relationships between mentors and mentees, this work is playing a critical role in shaping the success of research establishments from local to national levels within the USA, with potential for application even further afield.

Meet the researcher

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Dr Christine Pfund is a Senior Scientist at the Wisconsin Centre for Education Research at the University of Wisconsin-Madison (UW). She is also director of the Centre for the Improvement of Mentored Experience in Research (CIMER) at UW, one of the principal investigators of the National Research Mentoring Network (NRMN). Dr Pfund completed a PhD and post-doctoral projects at UW and served as the Associate Director of the Delta Program in Research, Teaching, and Learning and the Co-Director of the Wisconsin Program for Scientific Teaching for more than a decade. Dr Pfund's work is conducted in collaboration with an established network of colleagues and collaborators, focusing on the development of mentor-mentee relationships across several academic disciplines. Currently, Dr Pfund is co-leading multiple studies focused on the impact of training on both mentors and mentees, and understanding specific factors in mentoring relationships that account for positive student outcomes. She is a member of the National Academies committee that recently published the consensus report and online guide, The Science of Effective Mentorship in STEMM.

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THE HBCU-HDI WOMEN IN STEM CONFERENCES

Although the number of women enrolling in science, technology, engineering and math (STEM) courses has increased over the past few years, women still remain widely underrepresented in STEM fields. To address this serious issue, the HBCU-HDI Women in STEM Conference, an event organised by **Dr Sonya Smith** and her colleagues at Howard University, brings female scientists and graduate students from the US and South Africa together to openly discuss the challenges and opportunities for women pursuing careers in STEM-related fields.

Challenges Faced by Women in STEM

In the US and South Africa, women often face significant challenges when trying to affirm themselves in STEM disciplines. There challenges are often further accentuated for women of colour, who are still widely underrepresented in most STEM fields, particularly engineering.

While laws in the US and South Africa safeguard women against discrimination and harassment in the workplace, the overall cultural and professional climate in both countries deters many women from pursuing STEM-related studies and careers. The lack of female role models in science and engineering professions further exacerbates this problem, as many girls and women are unable to imagine themselves working in these fields. As well as being immensely unfair, this leads to a considerable waste of talent, at a time when STEM professionals are in high demand.

Like many countries worldwide, South Africa has an increasing need for highly skilled scientists and engineers, particularly due to the continuous growth of its energy and mining industries. Nonetheless, women are often discouraged from specialising in STEM subjects at university and applying for jobs in these sectors, as they find that the general work culture can be intimidating for women.

Similarly, in the US, women remain highly underrepresented in numerous STEM fields, particularly women of colour. Discussing and addressing these issues is of utmost importance, as it could ultimately pave the way towards initiatives that encourage more young women to enter STEM-related professions, leading to more diverse, inclusive, and enriching workplaces. Workplaces that combine people from diverse backgrounds and perspectives have been proven to be more creative and innovative – key factors for success in science and engineering.

To initiate important conversations about the issues encountered by women entering STEM fields and encourage more young women to approach these fields, Dr Sonya Smith and her colleagues at Howard University created the HBCU-HDI Women in STEM Conference. At this event, women from different disciplines can discuss their achievements and experiences,

'Some of the key highlights of the conference over the past years have really been the interactions between the South African women faculty from HDIs in South Africa and African-American women faculty from HBCUs in the US. There have been many areas of intersection and collaborations fostered. In our next phase, we are getting ready for student exchanges and faculty exchanges.'

while sharing the challenges they encountered throughout their professional journeys.

Empowering Women in STEM

Established as part of a long-standing academic venture called the Howard University Republic of South Africa Project (HURSAP), the HBCU-HDI Women in STEM Conference takes place every two years in either South Africa and the US.

The conference was first held in October 2015 in South Africa, engaging over 150 female scientists, engineers, and graduate students. The speakers at each event are mostly from Historically Disadvantaged Institutions (HDIs) in South Africa and Historically Black Colleges and Universities (HBCUs) in the US.

The event is marked by inspiring and interesting keynotes given by women who have established themselves in STEM-related fields. In addition, attendees can engage in discussions about the challenges typically faced by women of colour who are pursuing or working in STEM disciplines in the US and South Africa and how these can be overcome.

The HBCU-HDI Women in STEM Conference is also a great networking opportunity, as it can be the chance to establish new international academic and professional collaborations. 'Some of the key highlights of the conference over the past years have really been the interactions between the South African women faculty from HDIs in South Africa and African-American women faculty from HBCUs in the US,' says Dr Smith, who directs the conferences. 'There have been many areas of intersection and collaborations fostered. In our next phase, we are getting ready for student exchanges and faculty exchanges.'

Highlights of the 2017 Conference

After highly positive feedback was received from those who attended the first conference in 2015, Dr Smith decided to continue organising the event every two years. 'In 2017 we were very grateful to the national academies of science engineering in medicine for allowing us to host the conference at the historic building on Constitution Avenue, in Washington,' she says. 'This conference included a student poster session in the atrium Fourier of that building as well as an innovation panel.'

The 2017 HBCU-HDI Women in STEM Conference had 12 key speakers, including 10 women of colour who have had outstanding and inspiring careers in different STEM fields. In addition to Dr Smith herself, other speakers included medical scientist Dr Keolebogille Shirley Motaung, mathematician Dr Sibusiso Moyo, and Dr Arlene Maclin, an internationally recognised educator.

During the opening panel, attendees discussed the similarities and differences in the career trajectories of women in the US and South Africa, focusing on different STEM fields and professions. Other panels included student presentations on specific subjects, such as energy consumption in water supply systems and computational research investigating cancer biology, as well as a discussion session about catalysing innovation and entrepreneurship by women in STEM.

2019: Innovation, Commercialisation and Entrepreneurship

In 2019, the HBCU-HDI Women in STEM Conference was hosted in East

London, South Africa, with a new series of speakers, panels, and discussions. Some of the speakers from the 2017 event returned to give new talks on topics centred around the themes of innovation, commercialisation and entrepreneurship.

This included a panel with several industry experts outlining the lengthy process through which a research idea or engineering concept can ultimately be translated into a business. In a different panel, a group of female innovators gave presentations outlining research ideas that they had ultimately developed into products. The research findings and innovative concepts presented at the conference were rooted in a variety of different STEM disciplines, ranging from engineering to biology and medical sciences.
'In 2019, we focused on methods to turn research into patents and commercially viable products,' explains Dr Smith. 'During the conference, we discussed role modelling and the fact that you cannot be what you cannot see. It was an invaluable experience for the conference participants to interact with women faculty and students from their same township, ethnic group in South Africa or from the same state or region in the US who are succeeding in STEM.'

The Innovation Panel

So far, all of the HBCU-HDI Women in STEM Conferences included a special Innovation Panel. The key purpose of this panel is to give academics, industry leaders, entrepreneurs, government representatives, and other STEM professionals attending the event the opportunity to collaborate on developing strategies for attracting and retaining women in STEM fields.

The panel typically features a number of presentations by women innovators from both the US and South Africa who have successfully established themselves in a particular STEM field. It is also designed to spark discussions among attendees about possible interventions that could encourage more young women to pursue careers in STEM, including ways to overcome cultural barriers and strategies that could assist women who require venture capital funding for their projects and professional endeavours.

Some of the key themes commonly explored in this recurring panel are career paths, professional climate/ culture and challenges/opportunities that are specific to women from HBCUs and HDIs. For instance, the panel may encourage discussions about how the professional trajectories of women in STEM differ between the US and South Africa or about how the two countries' cultural and professional climates can impact how young women feel about pursuing a career in STEM fields.

The Innovation Panel is a great opportunity for women working in different fields to share their views and learn from the experiences of others, while also discussing strategies that could potentially help to make workplaces more diverse and inclusive.

Advancing the Role of Women in STEM

The HBCU-HDI Women in STEM Conference has proved to be a highly enriching and impactful event, which has already initiated a number of meaningful academic and professional collaborations.

In addition to being a space where women from the US and South Africa can discuss the challenges they face as they try to fulfil their career aspirations, it encourages industry leaders, academics, and government representatives attending the event to start thinking about strategies that could help to mitigate or overcome these challenges.

Women and men of different ages and with varying academic and professional experiences have attended the conferences in 2015, 2017, and 2019; thus, it has also proven to be a highly valuable space for networking. In the future, Dr Smith and her colleagues hope that the conference will spark fruitful research collaborations or other joint professional endeavours between attendees.

'The most meaningful achievements of the conference so far are that we have encouraged numerous women in STEM to obtain graduate degrees,' Dr Smith says. 'We have a community of scholars that are African-American and black South African women and we now keep in touch through our social media groups.'

The next Women in STEM Conference will take place in 2021 in the US, assuming that it would not be unsafe due to COVID-19. Dr Smith and her colleagues at Howard University will start planning for the conference and recruiting new speakers in the Fall of this year.

Meet the researcher

Dr Sonya T. Smith
Department of Mechanical Engineering
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Dr Sonya T. Smith holds a PhD in Mechanical and Aerospace Engineering from the University of Virginia. For the last two decades, she has been teaching mechanical engineering and related subjects at Howard University, where she was the first tenured female faculty member in the Department of Mechanical Engineering and the first woman to be appointed Chair of the department. Her key research interests include high-speed aerodynamics, computational fluid dynamics, heat transfer and biomechanics. She has received numerous grants for her work from both government agencies and private companies. Dr Smith was responsible for the creation of a new interdisciplinary theoretical and computational research lab at Howard University, dubbed the Applied Fluids-Thermal Research Laboratory (@FTERLab). In addition, she is the principal investigator for Howard University ADVANCE-IT, an NSF-funded research project aimed at developing a strategic model to increase the number of female leaders in STEM workplaces. One of her key personal objectives is to become a mentor and resource for all students and faculty at Howard University, particularly those who are currently underrepresented in STEM fields. Recently, she was also elected Chairman of the Association of Universities for Research in Astronomy's Workforce and Diversity Committee.

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HOWARD UNIVERSITY

THE ASSOCIATION FOR WOMEN IN SCIENCE

Founded almost 50 years ago, the Association for Women in Science (AWIS) is a global network that inspires bold leadership, research, and solutions that advance women in STEM, spark innovation, promote organisational success, and drive systemic change. In this exclusive interview, we speak with AWIS president and world-renowned biomedical innovator **Dr Susan Windham-Bannister**, who describes the barriers that women face in the STEM workplace, and the many ways in which AWIS supports women in science and works towards eliminating inequality through systemic change.

To start, explain why the STEM sectors are so important, and why women are key for meeting the demand for skilled workers in these areas.

The sectors that comprise STEM provide many of the solutions, products, services and tools to address what we call 'global grand challenges': managing pandemics, such as COVID-19; access to water, food, and basic resources; reversing climate change, etcetera. Our ability to solve these challenges will have major social and economic implications for decades to come.

According to a 2019 study by the Brookings Institution, the availability of STEM talent will be *the* key to our ability to solve these challenges. Given that women represent half of the world's population, the inclusion of women in the STEM talent pool is not just an issue of social justice – it is a *social and economic imperative.*

Because the *demand* for STEM talent has been growing faster than the *availability* of STEM talent in the workforce, we have attributed the gap to a supply problem: there is a limited or leaky 'pipeline' of up and coming talent, especially among women. And the emphasis on the supply side has meant that for years we have been making investments in STEM education for girls – building the pipeline – as the strategy for growing the talent pool.

While the investment in education is certainly important, I would argue that just investing in adding women to the talent pipeline will not enable significant progress in closing the talent gap. Why? Because our research at AWIS shows that beyond building the pipeline of women in STEM, we must pay equal – and perhaps greater – attention to the issue of *supporting, retaining and fully utilising the talent* of the women we have trained to enter STEM fields.

Women who are STEM graduates remain in STEM-related occupations at *half* the rate of men. Women earn over 40% of STEM degrees, yet only comprise 26% of the STEM workforce. In other words, women leave the STEM workforce after they have expressed an interest in STEM, have gone through rigorous programs to develop their knowledge, earned college-level degrees (and beyond) and have entered the workforce. Our inability to retain women who are trained in STEM is therefore negating the investment that we are making in educating and recruiting women in STEM fields.

‘Given that women represent half of the world’s population, the inclusion of women in the STEM talent pool is not just an issue of social justice – it is a *social and economic imperative.*’

Why are women underrepresented in the STEM workforce?

Our work at AWIS shows that numerous cultural and systemic biases and barriers negatively impact women when they enter the STEM workplace. AWIS researchers analysed data from the 2017 NSF Scientists and Engineers Statistical Data System and found that among the primary reasons that women with STEM degrees leave STEM-related jobs are inequities in pay, under recognition and utilisation of their expertise, lack of opportunities for promotion and leadership, and hostile day-to-day working conditions.

Women working in STEM are not always attributed credit when deserved. They can be intentionally left off emails and meeting invitations, ignored in the meetings they do attend, or otherwise be made to feel invisible. They receive lower compensation, smaller offices and fewer promotions; and they don’t see themselves reflected in the leadership of their institutions or companies. Women of colour, non-binary women, and those with special needs face additional, compounded barriers.

All of this leads to women feeling unwelcomed, discouraged, and exhausted. And many decide that their mental health, self-esteem, and potential to make meaningful contributions based on their capabilities can be better served in a career outside of STEM. As a result, society loses out on an incredible pool of talent, and the impact that their distinctive voices and expertise could bring to helping solve the problems facing the world today.

Please tell us about how AWIS was founded.

While attending the annual meeting of the Federation of American Societies for Experimental Biology in 1971, a group of women began discussing the challenges and injustices they faced in their careers. This was on the heels of the 1970 Women’s March on Washington and the mounting call for equal rights and opportunities for women. These women formed a non-profit organisation that would advocate for women across science disciplines: the Association for Women in Science.

That same year, AWIS filed suit against the National Institute of Health for underrepresentation of women and ultimately won. In 1975, the National Association for the Advancement of Colored People and AWIS won a lawsuit against the Office of Civil Rights for discrimination in higher education on the basis of sex and race. We continue to advocate for the advancement of all women in science and look forward to celebrating our 50th anniversary next year.

‘All of society will benefit when women are recognised and respected for their scientific and leadership achievements, compensated fairly and without discrimination, and advanced equitably and without bias due to their gender, race, sexual orientation or physical abilities.’

What are the Association’s goals, and how are they achieved?

AWIS is a global network that inspires bold leadership, research, and solutions to advance women in STEM, spark innovation, promote organisational success and drive systemic change. Throughout its history, AWIS has championed the interests of women in science and related STEM fields to advance gender equity and positive system transformation so that *all* women in these fields can fully participate in delivering the economic, societal and health contributions of the STEM sectors.

All of society will benefit when women are recognised and respected for their scientific and leadership achievements, compensated fairly and without discrimination, and advanced equitably and without bias due to their gender, race, sexual orientation or physical abilities.

We use our voices at AWIS to advocate for women who are working in science in all settings: industry, academic institutions, Congress and federal agencies, and even international coalitions. We expose challenges, celebrate successes, and share best practices to combat discrimination and initiate localised advocacy efforts. We provide our members and partners with programs that foster leadership and career development. Local AWIS chapters provide opportunities for women in STEM to network, learn and support one another. Our chapters also provide opportunities for the next generation of women in STEM to meet women who are already in the field, find mentors, and learn about different STEM career paths.

How does AWIS help women working in STEM to overcome the many hurdles they face in achieving their full potential, at every career stage and in all work environments?

AWIS supports women working in STEM in two ways. Firstly, we provide support directly to our members in the form of personal skill and leadership development, and access to a professional network of women in STEM. And secondly, we help our corporate, business and academic partners develop more inclusionary organisational cultures, adopt best practices in gender equity, and generally create workplaces where women in STEM can thrive.

Women in science join AWIS to grow their skills, professional connections and their careers. AWIS programs such as our upcoming webinar series support their continuous learning and growth. AWIS also facilitates networking, mentoring and volunteer opportunities to develop their leadership skills.

AWIS maintains a Career Center with over one thousand employment opportunities, and we recently hosted a Virtual Career Fair where 42 recruiters from 13 different organisations conducted 400 direct one-to-one chats with AWIS job seekers interested in available opportunities in Science and in STEM!

Our STEM to Market program curates intentional and inclusive investors and connects them with female entrepreneurs in STEM fields. We also award grants and scholarships to our chapters and members that help advance their STEM careers.

Building on the efforts of the National Science Foundation's ADVANCE program, AWIS supports the ADVANCE Resource and Coordination Network program with a community platform for sharing research and best practices for STEM equity. Members contribute reports, articles, datasets, toolkits, training videos and more.

To help create better places for women in STEM to work, AWIS provides data, advice, best practices, and other materials to help our organisational partners cultivate inclusive workplaces that are aligned with greater gender equity. In our award-winning AWIS magazine and newsletters, we celebrate the ways in which organisations support their diverse STEM talent and publicise progressive policies and programs that can help other organisations succeed as well.

In addition, we help corporate and institutional STEM partners recruit and retain talent. 79% of AWIS members hold advanced degrees, and 66% of our members are mid- to senior-level professionals. Organisations can reach this network through job postings in our Career Center and advertising opportunities.

What policy solutions and recommendations has AWIS developed for broadening female participation in scientific disciplines and industries, and for closing the gender pay gap?

In addition to our active membership network, AWIS keeps a pulse on the issues that affect women in science and STEM by participating in several science networks and consortia at the national level. We also monitor, and support, the development of legislation. Over the past year, we have supported the Building Blocks of STEM Act, to strengthen STEM education for young learners and to address the gender gap in STEM. We also supported the STEM Opportunities Act and the Combating Sexual Harassment in Science Act. We celebrated with Katherine Johnson, one of the 'Hidden Figures' of NASA last year, when she was awarded the Congressional Gold Medal, the nation's highest civilian honour.

We advocate for inclusionary hiring practices, gender equality in research grant awards, for expanding representation of women scientists in searchable databases, and for institutional report cards and other metrics to build in accountability for gender equality. And we release public commentary on legislation that we feel thwarts the progress of equity for women in science.

For example, on July 6, when the US Immigrations and Customs Enforcement Agency released a directive saying that foreign students would be stripped of their visas if they enrolled in online-

‘For 50 years, AWIS has been striving to eliminate gender and racial inequalities through systemic change. We invite you to join us.’

only courses this Fall, AWIS and other science and engineering societies signed an open letter to the White House, US Department of Homeland Security and US Department of State against this policy.

In September, we joined the American Physiological Society in signing a letter to Rep. Eddie Bernice Johnson, chair of the US House of Representatives Committee on Science, Space and Technology, supporting her request that the National Academies of Science, Engineering and Medicine undertake a study to acknowledge and assess systemic racism in academia.

Finally, through our gender equity research, AWIS and the ARC Network provide evidence-based advocacy for all women in science and STEM related fields. We focus on the intersections of gender and racial equity in innovation, science research funding, anti-harassment policy, employment and educational opportunity, pay, and member civil engagement.

Finally, AWIS’s 2020 Innovation and Inclusion Summit has unfortunately been cancelled, due to COVID-19. In what other ways is the pandemic affecting the Association’s activities, and how might it affect women working in science in general?

The pandemic has challenged us to find new channels for sharing our work in advocacy, research and programs with our members, our organisational partners, and the greater science community. One of our solutions was to develop a weekly member newsletter, *Fireside Fridays*, that enables us to be present in our members’ lives, to celebrate their accomplishments, and to remind them of the resources that we offer to help them navigate career uncertainty and work life integration. Our members have given us great feedback on this newsletter.

We check in with our members, chapters and, of course, our employees and are hearing they have adjusted well to virtual meetings and living room broadcasts. In fact, an unexpected benefit of our AWIS chapters moving to fully-digital meetings is the opportunity to free our stakeholders from geographic and time zone limitations. Many chapters are collaborating and offering their programs to all AWIS members, adding additional content and networking value. So, while the pandemic is certainly disruptive and devastating, it has also created new opportunities that unite our members.

Beyond the challenges that we face at AWIS, the pandemic has introduced new complexities for all women working remotely. Women who have young children are balancing home life, their children’s school work, and their own work responsibilities. And due to social distancing and safety requirements, women working from home may be adjusting to new schedules, and to collaborating virtually. But women who work in STEM also face challenges that are unique to our fields: access to labs may be limited, which can hinder the ability to conduct research. Lab projects have slowed down or even stopped, publications have been delayed, and funding often has been diverted to COVID-19-related work. Some labs have transitioned to rotating shifts, 7 days a week, including nights, to minimise the time that scientists are physically together in the lab – a schedule that obviously makes it difficult to balance work and family time. Each of us is finding ways to greet this new normal of constant change.

As a black woman, I am particularly concerned by the impact of the pandemic on members of marginalised communities. Workers from these communities are over-represented in ‘essential jobs’ and may not be able to work from home, thereby increasing their exposure to the virus. We have seen Blacks, Hispanics and Latinos testing positive for the coronavirus at rates that are much higher than would be expected given our percentage of the population.

But on a positive note, I am seeing signs that more people in the US now have a new and greater appreciation for essential workers, educators, scientists, the medical community and the larger issue of health disparities and social justice. I am hopeful that this growing empathy and awareness will translate into giving and support, and to a greater recognition of the need for inclusivity in our society in all respects.

For 50 years, AWIS has been striving to eliminate gender and racial inequalities through systemic change. We invite you to join us.

www.awis.org

AWIS
ASSOCIATION FOR WOMEN IN SCIENCE

ADDRESSING SOCIETAL NEEDS

ADDRESSING SOCIETAL NEEDS THROUGH TARGETED TRAINING

In the final section of this edition, we showcase several innovative educational programs, each designed to address a specific societal need – from teaching engineering students how to devise solutions that are socially responsible, to cultivating a new generation of environmental scientists.

Indeed, skilled environmental scientists are urgently needed to address many global challenges, including climate change, agricultural sustainability, biodiversity loss and pollution. In the first article of this section, we introduce Dr Elica Moss and her team at Alabama A&M University, who are providing students with extensive training and invaluable research experience, towards building a skilled and diverse environmental science workforce that can tackle these challenges.

Next, we travel north, to the state of Michigan – a region that is currently experiencing numerous environmental threats. STEM professionals are urgently needed to help solve these problems, but the number of students graduating with STEM degrees in the state has been declining. Therefore, researchers at Siena Heights University developed a program called SHAPE STEM, which aims to increase the recruitment and retention of low-income, academically talented students, equipping them to become the environmental innovators of tomorrow.

The third article in this section focuses on the growing issue of water scarcity, and the urgent need for professionals in the field of water security. Climate change and pollution are having a major impact on the quantity and quality of water available on our planet, ultimately threatening human health and wildlife. Here, we meet researchers at the University of Saskatchewan and other Canadian institutes, who have designed NSERC CREATE for Water Security – a career-oriented program that prepares graduate students and postdoctoral fellows to effectively tackle challenges relating to water security.

Our next few articles describe initiatives aimed at strengthening the engineering workforce. Engineering is one of the most impactful and transformative fields, as it shapes the world we live in and forms the basis for many systems that maintain human society. Therefore, it is crucial to introduce children to engineering concepts from an early age, as this could encourage them to pursue a career as an engineer in the future. With this in mind, Dr Zenaida Aguirre-Muñoz, Dr Magdalena Pando, and Dr Michelle Pantoya have been investigating the effectiveness of teaching practices aimed at introducing young children to engineering.

Then, we highlight a project entitled Automation Workforce Development through Aligned Industry Partnerships and Training (ADAPT), spearheaded by Dr Joshua Gamer at Western Technical College in Wisconsin. The ADAPT project is centred around creating a pipeline of trained graduates in the field of mechatronics – a multidisciplinary branch of engineering that combines fields as widely varying as robotics, telecommunications and product engineering. In collaboration with Ashley Furniture Industries and over 100 local schools, the project aims to equip a new generation of students with the necessary skills to revitalise the manufacturing industry in the region, while offering them clear pathways to fulfilling careers.

In the next article of this section, we showcase the Humanitarian Engineering Program at the Colorado School of Mines, which trains engineering students to devise solutions that are ethical, socially responsible and sustainable. Students on the program work closely with communities, thinking critically about their needs as they devise engineering solutions to diverse problems.

While the Humanitarian Engineering Program integrates engineering with sociology, the Biomedical Entrepreneurship Skills Development Program integrates engineering and medical science with training in entrepreneurial thinking and venture creation. This pioneering program, which we feature next, teaches students how to become successful entrepreneurs, so that they can bring new biomedical technologies to those affected by medical conditions.

Continuing on the theme of improving health and wellbeing, our final article highlights a course that offers high-school students the opportunity to become acquainted with the field of nutrition. In addition to preparing students for university studies in nutrition and food science, addressing a need for experts in these fields, the course also aims to improve students' personal eating habits.

TRAINING A NEW GENERATION OF SKILLED ENVIRONMENTAL SCIENTISTS

The environmental sciences are vitally important to address many urgent global challenges, such as climate change, agricultural sustainability, conservation and pollution. To lead the innovations that will bring us closer to achieving these goals, a diverse, well-trained and qualified workforce is required. In their new teaching program, **Dr Elica Moss** and her team of scientists at Alabama A&M University provide students with extensive training in advanced biotechnological methods and invaluable research experience, towards building a skilled and diverse scientific workforce that can take on humanity's greatest challenges.

Today's Students, Tomorrow's Leaders

Environmental issues, such as pollution and climate change, impact almost every aspect of human society. The intensification of agricultural practices to meet the food requirements of a growing human population is having negative consequences for the health of our soils, climate, waterways, and delicate ecosystems across the globe.

Atmospheric pollutants deposit into natural freshwater systems, disrupting these diverse ecosystems and causing the accumulation of toxic substances and metals. Soil microbial communities are altered by the effects of climate change and soil additives, which could have consequences for agricultural sustainability and the ability of plants to absorb and store atmospheric carbon.

Addressing these environmental issues requires a strong workforce of skilled scientists from diverse backgrounds in academic institutions, industry, and public agencies. Despite the growing need for a strong and diverse scientific workforce in the US, underrepresented minorities, especially from the African-American and Hispanic communities, make up a disproportionately small percentage of environmental scientists. This lack of inclusion not only means a significantly reduced talent pool; scientific progress is also severely hindered by the lack of diverse perspectives and experiences.

Through the development and implementation of their Integrative Agricultural Biotechnology Instruction Program, Dr Elica Moss and her colleagues at Alabama A&M University aim to train tomorrow's scientific leaders. 'This program, with its increased awareness of biotechnological issues, will reduce the national shortage of minorities in the sciences in general, but in particular, biological and associated sciences, thus building skilled, capable and stable societies,' says Dr Moss.

Their teaching program provides training and research experience to undergraduate and graduate students in the Department of Biological and Environmental Sciences, attracting students from within the university and transfers from community colleges.

The Program

Dr Moss's current teaching program, which began in 2017, builds on a substantial effort by Alabama A&M University to strengthen and enhance the training opportunities available to students in the environmental and agricultural sciences. During the lifespan of the project, Dr Moss and her team have been continually evaluating the training effectiveness and success of the various mentoring strategies used, with the aim of further enhancing the educational quality. In addition to strengthening their current program, the team's efforts also contribute to improving the teaching and training provision on Alabama A&M University's new agriculture-focused biotechnology degree.

Students Sameerah Rice and Jayla Pettway presenting their research at a conference

Dr Moss with students attending research conference where they presented their research

During the 2019–2020 academic year, Dr Moss developed a semester-long Course-Based Undergraduate Research Experience (CURE), to provide students with practical skills in advanced molecular science methods, such as DNA extraction and analysis. The US Bureau of Labor Statistics reported in 2016 that the demand for well-trained bio-technicians is going to increase in the coming decade, and therefore, developing these skills before entering the workforce provides students with access to a greater number of employment opportunities.

Each cohort on Dr Moss's Integrative Agricultural Biotechnology Instruction Program consists of five agricultural biotechnology and molecular biology undergraduate students, with the program also providing training and development opportunities to graduate students and early-career faculty members. Students are introduced to the fundamental concepts and methods used in environmental microbiology through a series of class discussions, and then provided with the opportunity to use their new skills in their own research project.

The research projects conducted by the students, under the guidance of Dr Moss and her team, span a range of environmental topics, from waterway pollution and soil ecology, to sustainable urban development. Most significantly, their research contributes knowledge to real-world issues facing environmental scientists, and students are encouraged to disseminate their work at academic conferences. The students from the 2019–2020 academic year cohort will be presenting their research findings in the poster section of the 8th annual Historically black colleges and universities (HBCU) Climate Change Conference in New Orleans.

Additionally, the students presented their work alongside other students from the departments of Biological and Environmental Sciences, Food Science, and Engineering and Physics at the annual Alabama A&M University STEM day. They also submitted research abstracts for the 97th annual meeting of the Alabama Academy of Science, which was unfortunately cancelled due to COVID-19. Experiences such as these provide the students with opportunities to engage with the wider research community and gain insights into this aspect of a career in research.

Investigating Pollution in Waterways

The freshwater ecosystems in Alabama, some of the most biodiverse habitats in North America, are at increasing risk from a rapidly growing human population. Pollutants from agriculture, urban development and atmospheric deposition have negative consequences for the animals and plants that inhabit these waters and pose a significant risk to human health. 'Atmospheric deposition is the process that removes gases and particles from the atmosphere,' explains Courvoisier Lewis, a student researcher on the Integrative Agricultural Biotechnology Instruction Program. 'Air pollution resulting in atmospheric deposition is a major environmental issue.'

The aim of this project was to identify the location of bodies of water impaired by atmospheric deposition and the 'brownfield' sites located nearby, which is imperative to informing conservation management decisions. Brownfield sites are previously developed areas that have since fallen into disuse. Redevelopment of brownfields is complicated by the presence of potentially harmful contaminants.

Using environmental monitoring techniques to investigate pollutants in these waters and soils, Lewis found that the predominant atmospheric pollutants deposited were mercury and other metals. By employing additional analysis techniques, such as geographic mapping, he contributed critical information about the spatial distribution of atmospheric pollution in Alabama.

Research projects such as these could help scientists identify which areas are most vulnerable to negative impacts on the ecosystem services provided by wild spaces – such as food security, carbon storage by plants, and clean drinking water.

Effects of Biochar and pH on Soil Ecology

The microscopic organisms living in soils interact with their environment, having impacts that scientists are only now beginning to fully understand. The composition of microbes – or the 'microbial community' – can have marked impacts on soil quality, plant health and development, and carbon storage, which is important for mitigating climate change. Thus, understanding how external factors such as pH levels, soil additives and crop type alter the soil microbial community is imperative to developing sustainable agricultural practices.

SOIL MICROBIAL COMMUNITIES IN BIOCHAR AMENDED SOILS AT WINFRED THOMAS AGRICULTURAL RESEARCH STATION

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ABSTRACT

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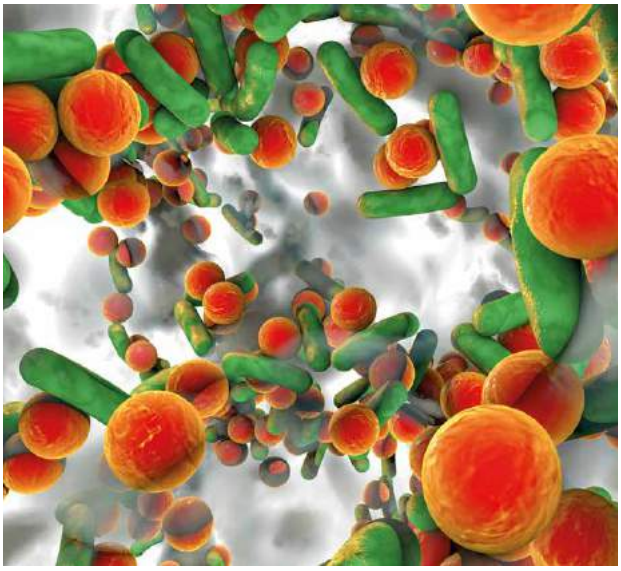
ACKNOWLEDGEMENTS

Example of research completed by students during the semester-long CURE in Environmental Microbiology



Artist's representation of a soil microbial community

The Winfred Thomas Agricultural Research Station at Alabama A&M University produces a range of crops, such as hemp, switchgrass, sweetgum and soybean, and provides students with an active agricultural system to investigate their research questions. Additionally, some soils at the research station are supplemented with 'biochar' – a carbon-rich substance created by burning waste from agriculture and forestry at high temperatures. Incorporating biochar into soils is a promising new method that increases carbon storage, while also improving plant productivity and nutrient cycling.

However, the effects of biochar on soil microbial communities is not yet fully understood. Adding biochar to soils alters soil pH, which may have additional impacts on microbial community composition. In their projects, student researchers Autumn Hill and Jayla Pettaway used advanced genetic analysis and soil monitoring tools to investigate the effects of biochar and pH on soil microbes.

Through their research, they showed that biochar, pH and crop type are associated with increases in some types of soil bacteria and decreases in others. Their work provides the basis for understanding how the effects of biochar and soil conditions can alter carbon storage in agricultural systems.

Revitalising a Historic Community

Africatown, Alabama, is a historic community formed by a group of 32 West Africans brought to America on the last known slave ship, the Clotilda. At its peak, Africatown was home to around 10000 people, but the population has since decreased to around 3000, leaving many homes vacant and abandoned. These properties pose a barrier to the revitalisation of this historic town. However, focused efforts to stimulate the local economy require a good understanding of home ownership and rental patterns, property tax rates, and housing and condemnation rates in the area.

Advanced environmental mapping tools can facilitate a detailed analysis of these trends in urban and suburban areas, helping to inform revitalisation decisions. Applying these tools to publicly available data, student researcher Sameerah Rice investigated the trends across five years for 450 homes in the town's quiet and compact residential area.

'This study serves as the genesis to combat the issue of vacant and abandoned property problem in Africatown, that could lead to aggressive code enforcement, tax foreclosure, eminent domain, and cosmetic improvements, thereby stimulating economic development,' she says.

Research efforts such as these can also provide evidence to help communities safeguard their future health and wellbeing. Industry development in Africatown and the local areas pose a threat to the quality of the air, soils, and water that the town's residents depend on. Responsible development and redevelopment of abandoned properties should be mindful of local communities, and rigorous scientific evidence provides the basis on which these decisions are made.

The Program's Future

Building on the previous success of their program, Dr Moss and her team plan to continue training new cohorts of environmental science students. By giving students the opportunity to learn and practice the skills they need for a career in environmental biotechnology, Dr Moss and her team are providing society with more than vital research – they are giving us tomorrow's leading scientists.

Meet the researcher

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Dr Elica M. Moss earned her PhD in Microbial Ecology and Environmental Toxicology from Michigan State University. She currently holds the position of Research Assistant Professor and Environmental Health Science Coordinator within the Department of Biological and Environmental Sciences at Alabama A&M University. She has also developed and teaches on a range of environmental science undergraduate modules and advises postgraduate students in addition to her research activities. Dr Moss has published her research in numerous peer-reviewed journals, and has received multiple awards for her work, including in recognition of her community service in education. Several of Dr Moss's projects have directly improved the educational opportunities and outcomes for women and minority groups, both at Alabama A&M University and within her local community.

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ALABAMA A&M UNIVERSITY

SHAPING MICHIGAN'S NEXT GENERATION OF ENVIRONMENTAL SCIENTISTS

The state of Michigan is experiencing numerous environmental threats, risking the health and wellbeing of its residents. STEM professionals are urgently needed to help solve these problems and mitigate the impending public health disasters. However, the number of students graduating with STEM degrees in the state has been declining. Researchers at Siena Heights University are addressing this need through their teaching and development program, SHAPE STEM, which aims to increase the recruitment and retention of low-income academically talented students in STEM subjects.

Environmental Crises in Michigan

Environmental problems plague the state of Michigan, threatening the health of both people and wildlife. The Flint water crisis, which began in 2014 as a result of switching the city's water supply to the contaminated Flint River, brought into focus the dire consequences of environmental mismanagement. Residents, including thousands of children, suffered ill health from consuming the lead-contaminated drinking water. Additionally, at least 87 people were affected by an outbreak of Legionnaires' disease, with 12 people losing their lives as a result.

The polluted waters of Flint are by no means an isolated issue. Lead-polluted air threatens the health of the residents in the metropolitan city of Detroit. Run-off from agriculture, industry and landfill sites contaminates the waterways of the Great Lakes surrounding the state. Agricultural products tainted with toxic herbicides have found their way to consumers. The Environmental Protection Agency has designated 89 sites in Michigan as 'Superfund hazardous waste sites' – requiring extensive, long-term action to clean up contaminants.

There is an urgent need for graduates of science, technology, engineering and mathematics (STEM) in the region to help solve these environmental problems and mitigate future public health crises. In 2015, the Michigan Department of Technology, Management, and Budget reported that STEM employment is growing by 4.3% per year in the area, and the Alliance for Science and Technology Research in America anticipates a growth of STEM occupations ranging from 7% to 23% between 2016 to 2025. Despite this, the number of STEM graduates has been declining. In 2016, the Michigan Farm Bureau estimated that 54,000 agricultural jobs will be available annually in Michigan, but only 55% of these openings will be filled by people with degrees from colleges of agriculture, life sciences, natural resources, or veterinary medicine.

A team of researchers and professors from Siena Heights University in Adrian, Michigan, are addressing these needs through a comprehensive training and mentoring project funded by the National Science Foundation's STEM scholarship program. The project, entitled Siena Heights: Applying Psychological Constructs and Student Supports to Improve the Education of Students in STEM (SHAPE STEM), aims to increase and retain the number of qualified graduates trained to address

‘SHAPE STEM has the potential to generate evidence that can be used to improve motivation and learning in other Siena Heights University students. This support structure could also be adapted and used by other higher educational institutions.’

issues of environmental sustainability and health entering the Michigan workforce. With approximately 78% of Siena Heights University’s STEM graduates remaining in the region after graduation, SHAPE STEM scholars will help to support this regional growth.

Psychological Support and Mentoring

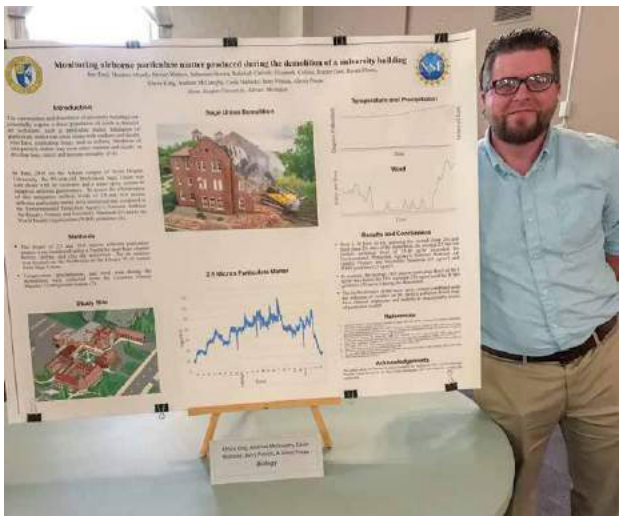
The SHAPE STEM program awards scholarships to academically-talented undergraduate students from low-income backgrounds majoring in biology, chemistry or environmental sciences at Siena Heights University. In addition to financial support, the program offers students a range of motivational and psychological support elements geared towards increasing persistence in the demanding STEM subjects.

The program’s motivational supports build on the university’s successful student support services aimed at improving retention and educational outcomes. SHAPE STEM aims to retain 20 students recruited to the program each year, graduate those retained, and help graduates secure STEM jobs or continue on to postgraduate courses. The National Academy of Sciences has suggested that increasing the number of employees from varied social and cultural backgrounds in the STEM workforce fosters inclusivity and can enhance innovation and productivity.

During their first two years, SHAPE STEM students participated in seminars, facilitated by Principal Investigator Dr Jun Tsuji, along with Drs Heather Moody and Steve Wathen, to introduce them to strategies to overcome the problems often experienced by low-income and first-generation students. On average, first-generation students achieve lower grades and have poorer retention rates than their peers. These students often lack a sense of belonging and the confidence to seek help or pursue opportunities. Psychological support seminars, provided by co-Principal Investigators Dr Patricia Rousselo and Dr Jeffrey Lindstrom, are integrated into the SHAPE STEM seminar series and aim to overcome these educational barriers. The ‘Social Belonging’ seminars offered to students in their first semester included panel discussions with a demographically-diverse group of science majors at Siena Heights University, promoting the message that adversity is not inherent to their gender or socioeconomic background, but can be overcome. Seminars in ‘Positive Psychology’ helped the students identify personal strengths and adopt behaviours that contribute to their wellbeing. Finally, during their second year, students participated in a ‘Possible Selves’ panel discussion with working STEM professionals in the local area. These aimed to provide positive role models and help students to identify career goals.

During their second year, the SHAPE STEM seminars included professional skill development in addition to exploring career options led by career specialist Ms Melissa Tsuji. These activities have been found to increase academic achievement among students from underrepresented minorities. Seminars are supplemented with field trips, conferences, guest speakers and team-building activities.

The project team continually monitors the students’ progression and psychological wellbeing. Additionally,



Dr Rousselo and Dr Lindstrom are evaluating the effectiveness of the psychological supports and mentoring offered to the students, with the aim of refining these strategies over the project lifespan and improving student support across the university and beyond.

'SHAPE STEM has the potential to generate evidence that can be used to improve motivation and learning in other Siena Heights University students,' explains Dr Tsuji. 'This support structure could also be adapted and used by other higher educational institutions.'

Gaining STEM Skills and Experience

Group work and undergraduate research are considered high-impact learning activities, and as such, SHAPE STEM students are encouraged to participate in group research projects. These projects, guided by Dr Tsuji and co-Principal Investigators Dr Heather Moody and Dr Steven Wathen, provide students with an opportunity to experience academic research that has real-world implications, as well as foster camaraderie within and between cohorts.

Three of the student group projects completed as part of the program so far were presented at the Michigan Academy of Science, Arts, and Letters annual conference as well as at the Siena Heights University Scholarship Symposium.

In one such project, students took advantage of the demolition of an old building on campus to monitor the effectiveness of measures to reduce airborne particulate matter, which can damage lung health. Another group explored the impact of climate change on the migration timing of monarch butterflies. By combining analysis of historical data with capture, tagging and release experiments, the students discovered monarch migration has been shifting later in the season. The third of these groups tested various water sources in south-eastern Michigan for microplastic contamination, by filtering water through special membranes.

In addition to learning valuable skills, students have found the projects enjoyable and inspiring. 'The research project and everything related to it was really fun,' reported one student. 'I liked playing around with ideas and trying to find solutions. I immensely enjoyed having a broader knowledge, and ideas regarding research.'

SHAPE STEM students are also given the opportunity to undertake internships or independent research projects, depending on their individual interests. Mentors and career advisors work closely with the students to help them identify and apply for suitable opportunities. Students have conducted research in green chemistry and biology, and completed internships in sustainability and other environmental topics. Some of the students have participated in an environmental leadership experience during summer, which taught them about sustainable agricultural ecosystems and provided practical experience in permaculture – an agricultural technique that works with the surrounding ecosystems to improve environmental outcomes.

Responding to COVID-19

In March 2020, approximately two years into the five-year SHAPE STEM project, Michigan residents were ordered by the Governor to stay in their homes due to the COVID-19 global pandemic. As all students returned to their permanent residences, the project team worked quickly to adapt to delivering the program activities online. In particular, continuing the presentation of the psychological elements of the seminar series has helped the students cope with the stress and uncertainty of the developing situation and maintain motivation. The 'Positive Psychology' seminar, the 'Possible Selves' panel discussion, and the Siena Heights University Scholarship Symposium were all offered to students online, in addition to other SHAPE STEM activities.

In feedback following the 'Positive Psychology' seminar, one student said, 'I started doing things that were suggested on the positive psychology paper, such as writing in a journal, going on walks, and trying meditation. I found that it actually helped me when I was feeling lost or bored. It helped me focus on what I needed to do, whether that was schoolwork, or laundry, or something like that.'

'The positive psychology definitely helped,' reported another. 'It reminded me why I am doing what I'm doing and provided me with the motivation that I needed to overcome the stress that accompanied this global pandemic.'

Although the pandemic continues to affect education around the globe, the fast response of the SHAPE STEM project team has ensured that these students are still receiving the support, mentoring and activities that will help them succeed in their STEM courses, equipping them to become the environmental innovators of tomorrow.

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SECURING OUR FUTURE BY CREATING A NEW GENERATION OF WATER PROFESSIONALS

Canada, like most other countries worldwide, is facing serious issues related to water security. To better address these challenges, **Dr Cherie Westbrook** at the University of Saskatchewan, and her collaborators from various Canadian universities, developed NSERC CREATE for Water Security. This add-on academic program provides graduate and postgraduate students with skills and learning opportunities that prepare them to tackle current and future water security issues.

Increasing Water Scarcity

Climatic and environmental changes are having a major impact on the quantity and quality of water available on our planet. Such water scarcity can have serious repercussions on all areas of society, ultimately threatening the sustenance of humans, animals and ecosystems on Earth.

Canada is among the many countries currently facing water security issues, due to serious shortages in its river basins, increasingly frequent floods and droughts that are worsened by climate change, a growing urban population, and several other factors. Integrative research agendas and collaborations focusing on both science and governance-related aspects of water security could play a key role in tackling and overcoming these challenges.

Identifying solutions to water security problems requires a vast skill set and a solid knowledge of complex systems. As water security issues are expected to rise further over the next few decades, due to the rapidly changing climate, universities should ensure that they are training new generations of experts who have the skills necessary to tackle these challenges.

A good water professional should be able to shift between theory-based science and practice, in order to conduct research, but also apply interdisciplinary scientific findings in her field work. Currently, however, most graduate training programs in Canada are based on a traditional academic model that focuses on a single discipline, without linking scientific knowledge with its practical applications.

New academic programs and training models could thus ensure that young people are better prepared to face current and future water security-related challenges, both in Canada and worldwide. With this in mind, researchers at the University of Saskatchewan and other Canadian institutes, led by Dr Westbrook, have designed NSERC CREATE for Water Security, a career-oriented academic program that prepares graduate students and postdoctoral fellows to effectively tackle water security-related challenges.

NSERC CREATE for Water Security

The Collaborative Research and Training Experience Program (CREATE) was introduced by the Natural Sciences and Engineering Research Council of Canada (NSERC) in 2008, with the mission of funding initiatives aimed at tackling important scientific challenges in Canada. The CREATE program offers financial support to projects that introduce collaborative and integrative approaches to address key scientific issues, as well as initiatives that facilitate the professional development of new generations of scientists.

In 2015, Dr Westbrook and her colleagues were awarded one of these grants for the development of the NSERC CREATE for Water Security program. While their project is led by the University of Saskatchewan, it also involves scientists at the Universities of Waterloo, Calgary, McMaster and Manitoba.

'What sparked our interest in applying for the CREATE program is the increasing recognition that water security is a very response-based field,' says Dr Westbrook. 'There is high demand for water security professionals across all sectors – technical experts, innovators, leaders and influential researchers. To get these jobs, graduates need more than just the skills and knowledge they acquired at university.'

Dr Westbrook and her colleagues observed that PhD graduates in Canada often found entering workplaces outside of academia difficult, due to their lack of professional skills and established networks. In addition, many graduating students struggle to effectively convey the value of skills acquired in their studies to potential employers.

'We noted an underdevelopment of professional skills needed for researchers to work inside academia too, owing to the wider skill set needed by professors to be successful in all aspects of their jobs,' says Dr Westbrook. 'We identified a gap and found that a shift in the existing education model was needed to meet the current shift in demands.'

A Career-oriented Training Model

To fill the gap between traditional training approaches employed by most universities in Canada and the skills necessary to become a proficient water professional, Dr Westbrook and her colleagues created a new academic model. This model is designed to provide students with an interdisciplinary knowledge and the tools needed to apply this knowledge in professional settings.

NSERC CREATE for Water Security is a comprehensive research and training program for both graduate students and postdoctoral fellows with a key focus on their professional development. It is designed to teach prospective water professionals how to solve complex, multi-faceted and dynamic problems, such as those that currently threaten water security worldwide.

'The complexity of the water security problems facing Canada (and the world), requires future researchers and practitioners be trained using a new model, one that is collaborative and integrative across multiple disciplines, and develops the necessary personal and professional skills,' explains Dr Westbrook.

The program introduced by Dr Westbrook and her colleagues is based on a scholar-practitioner model that trains students to integrate science, engineering and policy analysis, applying concepts from all these disciplines to tackle the challenges associated with managing complex and uncertain water systems.

Program Structure

All students in the NSERC CREATE for Water Security program must complete two mandatory modules, which are designed to broaden their understanding of different disciplines involved in the field of water security. These modules also teach students how to combine these different concepts and apply them to real-world problems. They can also participate in five additional program opportunities, including short courses, off-campus activities, workshops, career development sessions, and research opportunities.

'The program provides trainees with a common platform and customisable career path mentoring to facilitate their transition to a research or practitioner career of their choosing,' explains Dr Westbrook. 'Mandatory in the program is a course called "professional practice in water security", where students are introduced to the request for proposals competitive bid process as a demonstration of how academic

skills can be translated to professional practice.'

In addition to mandatory modules, students who take part in the program can attend supplementary short-format courses focusing on specific topics or areas related to water security. They are also offered the opportunity to expand their skills further in laboratory settings or by completing internships outside of their university.

'The students have the opportunity to engage with the consulting industry, municipal and federal governments, and Indigenous peoples to learn different perspectives of integrative science and problem solving,' says Dr Westbrook. 'For the customisable component of the program, some students were very creative in choosing the opportunities important to them. Three students, for example, attended the Science Outside the Lab workshop, which provides a deep-dive, immersive introduction to science, policy, and societal impacts. One of these students met their current employer there.'

Students participating in the program are also asked to complete interdisciplinary research as part of their final thesis. This might entail the integration of research methods from different fields, as well as focusing on a particular topic on the boundary between two or more disciplines.

Key Milestones

So far, 61 graduate students and four postdoctoral fellows have taken part in the program. The feedback received from these students was overwhelmingly positive, as most felt that it helped them acquire an interdisciplinary understanding of problems, showing them how they can apply skills acquired academically in a variety of professional settings.

'There is still a very strong culture of focusing graduate training on preparing students for academia in the field,' says Dr Westbrook. 'To see so many students engage in CREATE for Water Security indicates the beginnings of a cultural shift. The project also enhanced Canadian research momentum in the field of water security.'

Dr Westbrook and her colleagues observed that internships and lab exchanges were widely appreciated by those participating in the program, as they provided hands-on learning opportunities that are not offered by traditional academic courses. 'They have made many connections with professionals and other researchers,' adds Dr Westbrook. 'Several also secured jobs after graduation with the company they did internships with.'

Paving the Way Towards Change

The grants offered as part of the NSERC CREATE initiative cannot be renewed, therefore in March 2021 the program developed by Dr Westbrook and her colleagues will come to an end. Given its great success, the researchers plan to integrate some of its elements into other courses offered at their universities, while also encouraging other institutions to follow a similar training model. For instance, Dr Westbrook and faculty in her department plan to make a modified version of one of the program's core courses available to all graduate students at the University of Saskatchewan.

'As a result of our efforts, individual researchers, including myself, now better see the value of having graduate students engage in professional development workshops, and even lab exchanges and internships,' says Dr Westbrook. 'I think supervisors will continue encouraging their graduate students to explore various opportunities and hopefully provide funding to them to build professional skills.'

Interestingly, faculty members involved in this project observed that memberships to student-led professional development societies, such as the Global Water Futures Young Professionals, have recently increased. This rise in interest could ultimately encourage faculty members to provide similar opportunities as part of regular courses offered at their universities.

Dr Westbrook and her colleagues are now writing a journal article summarising their experiences with the use of a scholar-practitioner model throughout their six-year project. In the future, their training model could serve as an example for other universities in Canada and worldwide, inspiring a cultural shift in academia within the field of water security.

Meet the researcher

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Dr Cherie Westbrook is a Professor of Ecohydrology at the University of Saskatchewan. She holds a BSc in Environmental Science from the University of Toronto, an MSc in Environmental Biology and Ecology from the University of Alberta and a PhD in Ecohydrology from Colorado State University. Dr Westbrook has been engaged in research investigating areas of wetland science and conservation for over two decades. Most of her studies are aimed at understanding how mountain wetland systems are responding to environmental changes. Her work is typically carried out directly in the field. Dr Westbrook has published over 40 peer-reviewed papers related to wetland science, and has also prepared several technical reports for both government agencies and non-profit organisations. Her research has been featured by several renowned publications, including *New Scientist*, *Canadian Geographic*, and *Atlantic.* Dr Westbrook has served as an advisor for numerous government projects and was a key speaker at a number of important conferences on water security. She is also a founding member of the University of Saskatchewan's Global Institute for Water Security.

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NSERC CREATE for Water Security

FOSTERING ENTHUSIASM FOR ENGINEERING FROM AN EARLY AGE

As engineering and other scientific disciplines play an increasingly prominent role in our society, it is crucial to introduce children to these subjects from an early age, as this could encourage them to pursue careers in these fields in the future. With this in mind, **Dr Zenaida Aguirre Muñoz**, **Dr Magdalena Pando**, and **Dr Michelle Pantoya** have been conducting research investigating the effectiveness of teaching practices and methods aimed at introducing young children to engineering and science.

Introducing STEM to Young Children

Technology is a central part of our daily lives, from early inventions such as doorknobs and pencils to modern advancements including smartphones and tablets. Such technologies make our life easier by solving a problem or fulfilling a need. Engineers design technologies using an understanding of math and science. To sustain the current speed at which new technology is developed, and to address societal challenges such as medical needs and energy demands, it is crucial that we prepare the next generation for careers in engineering.

To this end, governments worldwide have been calling for meaningful initiatives and academic programs aimed at introducing younger generations to science, technology, engineering and mathematics (STEM). In 2012, the National Research Council published the Next Generation Science Standards, which specifically encouraged schools to integrate engineering curricula in K-12 education.

Despite the call for more academic programs designed to teach engineering-related skills to young children, the vast majority of engineering education initiatives developed so far have targeted secondary school and college-level students. Introducing engineering to kindergarten or primary school children, however, could have significant advantages, as it could give them a chance to cultivate an interest while they are still young, potentially encouraging them to pursue a career in engineering later in life.

Teaching STEM-related topics to young children from varied backgrounds could also help increase diversity in the engineering workforce, encouraging more girls and children from underrepresented minorities to become engineers in the future. Engineers from diverse backgrounds can provide unique perspectives on the design of future technologies that positively impact our way of life.

One of the reasons why programs aimed at teaching engineering-related skills to very young children are still scarce

is that effective engineering-focused teaching strategies are limited. Children between the ages of 3 and 7 often have short attention spans, which can make their learning of more advanced concepts particularly difficult.

Dr Aguirre-Muñoz, Dr Pando and Dr Pantoya, three researchers working at the University of Houston, New Mexico State University and Texas Tech University, respectively, have been investigating different teaching practices designed to introduce children to engineering from an early age. Their work explores both the challenges and potential associated with these practices, while also assessing their possible impact on the engineering field at large.

Teaching Practices

The overall goal of the team's research is to promote STEM learning among young children, by introducing and evaluating engineering-centred literacy practices that could be applied in kindergarten and elementary schools. Their research was supported by grants from the National Science Foundation.

Because very few STEM-education programs have targeted children from ages 3 to 7 years, the researchers set out to identify existing engineering-related materials and integrate them into curricula for these particular age groups, adapting them to ensure that they were age appropriate.

The materials and engineering-centred teaching practices they devised are based on the intentional use of a variety of tools, ranging from storybooks to technological devices, such as iPads. They then tested these teaching practices in real classrooms, evaluating their impact on children's attitudes towards engineering, on their identity development, and on their understanding of STEM-related content.

The researchers set out to explore two key research questions. Firstly, they wished to assess the impact of the engineering-related teaching practices on STEM learning, knowledge of technology, and identity development of children from kindergarten to the second grade. Secondly, they investigated whether children who were exposed to a combination of these practices learned more than those who were only exposed to some of them.

Developing Children's STEM Identity

One study specifically evaluated whether engineering-related curricula could aid the development of an engineering identity in early childhood.

The strategy they evaluated involved the use of storybooks that present simple STEM-related concepts, combined with interactive discussions, and a creative drawing activity. In their study, the researchers specifically used a book called 'Engineering Elephants' to introduce the concept of technology and the work of engineers to young children in an engaging and age-appropriate way.

Instruction for the children participating in the study started with their teacher or supervisor asking them the simple question: 'What do engineers do?' The children's answers were then written on a board, initiating a discussion about technology that lasted several minutes. This discussion was followed by the teacher reading 'Engineering Elephants' aloud, while reinforcing concepts presented in the book, including technology, science, and math. The story ends with a question: 'When you grow up to be an engineer, what new things will you create?'

The children's answers to this question were compared to their initial responses about technology and the nature of engineering, sparking further discussion on the topic. Finally, the children were asked to sketch or draw something that they would create as engineers, solidifying their understanding of technology and design that incorporates math and science thinking.

The researchers were able to introduce this simple storybook-based lesson into several different classrooms with students aged between 3 and 7 years.

Overall, the teaching practice was found to encourage many children to develop an engineering identity, potentially seeing themselves as becoming engineers in the future.

Children's Responses to Engineering Activities

Another study investigated how kindergarten students responded to literacy-enriched engineering activities, both in terms of their engagement and understanding of the curricular material.

The researchers trained teachers working at two different kindergarten schools in Texas to deliver the lesson centred around the 'Engineering Elephants' book to young students, while also using engineering challenges and investigations of materials designed to teach engineering-related content to children. This curricular material was delivered at the two schools, which had a total enrollment of approximately 650 children from various cultural backgrounds.

The research team recorded the children's engagement and their participation in discussions, to assess the impact of the simple classroom activities devised by the researchers. Overall, the data collected indicated that the children found the engineering-related lessons highly engaging and their understanding of the material increased throughout the course of the intervention.

Age-appropriate Language Tools

The team also carried out a study exploring the use of language tools to deliver engineering-based curricula to young children. In particular, the researchers wanted to investigate the degree to which children who were not proficient in English learned language through science and engineering classroom discussion and activities.

This study involved children with a Latinx cultural background from K-2nd grade. The children took part in a series of activities modified for age appropriateness based on a unit from a specific curriculum called Engineering is Elementary (EiE). The EiE curriculum was designed to increase the technological literacy of young children through the use of narrative texts and other activities that involve problem-solving, collaboration, and communication.

The researchers tested the children's learning of science and engineering-related practices and vocabulary before and after the intervention. They found that the young English language learners' use of linguistic structures to paraphrase, elaborate on specific ideas, or challenge these ideas greatly improved over time. Overall, the incorporation of engineering-based academic conversations promoted language development in ways that supported meaningful participation in science and engineering activities.

Initial Outcomes

Further research by the team aimed to evaluate the impact of a teaching approach called Engineering Everything, which included Cheers for Engineers, an interactive iPad game for children they developed.

Engineering Everything is an instructional approach designed to increase young children's engagement in and understanding of engineering-related topics, while also promoting their development of an engineering identity. Cheers for Engineers, on the other hand, is an engaging and interactive iPad game that exposes children to a variety of engineering practices using age-appropriate language and visual aids. It is designed to reinforce engineering-based problem solving when considering materials for specific engineering challenges.

The researchers implemented these two different teaching activities in nine different classrooms. A total of 349 participated in this study: 120 kindergarten, 107 first grade, and 122 second grade children. Overall, the team found that the Engineering Everything intervention consistently led to an increase in the children's understanding of technology and science learning. In addition, those exposed to this teaching practice seemed to find it easier to see themselves as engineers in the future.

The Cheers for Engineers game uniquely strengthened the first and second grade children's learning and sense of self, yet it typically did not uniquely improve kindergarten children's knowledge of technology above the improvements of the components of the intervention (literacy and language tools).

Towards a Diverse Engineering Workforce

Overall, the results of the team's research highlight the promise of introducing engineering-related curricula and teaching practices in kindergarten and elementary school classrooms. In particular, the researchers found that simple STEM-based activities, including classroom discussions, storybook readings, and creative drawing tasks enhanced young children's knowledge of technology and engineering as a whole, while also helping them develop an engineering identity.

In the future, their findings could inspire more educators to introduce similar teaching practices in kindergartens and elementary schools, sparking greater interest in engineering among children from an early age. These practices could encourage children from diverse backgrounds to develop an engineering identity early on in life and to ultimately aspire towards engineering-related careers, potentially leading to a more diverse STEM workforce.

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ADAPT: CULTIVATING SKILLED MANUFACTURERS IN RURAL WISCONSIN

The manufacturing industry has long been central to the livelihoods of people in rural Wisconsin. Increasingly, however, the speed of change and innovation that many of these businesses need to incorporate to stay competitive are profound. This change, known as 'Industry 4.0', is being applied to businesses both large and small. In Western Wisconsin, the Trempealeau Valley Cooperative 2.0, Western Technical College and Ashley Furniture Industries are collaborating to develop a new educational model that will equip a new generation of students with the necessary skills to retain a cutting-edge manufacturing industry in the region.

Manufacturing in Wisconsin

Rural Wisconsin has historically been dependent on manufacturing and agriculture for much of its income. With a population of about only 3,000 people, Arcadia is the major employment center for the region. This city is home to both global companies and many more small businesses.

Ashley Furniture Industries, Inc. – the world's largest manufacturer of furniture, and one of the largest employers in Western Wisconsin – has been headquartered in Arcadia since 1970 and employs more than 30,000 people throughout the world. Each day, over 4,000 people either live in or travel to Arcadia to be a part of the company's growing team of employees.

The nearest post-secondary educational institution to Arcadia is Western Technical College, located about an hour away in La Crosse, Wisconsin. With such limited opportunities for people to gain skills relevant to their home region, the need for collaboration between Western Technical College and Ashley Furniture Industries was recognized as a necessity.

An exciting new partnership between local school districts, Western Technical College, and Ashley Furniture Industries aims to ensure a skilled workforce by providing innovative new educational programs. This project will ensure that cutting-edge techniques are at the forefront of advanced manufacturing in rural Wisconsin, in addition to providing fulfilling career opportunities for young people who live there.

The ADAPT Project

A core component of this partnership is a project entitled Automation Workforce Development through Aligned Industry Partnerships and Training (ADAPT), which is spearheaded by Dr. Joshua Gamer at Western Technical College.

The ADAPT project is centered around creating a pipeline of trained graduates in the field of mechatronics. This multidisciplinary branch of engineering concerns both electrical and mechanical systems, combining fields as widely varying as robotics, Industrial Internet of Things (IIoT), telecommunications, and product engineering. Mechatronics graduates who are skilled in advanced

Jason Everett of Amatrol Inc. shares with a middle school student the capabilities of an advanced piece of equipment called the Skills Boss, which is used to evaluate the skill levels and competencies of future machine operators.

automation and IIoT technologies are urgently required in the shift to 'Industry 4.0'. This concept, which first emerged in Germany, describes the increased automation of traditional manufacturing practices, using smart technology.

Incorporating lessons learned from the Applied Sciences College in Mosbach, Germany, the ADAPT project aims to incorporate cutting-edge manufacturing processes into innovative new educational programs. Dr. Gamer and his colleagues' approach involves merging traditional classroom lessons and apprenticeships with an active engagement in industry – enabling students to apply their skills at real job sites as they earn their degrees.

Launching such an ambitious project initially presented Dr. Gamer with numerous barriers to success. One of the most significant challenges related to the project's economic costs: not only would expensive equipment be required, but extensive training for college faculty and high school educators would also be needed. Furthermore, since the technology associated with advanced manufacturing is so cutting-edge, it changes rapidly – meaning that training courses would need to be continually updated to keep up with new advances. There would also be the need to identify industry-recognized credentials, which could be offered at the high schools while also being embedded in college credentials.

Just as importantly, the scope of the project meant that communities would need to be educated on 'Industry 4.0', the importance of a skilled workforce, and what is needed to make a region competitive. A skilled workforce provides economic opportunities for businesses to grow, raises the standard of living, and as a direct result, enriches an area.

Although these challenges were significant, Dr. Gamer realized that they could be overcome through collaboration. He knew that Ashley Furniture Industries was planning on investing in local educational initiatives, and was coordinating their efforts with the Trempealeau Valley Cooperative 2.0 (TVC 2.0) – a collaboration between different school districts in Western Wisconsin. 'The timing was perfect to try and connect the efforts of Ashley and the TVC 2.0 to Western Technical College, and build pathways for students in high school,' says Dr. Gamer.

Founding the TVC 2.0

At the same time that Dr. Gamer was conceiving of the ADAPT project, Mike Beighley, the Superintendent of Whitehall School District, already knew that change was urgently needed within the K-12 school system, particularly within the small rural communities in Trempealeau County. He knew that if the region's schools continued along the same traditional path, that their local economies and their students' career opportunities would suffer.

Mike and the superintendents in the neighboring school districts of Arcadia, Blair-Taylor and Independence – all situated within Trempealeau County – began discussing how they could better utilize the available resources. From these discussions, the TVC 2.0 was created. The vision for the TVC 2.0 is to develop career-ready and college-

Through a continued and collaborative effort between Ashley Furniture Industries, Inc., students also have the ability to learn and work with cutting-edge technology in the Ashley Automation Laboratory at Western Technical College's Integrated Technology Center in La Crosse, Wisconsin.

ready students by providing high-caliber learning experiences, preparation and pathways, in partnership with the greater community. By achieving this vision, the ultimate aim is to achieve regional stability and a greater quality of life for the citizens of Trempealeau County, Eastern Buffalo County and Western Jackson County.

During the same timeframe, Ashley Furniture Industries was also going through a transition of their own. As mentioned, Ashley is one of the largest employers in Western Wisconsin and has grown to become 'the world's largest manufacturer of furniture'. To continue to be the world leader in manufacturing furniture, Ashley puts an incredible amount of time and effort in researching and implementing new technologies and machinery into their advanced manufacturing facilities.

On one of the company's many trips to furniture manufacturing tradeshows in Germany, there was a great deal of discussion around the concepts 'Industry 4.0' and the 'Industrial Internet of Things (IIoT)'. It was clear that such technologies would soon become commonplace in manufacturing, and that Ashley would need to incorporate them in order to remain competitive. However, finding technicians with the necessary skillsets to operate advanced automation technologies proved to be extremely difficult.

In 2016, Mike Beighley made some connections and was able schedule a meeting with both the founder, Ron Wanek, and CEO, Todd Wanek, of Ashley Furniture Industries, to see what he could learn from two incredibly successful individuals who grew an empire in the furniture industry. This was the first time that these three individuals had met. After some introductions and pleasantries, Ron Wanek asked the question: 'So what is it that you would like?' Mike's reply was simple. 'To be completely honest, I don't know,' he replied. 'I'm tired of feeling like we're getting our butts kicked [in not fulfilling the educational requirements that employers are seeking]; education needs to change.'

Setting Out Goals

Working together, this collaboration between the TVC 2.0, Western Technical College and Ashley Furniture Industries has now set out three broader goals for the ADAPT project.

Firstly, the team aims to increase opportunities for mechatronics training programs. This will involve developing state-approved programs which align with industry standards, to be integrated into the curricula of local schools and Western Technical College. Secondly, they plan to increase recruitment, retention, graduation, and employment of the mechatronics-skilled workforce, specifically focusing on increasing workforce diversity. Finally, the team aims to expand the commitments of local industries in supporting the co-delivery of these courses and forge pathways from the programs into universities.

A variety of smaller-scale objectives also arise from these goals, including creating clear pathways to employment for students in high schools and technical colleges, and utilizing work-based learning opportunities such as internships and apprenticeships.

In setting out these numerous goals, the team first needed to identify a rigorous curriculum through which students could earn a credential in Advanced Mechatronics upon graduation. Throughout the program, students will develop critical skills including rapid prototyping, robotic maintenance, robotic programming, IIoT, and industrial safety. Furthermore, these skills will be solidified through the hands-on operation of specific technologies – with tasks including troubleshooting, design, installation, and programming.

For a program with such an ambitious scope to run smoothly, it is critical for students across numerous institutions to have easy access to equipment. Since it would be far too expensive for every institution to own such advanced equipment themselves, high school students must instead be given access to mobile equipment. To do this, Western Technical College,

Grand opening of the Mobile Skills Laboratory at Whitehall School District. From left to right: Ron Wanek, Founder and Chairman of the Board at Ashley Furniture Industries, Rebecca Kleefisch, Former Lieutenant Governor of Wisconsin, Todd Wanek, President and CEO of Ashley Furniture Industries.

Ashley Furniture Industries and TVC 2.0 have developed a state-of-the-art training facility.

The Mobile Skills Laboratory

Imagine yourself as a middle-school or high-school student who has been given an opportunity to step out of a traditional classroom and into a state-of-the-art laboratory, which allows you to learn about and physically operate some of the most advanced equipment and technology on Earth. Now, also imagine yourself being offered the opportunity to acquire technical skills that many employers are continuously searching for within their workforce. Would you take it?

For many students who attend school in rural Western Wisconsin, their answer to this question is simply 'Yes'. This new-age classroom experience, known as the Mobile Skills Laboratory, is a $3 million investment made by Ashley Furniture Industries, to provide students with valuable technical skillsets and allow them to become 'future-ready' for wherever their career path takes them.

The conception of the Mobile Skills Laboratory required three years of research and visits to over 100 K-12 schools, colleges and universities, to determine where the gap was between educational offerings and the employment needs of many advanced manufacturing companies.

The Mobile Skills Laboratory was then launched in August 2018, at Ashley Furniture's annual charity event, 'Ashley for the Arts', which raised money for over 40 local non-profit organizations.

During the festival, more than 10,000 visitors walked through the 900-square-foot lab, where they could interact with advanced manufacturing equipment – providing them with a unique educational experience. The Mobile Skills Laboratory has now gone from an interesting public exhibition to a vital tool in preparing students in Western Wisconsin to become 'future-ready'.

The Mobile Skills Laboratory provides competency-based learning opportunities for students, focusing on advanced manufacturing processes, electronics, smart sensors, programmable logic controls, automation and robotics. With over 300 courses available within the lab, students have the ability to earn high school and technical college credit recognized by real industries. These industry-recognized credentials are awarded by Western Technical College and the Smart Automation Certification Alliance (SACA).

Throughout the academic year, the facility now travels between the high schools involved in the project – providing a key element of the training required for ADAPT's Advanced Mechatronics program. Since these schools have full access to the equipment through this partnership, they aren't required to own it themselves – offering significant cost reductions both to institutions and their students.

Overall, the Mobile Skills Laboratory has provided innovative solutions to challenges that seemed insurmountable just a few years ago, enabling the project first conceived by Dr. Gamer to become a reality.

Betty Baker (right), Domestic Casegoods Product Engineer for Ashley Furniture Industries, welcomes students, parents and educators into the Mobile Skills Laboratory at Ashley for the Arts.

Furthermore, that 30-minute meeting between Mike Beighley, Todd Wanek and Ron Wanek in 2016 has blossomed into an educational model that includes many K-12 schools, technical colleges, universities, businesses, economic development organizations and government. All of these participating groups are putting their best foot forward in an effort to close the 'skills gap' and grow Wisconsin's economic prosperity.

The same passion that Ron Wanek has for manufacturing furniture has now grown to include a passion for providing youth with high-quality educational and career opportunities. He believes that the Mobile Skills Laboratory is simply scratching the surface of what can be achieved, as the involved parties continuously have discussions with education, industry and legislation to grow this partnership to become the 'national model'.

'At Ashley, supporting education at all levels is a priority of ours,' said Ron Wanek. 'We are extremely proud of the developments that have been created to help inspire students and provide them with the necessary tools to become the next generation of our country's skilled workforce. This is just the beginning and we are looking forward to growing our already successful partnerships.'

Successes and Impact

The collaborating partners are proud of the project's successes thus far. In short, these include the creation of the new academic program in Advanced Mechatronics, the alignment of the traditional academic programs to SACA credentials, creating a high school pathway of up to 10 credits through the use of the Mobile Skills Laboratory, addressing the language barrier in recruitment and marketing material, the creation of a transfer agreement from Western Technical College to the University of Wisconsin-Stout, and the upskilling of high school teachers in nine school districts in addition to Western's own faculty.

Once high school students graduate with an Advanced Mechatronics certificate, their skills will enable them to go directly into the workforce, or to further their knowledge by enrolling within a technical college. Additionally, upon graduation from a technical college, the credits can be transfered towards the completion of a Bachelors degree in Engineering Technology, with a specialization in Automation.

As this partnership continues to grow, students may have the opportunity to possibly earn an Associate degree at the time of their high school graduation. This would provide them with an incredible start to a Bachelors degree if they so choose.

Ultimately, the ADAPT project and the Mobile Skills Laboratory provide students with a realistic view of what the world of work will look like after graduation, and offer them clear pathways towards fulfilling careers through which they can earn excellent wages without moving far from home. At the same time, faculty staff can be assured that their teaching is relevant to the needs of their local region, and can actively contribute to its economy.

Revitalizing an Industry

Having started from just a few individuals, the Mobile Skills Laboratory and the ADAPT project are still in their early stages, and will require highly skilled and continually adapting leadership as they progress to their next stages. Western Technical College, Ashley Furniture and TVC 2.0 are confident that through their approach, many skilled graduates will be produced in the coming years.

In the near future, this will provide the long-established manufacturing industry of rural Wisconsin with access to workers skilled in the most cutting-edge technologies – ensuring its continued success for years to come.

Meet the researcher

Dr. Joshua Gamer
Integrated Technology Division
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Dr. Gamer earned his Ed.D. in Career and Technical Education at the University of Wisconsin – Stout in 2017. His transition into education followed a 10-year career in the manufacturing industry, where his most recent role was Director of Operations. While at Western Technical College, he took on many responsibilities including three years as an instructor, two years as the Associate Dean of the Business Division and a year as the Interim-Vice President of Academics. Dr. Gamer is currently the Dean of the Integrated Technology Division at Western Technical College, where he aims to infuse cutting-edge technology and skills into STEM education. Through his numerous efforts, he has secured funding to expand advanced manufacturing education into new areas; worked with local correctional departments to help establish new vocational training programs in skilled crafts; and overseen the planning and construction of a new state-of-the-art apprenticeship center and the newly remodeled Integrated Technology Center. Dr. Gamer was formally recognized as a Rising Star under 40, a 2020 Friend of Correctional Education, and has served in multiple volunteer capacities within his community. Using business acumen acquired through his MBA and industry experiences, he enjoys bringing local industry and education together in unique partnerships aimed at addressing the skills gap and ensuring the vibrancy of the local economy.

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HUMANITARIAN ENGINEERING: TRAINING ENGINEERS TO BEST SERVE COMMUNITIES

Engineering is one of the most impactful and transformative fields of teaching, research, and practice, as it shapes the world we live in and ensures the functioning of many systems that maintain human life. The Colorado School of Mines created the first Humanitarian Engineering (HE) program to train engineering students to devise solutions that are efficient, ethical, socially responsible and sustainable. Its students work closely with the communities they serve, thinking critically about their needs.

HE students work with residents of the Bolivian altiplano to map an aquifer using geophysical techniques.

The Need for Responsible Engineers

An engineer's work can be immensely rewarding, as it entails coming up with innovative concepts and solutions to a multitude of real-world problems. Today, communities worldwide face numerous challenges, including environmental issues, a scarcity of natural resources, poverty, and social inequality. Yet few engineering programs focus on responding to the needs of the poor and marginalized, nor do they often consider the intersection of corporate activity with the communities those corporations serve.

Engineers who can think critically and responsibly about these problems and who are equipped to address them are urgently needed, as these professionals can facilitate the development of infrastructure and technologies that meet the needs of many diverse communities while promoting greater environmental justice, social equality and societal sustainability.

The Colorado School of Mines, a public university founded in 1874 and renowned for its engineering and applied science programs, is rising to meet these challenges through its Humanitarian Engineering (HE) program. While the field of humanitarian engineering is growing quickly in the US and around the world, the Mines HE program was the first and stands out by fully integrating the social sciences and engineering in its courses, projects, and research. Through this integration, faculty train students not only to solve technical problems but to understand and responsibly intervene in sociotechnical systems. In particular, students learn to be 'problem definers' first and 'problem solvers' second, always asking, 'Should we do this?' and working with and from the perspective of the communities affected by their designs.

The HE program is led by faculty with a variety of motivations who are committed to the idea of engineering truly making a difference. These include engineers turned social scientists, who have witnessed first-hand the limitations of engineering solutions designed for the wealthy to serve the poor. Designing for affordability requires engineers to put social justice at the center of design. Several faculty members are anthropologists who frequently collaborate with engineers and applied scientists on projects related to social responsibility. Other faculty members are engineering professors who have learned that their technical expertise is not enough to solve the complex problems in society and that a human-centered approach is essential.

During a design focus group in Guatemala, HE students apply community engagement methods learned in the HE classroom.

Community-Centered Engineering

Typically, engineering courses focus on providing students with the technical knowledge they need to solve problems, without considering the importance of collaborating with the communities who will be impacted by those solutions. This can result in technologies for solving problems that no one actually needs, while leaving real problems unaddressed.

In contrast, the HE program helps students understand the value of developing trusting relationships with local communities, in order to co-define problems and only then co-create sustainable and socially responsible solutions to them. Through their coursework and projects, HE students use the social sciences to think critically about the culture, politics, and practice of engineering itself so that they can provide different answers to the question 'What is engineering for?'

The program leads students to be engineers who can view the world using tools from anthropology and other social sciences, reflecting on the communities, workers, governments, and others who will be affected by new technologies. As one of the faculty members who is an anthropologist says: 'We're not just training students to have good intentions and help others. We also teach them to think critically and work directly with the people they're intending to serve, defining problems together and seeing if they share the same assumptions and goals. In contrast, other engineering programs often assume that engineers are the ones who define problems and solve them, whether they have good intentions or not.'

HE students engage in project activities as part of their education. These projects may be in the US or abroad. Before working on HE projects, whether domestic or abroad, students complete coursework that encourages them to critically reflect on their desire to help communities and assess the strengths and limitations of traditional engineering methods and mindsets when working with people. This shows them the importance of listening to others' views openly, rather than looking at a problem based on what they already know and assume.

The HE program plays a leadership role at Mines and in national and international networks through its undergraduate minors, graduate degree, and research and outreach efforts.

Undergraduate Changemakers

Undergraduate students at Mines can be a part of HE by applying to become a Humanitarian Engineering Shultz Scholar, by enrolling in one of two minors, and by participating in HE-oriented student clubs.

The two HE minors are Engineering for Community Development and Leadership in Social Responsibility. Both of these entail taking 18 semester credits, including coursework and project activity, beyond their formal engineering major.

The Engineering for Community Development minor is centered around the ideals of sustainable community development and social justice. Students in this minor often go on to join the US Peace Corps or start working at NGOs and international development organizations. The Leadership in Social Responsibility minor more specifically prepares students for work in the private sector, helping them to promote shared social, environmental, and economic value between corporations and communities. The majority of its graduates work for private companies that require engineers who can tackle complex problems while taking into account community development and environmental sustainability.

Regardless of which HE minor a student pursues, they must carry out a project related to humanitarian engineering. A few years ago, a team of undergraduate students participating in the program devised a geographic information system in close collaboration with a non-profit food justice organization based in Golden, Colorado. This system is now being used to improve access to healthy and local food products in the county that is home to Mines. Another group of students helped redesign a mountain bike for quadriplegic riders that is now being used in biking resorts in Colorado. Yet another group of HE students designed a village of self-sustained eco-cottages that could provide an income for the Maya-Itzá community in Guatemala. These cottages were built in close collaboration with the Maya-Itzá community in Guatemala and the Bio-Itzá 'Preserve the Source' fund and modeled in ways that best fit the community's needs, conservation goals, cultural background and environment.

In addition to formal coursework and project activities, students at Mines can get involved in HE though several affiliated student clubs, notably Mines Without Borders, which is associated with the national organization Engineers without Borders, and the Socially Responsible Scientists and Engineers club. These clubs, which are student-led, work to advance the principles of HE and allow students and faculty to 'walk the talk'. In this regard, HE undergraduate students are change-makers at Mines who found and lead student organizations, host events, and engage in award-winning design projects.

The Next Step: HE Graduate Opportunities

The graduate program comprises an online certificate and a residential Master's program in Humanitarian Engineering and Science (HES). The master's program is deeply interdisciplinary, as students take half of their classes with the Humanitarian Engineering faculty and the remaining classes with faculty from other departments, following a specific disciplinary track. Currently, students can specialize in the fields of environmental engineering, geophysics, and geological engineering.

Mines Geoscientists Without Borders members deploy low-cost geophysical instrumentation for locating water at-depth with citizens in Benin, Africa.

In particular, the interdisciplinary mix of faculty and students positions Mines as a leader in the field of humanitarian geoscience. One recent example is the close collaboration between the geophysics faculty and Geoscientists Without Borders. For example, several geophysics and geology faculty are working with HE students on a project to develop low-cost geophysical instrumentation to improve groundwater management in West Africa.

The master's program is designed for students and working professionals who have technical backgrounds. Students learn about the inextricable link between engineering and society so that they can harness their technical training to promote sustainable community development and more socially responsible engineering practice.

Cutting-Edge Research

In addition to educating engineers that can serve communities more justly and effectively, the HE program has given rise to several cutting-edge research endeavors. One example is the Responsible Mining Resilient Communities (RMRC) project, a collaboration among interdisciplinary researchers from various institutions worldwide, founded by a $4 million National Science Foundation grant. The key institutes involved in the RMRC project are the Colorado School of Mines, University of Texas-Arlington, US Air Force Academy, University of Colorado, Universidad Nacional de Colombia, Universidad Minuto de Dios (Colombia), and Pontificia Universidad Catolica de Peru.

Today, approximately 30% of the world's gold – used in jewelry, electronics, high tech equipment, and financial markets – is mined through artisanal and small-scale gold mining (ASGM), which typically is done informally by individual and groups of miners seeking to make a living, in contrast with mining that is done formally by corporations. While ASGM is a key livelihood strategy for poor and marginalized communities,

ASGM practices can negatively affect the environment while also threatening the health of both workers and nearby communities. This is because many miners use mercury, an element that is highly toxic for both humans and the environment.

The RMRC project was created with the key mission of working with ASGM communities to create methods and networks that enhance social and environmental sustainability for miners and their communities. Students participating in the project closely collaborate with miners, communities and academics in Colombia and Peru to co-design, implement and evaluate socio-technical innovations.

HE students and faculty travel to Latin America to work with a variety of stakeholders, including small-scale miners, local government officials, students, and professionals.

As one of the project principal investigators notes: 'Though the RMRC project, we are working with local governments and gold companies in Colombia, which is a good example of how our graduates are well-positioned to become advocates for socially responsible engineering inside of companies and government agencies. If we can train mining engineers to think more empathetically and creatively with artisanal miners, when they end up in corporate structures, they will be better prepared to shape their companies' policies to be more socially responsible.'

A New Engineering Vision

The HE program has already led to a wide range of initiatives that have improved the lives of local communities in different parts of the world while protecting the natural environment. The program has also been noticed by its peers. Both the HE program and one of its core courses, Corporate Social Responsibility, were named Exemplars in Engineering Ethics by the United States National Academy of Engineering.

The HE team's next goals are to build new bridges with more engineering disciplines, expand their projects and impact into other US and global communities, diversify their research to include the social justice dimensions of renewable energy, and teach engineering in non-traditional settings such as refugee camps. For example, in collaboration with the MIT D-Lab, Universidad de Colombia, and UNIMINUTO, HE is planning to work on a project that involves Venezuelan refugees migrating to Colombia, in one of the largest humanitarian crises in the world. The project is trying to find ways to give the refugees employment, by figuring out how to reuse and recycle construction waste – piles of bricks and concrete and asphalt – that are sitting unused.

These combined efforts could ultimately pave the way towards a more responsible and human-centered engineering vision that takes the perspectives of the people directly impacted by new technologies into account, while also preserving their health and the environment in which they live.

Join the Humanitarian Engineering Movement!

Are you an engineering or STEM professional looking for more in your career or a student interested in engineering and STEM, and wanting to make a significant difference? If so, join us today!

To Learn More

Kevin Moore, Executive Director, can discuss ways to engage with the Mines HE Program, including though philanthropic support, project sponsorships and other partnering opportunities.
E: kmoore@mines.edu

Juan Lucena, Director of HE Undergraduate Programs can provide prospective students with more information about how they can make an impact on the world by joining the HE program at Mines.
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COLORADO SCHOOL OF MINES

CULTIVATING A NEW GENERATION OF BIOMEDICAL ENTREPRENEURS

In recent years, scientific and technological advances have brought great innovation within the life sciences industry, introducing the need for entrepreneurship training for medical and engineering graduates. With this in mind, **Michal Gilon-Yanai**, **Dr Robert Schneider** and their collaborators developed an academic program designed to provide students and faculty members with the skills they need to become successful entrepreneurs. The team of collaborators includes **Dr Gabrielle Gold-von Simson**, an expert in implementing academic programs, and **Dr Colleen Gillespie**, who specialises in education, evaluation and dissemination science. Their pioneering program trains students on how to bring new biomedical technologies to the market.

A New Wave of Opportunities

Over the past few decades, there has been a rapid surge of new therapies, medical devices and digital health solutions aimed at improving the health of those affected by medical conditions. From robotic prosthetics to smartphone apps that monitor symptoms, these medical innovations have enhanced the quality of life of millions of people across the globe.

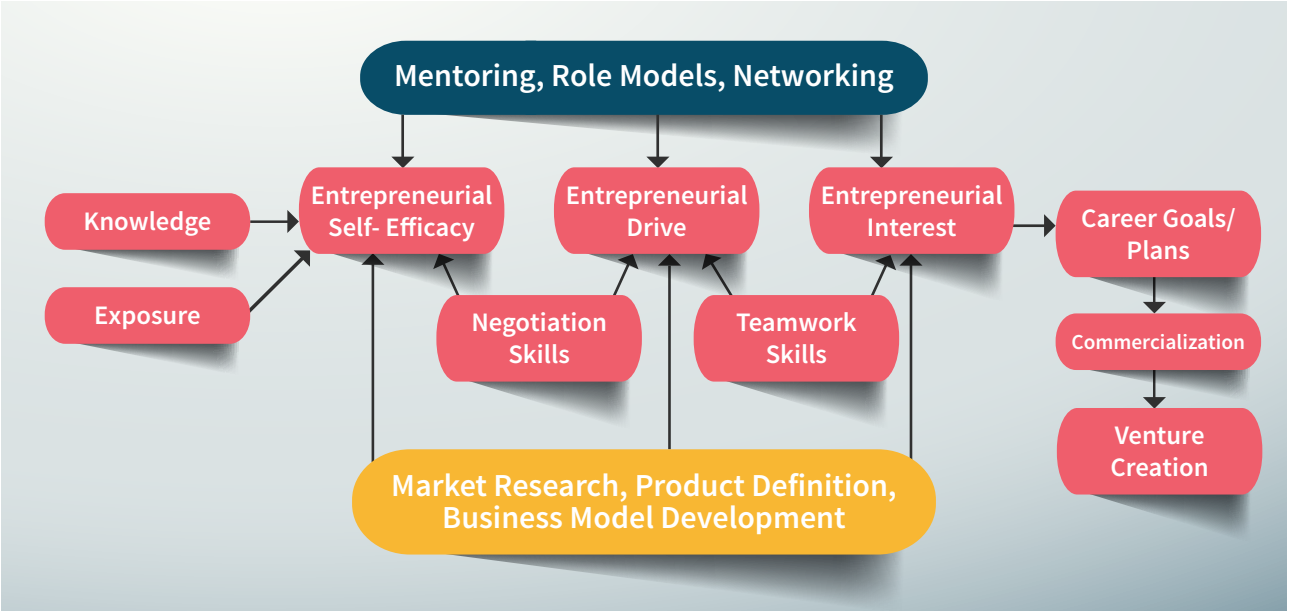
This rise in these innovative technologies and therapies has opened up new exciting possibilities for medical science and engineering graduates, broadening their career options and offering them the choice of starting their own business ventures. While knowledge of the biomedical sciences is highly valuable for developing a new medical device, therapy or service, launching a successful business also requires entrepreneurial skills, which are not typically acquired during traditional medical degree courses.

Therefore, a team of researchers at the New York University (NYU) Grossman School of Medicine has created an academic program aimed at providing postdoctoral and graduate students, as well as faculty, with the entrepreneurial skills they need to start their own business ventures. This academic program, called the Biomedical Entrepreneurship Skills Development Program, trains participants on many different facets of venture creation, using real projects as examples.

The Program

The Biomedical Entrepreneurship Skills Development Program builds on the success of a previous drug development educational program developed by Dr Gold-von Simson, in collaboration with her colleague Dr Ravichandran Ramasamy. It is ultimately designed to further expand the skill set of graduating medical and engineering students at NYU, teaching them to effectively translate the knowledge they have acquired into practical health solutions and commercial ventures.

'The goal of the Biomedical Entrepreneurship Program is to teach and train students in Biomedical Entrepreneurship, with a focus on the commercialisation of academic discoveries and inventions,' says Dr Gold-von Simson. 'Through a variety of methods, our hope is that participants will gain an understanding of the requirements for launching and building a new venture in the complex and highly regulated life sciences industry, as well as the entrepreneurial journey of the scientist entrepreneur.'



The program was devised by Michal Gilon-Yanai and several of her colleagues, including the new director, Dr Sadhana Chitale, who developed the curriculum and assisted its launch. Dr Colleen Gillespie, an expert on the evaluation and dissemination of academic programs, Dr Gold-von Simson, director of the health innovations and therapeutics program, and Joy Achuonjei, a NIDDK T35 scholar, have been working together to make improvements, evaluate the merits of the course, and measure outcomes with the intent of disseminating methodology to ultimately bridge the gap in research translation.

'The program focuses on advancing health innovations and developing effective solutions; this is at the core of the mentored, entrepreneurial process,' explains Dr Gold-von Simson. 'We aim to build upon the academic excellence at NYU with its track record of success.'

Advancing Research Translation into Business Ventures

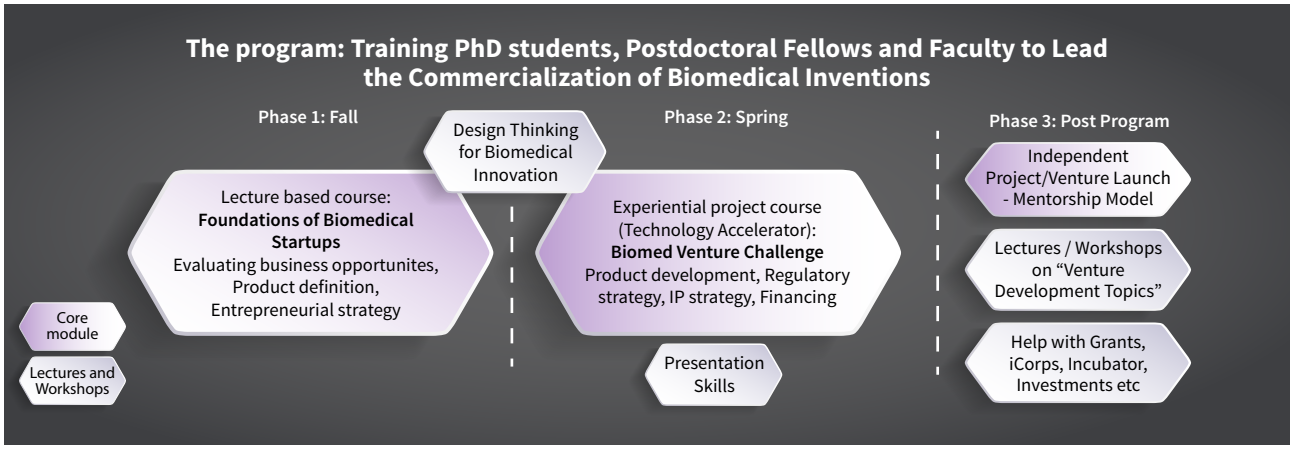
'Our program aims to promote commercial development of novel discoveries and breakthroughs, while leveraging early-stage researchers with innovative and creative ideas,' the team says. 'The goal is to teach scientists and like-minded individuals at an early career stage how to create solutions, whether at the molecular level or via the creation of medical devices or software tools, to benefit those who suffer from disease.'

So far, the Biomedical Entrepreneurship team has devised a series of curricular activities that span across one academic year. These activities are each designed to teach participating students how to translate their knowledge of medical science and engineering into promising and successful business ideas, such as novel therapies, medical devices, health-related mobile apps and other digital healthcare tools.

'By introducing participants to the similarities and connections between the biological mechanisms underlying diabetes, metabolic disease, and other medical conditions, we enable and encourage them to think creatively about potential applications for their own research from seemingly unrelated disease contexts, such as autoimmunity and hyperimmunity, cancer and inflammatory diseases, ultimately advancing the goals of the National Institutes of Health,' the researchers explain.

The core course offered as part of the Biomedical Entrepreneurship Skills Development Program is 'Foundations of Biomedical Startups'. This course gives students an overview of the process by which a medical product makes its way onto the market, through a series of lectures and case studies delivered by faculty members, experienced entrepreneurs, and investors. The first piloted course in this area was offered in 2017 and was called 'Introduction to Biomedical Entrepreneurship'. In fall 2019, after several adjustments and a course name change, 'Foundations of Biomedical Startups' was offered and approximately 50 students enrolled.

In the spring of 2019, students were also given the opportunity to take part in a competitive technology acceleration program called the 'Biomed Venture Challenge', which was subsequently offered online in the spring of 2020 due to the COVID-19 pandemic. Working together in teams, the participating students applied the knowledge and skills they had acquired in lectures to develop business models and commercialisation pathways for new medical technologies. Several industry experts were then called upon to evaluate the students' inventions. The team that received the most positive feedback won an award of $30,000 USD, which was to be invested in advancing their technology towards commercialisation. The program is funded by industry sponsors Pfizer Inc, Kairos Ventures and Wilson Sonsini Goodrich & Rosati.



A third component of the Biomedical Entrepreneurship Skills Development Program at NYU is a workshop called 'Design Thinking for Biomedical Innovation'. The main aim of this workshop is to introduce students to the concept of design thinking, which is an approach often used by entrepreneurs when they are trying to come up with innovative projects.

Evaluating the Program's Impact

The complete Biomedical Entrepreneurship Skills Development Program in its current form was first offered during the academic year spanning from the fall of 2019 to spring of 2020. To evaluate its impact, participants in the Foundations of Biomedical Startups course, the Design Thinking for Biomedical Innovation Workshop and the Biomed Venture Challenge were asked to complete surveys that elicited their feedback on these activities, assessed their biomedical entrepreneurial skills, and explored the impact of participation on their future career and research plans.

Overall, the students who attended the core course and Biomedical Innovation workshop provided highly positive feedback, suggesting that the topics were interesting and the sessions were taught well. Most survey respondents found speakers highly engaging, particularly those who delivered the Therapeutics and Venture Creation lectures. They also offered feedback on how certain modules could be improved, noting that speakers could place more emphasis on the practical aspects of technology development.

The team also tested students' assessment of their own entrepreneurial knowledge and skills before and after they attended the Foundations of Biomedical Startups course and found that based on their self-assessment, their knowledge of venture creation and their entrepreneurial skills had significantly improved.

Students who took part in the Design Thinking for Biomedical Innovation Workshop reported that their understanding of the three key topics covered during the workshop – design thinking principles, design thinking methods, and knowledge of diabetes and chronic kidney disease – had greatly improved.

Perhaps most importantly, all participants agreed (somewhat or strongly) that the Foundations of Biomedical Startups course made them more likely to pursue commercialisation, better able to collaborate with those seeking to develop drugs, and more likely to conduct high-impact research.

A Successful Initiative

The Biomedical Entrepreneurship Skills Development Program has so far proved to be highly successful in introducing students to biomedical venture creation, while also teaching them to translate their knowledge of the medical sciences and engineering into innovative and potentially profitable business ideas.

In the future, the program could serve as an inspiration for other medical schools that are considering introducing courses or programs focusing on biomedical entrepreneurship. The team is now planning to share the curriculum they developed with other academic centres in the US, towards facilitating the creation of similar academic programs.

Since they were awarded the grant a little over a year ago, the research team focused most of their efforts on developing the course curriculum, implementing it, and conducting a preliminary evaluation of the program. Although the COVID-19 crisis caused a series of disruptions, meaning that much of the course needed to be delivered online, the feedback received from participating students has been highly positive.

In the upcoming year of the program, The Biomedical Entrepreneurship team plans to forge deeper collaborations with both the Business School and the School of Engineering at NYU, in order to encourage interdisciplinary innovation amongst students and faculty. Additionally, as teams that include diverse perspectives have been shown to lead to greater innovation, the researchers also plan to encourage the participation of more students from underrepresented minority backgrounds.

Meet the researchers

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Michal Gilon-Yanai was until recently associate director of the Biomedical Entrepreneurship Program. She holds an MBA from the MIT Sloan School of Management, a BA in computer science and LLB in Law from Tel Aviv University. Before joining NYU, she managed two entrepreneurship programs at MIT: the Entrepreneurship Educators Forum and Translational Fellows Program. Prior to her academic career, Gilon-Yanai worked at iMDsoft, a healthcare IT startup, where she gained management experience and a better understanding of real-world business challenges. She is currently an executive venture partner at Two Lanterns Venture Partners.

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Joy Achuonjei is a medical student at The Zucker School of Medicine at Hofstra/Northwell. She holds an MS and a BA in Neuroscience from Columbia University. Her current research interests include medical education, innovation and initiatives to help underrepresented medical students develop entrepreneurship skills. As an NIDDK T35 summer research scholar, she worked with Dr Gold von-Simson and the Biomedical Entrepreneurship team. Achuonjei is also a member of the national working group for White Coats for Black Lives.

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Daniel Cobos holds a BA in Psychology from St. John's University and began working at NYU in 2013 as a project associate and clinical trials assistant and subsequently joined the NYU CTSI as an administrative coordinator of the NYU CTSI's Translational Research Education and Careers Core. He also facilitates other NYU educational programs such as the Drug Development and Health Innovations and Therapeutics Program and serves as the coordinator of the NYU Biomedical Entrepreneurship Program.

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Dr Chitale holds a PhD in Microbiology from the University of Mumbai and an MBA from the University of Pittsburgh. She is the new Program Director of the Biomedical Entrepreneurship Program as well as the Senior Director of Life Sciences/Technology Transfer in the office of Industrial Liaison within NYU's Technology Venture and Partnerships. At NYU she is involved with the management of intellectual property and technology transfer. Previously, Dr Chitale was a Licensing Manager at the Weill Cornell Medical School; she is also a Certified Licensing Professional and a registered patent agent.

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CULTIVATING HEALTH-CONSCIOUS HIGH SCHOOL STUDENTS THROUGH NUTRITION EDUCATION

Providing high school students with nutrition-related knowledge enables them to lead healthier lives by selecting foods that are both tasty and nutritious. Researchers at Middle Tennessee State University and Lipscomb University have created a course designed to offer high school students the opportunity to become acquainted with the field of nutrition, allowing them to apply this knowledge to improve their personal lives, earn college-level credit and prepare for future careers.

The Importance of Culinary Nutrition

According to statistics released by the World Health Organization in 2016, the global adult population was at a 39% overweight and 13% obesity rate. Likewise, these data also revealed that worldwide obesity tripled in the past 45 years. This is particularly worrisome, as obesity is associated with a significantly higher risk of developing a variety of health conditions, including diabetes, heart disease, and some cancers, much of which could be prevented and tackled through interventions aimed at improving people's eating habits and lifestyle choices.

Providing younger generations with quality nutrition-related education could help to address the problem of obesity, as it could increase their likelihood of adopting healthy eating habits. Such education could also ultimately result in a greater number of nutrition students with improved knowledge of preparing healthy food, and nutrition experts that can guide others in making healthier choices.

Dr Janet Colson, Dr Liz Smith and Dr Tracy Noerper, three researchers working at Middle Tennessee State University (MTSU) and Lipscomb University, have recently created a project utilising a previously developed course aimed at introducing high school students to nutrition-related concepts, all while affording them college credits. Through enrolment in this nutrition course, the team hopes to spark an interest in students to pursue careers in the food and nutrition industry.

Facilitating the Shift to College Education

In recent years, researchers have devised a number of courses and academic initiatives aimed at facilitating young people's shift from high school to college-level education. The key motivation behind these efforts is to better prepare high school students for college, allowing them to become acquainted with core topics related to their field of interest earlier in their academic journey.

MTSU nutrition student demonstrating appropriate portion sizes

One strategy that can facilitate students' transition from high school to college or university is known as 'dual enrolment'. As the name suggests, dual enrolment courses allow students to simultaneously participate in classes from two different levels of education.

This dual enrolment initiative devised by Dr Colson, Dr Smith and Dr Noerper allows high school students enrolled in the nutrition science pathway to attend college-level nutrition classes. The key aim of the course is to provide students at high schools in Middle Tennessee with high-quality education in nutrition science, offering them the opportunity to gain college-level credits while completing their secondary education.

‘We introduced students to college life by taking a dual enrolment nutrition class, bringing them to our MTSU campus to tour the food and nutrition-related programs. We then took the high school students to the Tennessee Academy of Nutrition and Dietetics meeting and trained high school teachers during the summer.’

High school students touring the MTSU campus

‘We introduced students to college life by taking a dual enrolment nutrition class, bringing them to our MTSU campus to tour the food and nutrition-related programs,’ says Dr Colson, the project director. ‘We then took the high school students to the Tennessee Academy of Nutrition and Dietetics meeting and trained high school teachers during the summer.’

Students completing the dual enrolment program offered by MTSU take part in MTSU’s 2000-level Nutrition for the Health Sciences class online. High school teachers are advised to facilitate the students’ learning by aligning the content delivered in their normal classes with the Nutrition for the Health Sciences curriculum offered to high school juniors. Students completing MTSU’s courses are also asked to complete practical tasks that merge their culinary training with nutrition concepts. For instance, they could be asked to plan and prepare a menu that meets the Recommended Dietary Allowances and Dietary Guidelines.

The dual enrolment course offered by MTSU has two key objectives. First, as high school teachers often have limited and inadequate knowledge of nutrition, Dr Colson and her colleagues wanted to strengthen both the available nutrition course content and the way it was delivered to students. The second goal of the course was to recruit high school students who might be interested in pursuing majors in nutrition and food science or other related disciplines.

Dual Enrolment vs Dual Credit Classes

In addition to the current dual enrolment offering at MTSU, Dr Colson and her colleagues have developed a dual credit challenge examination, which allows high school sophomores to earn credit for their 1000-level nutrition course.

The Nutrition and Food Science dual credit and dual enrolment courses are broken down to include: ‘Nutrition Across the Lifespan/Principles of Nutrition’ and ‘Nutrition Science and Diet Therapy/Nutrition for the Health Sciences’. The former is a dual credit course, while the latter is a dual enrolment course. Both of these courses allow students to gain college-level credits while still in high school. Students may take only one to earn three hours of college credit or both to earn six hours.

The key difference between the dual credit and dual enrolment courses is that while the first is a college-level course taught by high school teachers, the latter allows high school students to enrol in college and complete the exact same classes taken by undergraduate students at MTSU, delivered by university instructors. Moreover, students completing the dual credit course are evaluated in an independent online exam proctored by the high school teacher.

If the student receives a 70% or higher score on the examination, they are eligible to receive dual credit for this class. Those who are part of the dual enrolment program complete the same assignments and exams as MTSU undergraduates, which are also accessed online. They receive a course

Students touring MTSU's milk processing plant

grade from the MTSU instructor and are eligible for college credit for this course.

The dual credit nutrition class and examination devised by Dr Colson and her colleagues offer a broad introduction to nutrition-related concepts, typically taken by college freshmen. It focuses on topics such as food safety, macronutrients and micronutrients, digestion, healthy cooking, the role of nutrition in health, food controversies, artificial sweeteners, and dieting.

High school teachers delivering these courses are provided with a wide range of materials that they can use in class, including PowerPoint presentations, notes, articles, relevant websites assignment ideas, and study sheets. The teachers will then be able to use these resources, along with introductory nutrition textbooks, to create their own course aligned with their teaching methods. At the end of the course, students will be eligible to sit for an examination over the topics covered.

'Recently, we submitted a grant proposal to work with high school culinary arts teachers and students to develop a culinary nutrition component for their classes,' Dr Colson explains. 'We plan to prepare the students to sit for the dual credit exam to earn college credit. We will include summer teacher training for culinary arts teachers so they will be better prepared to teach nutrition to their culinary arts students.'

Initial Evaluations of the Courses

So far, the team has offered their dual enrolment course to high school nutrition science students in Middle Tennessee. To evaluate the effectiveness of the course in enhancing the students' knowledge of nutrition, the team tested students before and after they completed the course.

Most of the students scored significantly higher on the tests after completing the courses, attaining grades that were consistent with those scored by college students at MTSU. In addition, the change in test performance before and after taking the course at MTSU appeared to be more prominent than that of college students, yet both groups of students benefitted greatly.

The initial results collected by Dr Colson and her colleagues suggest that the dual enrolment course can considerably improve high school students' understanding of nutrition course material, and better prepare them for their future studies and careers. The dual credit class will be offered to nutrition students during the 2000/2021 academic year, with plans to offer it to culinary arts students at high schools in subsequent years.

Enhancing Students' Nutrition and Food Science Knowledge

The dual enrolment and future dual credit courses introduced by Dr Colson, Dr Smith, and Dr Noerper have already proven to be highly promising in preparing high school students for further studies in nutrition and food science. In addition, the dual enrolment class has been found to significantly improve the students' knowledge of nutrition-related concepts, which could greatly benefit their academic and professional development, as well as their personal eating habits.

In the future, the team's work could inspire other universities and schools to incorporate college-level nutrition course curriculum into classes for high school students, ultimately enhancing their knowledge, skills and awareness of healthy eating.

Dr Colson and her colleagues now plan to continue working on expanding both the scope and reach of the courses they developed, in order to reach more students and further enhance the quality of the classes they will take part in. These educational programs are likely to culminate in a broad range of positive effects, generating better qualified nutrition professionals, and food specialists, while also spreading greater awareness about the importance healthy eating among younger generations.

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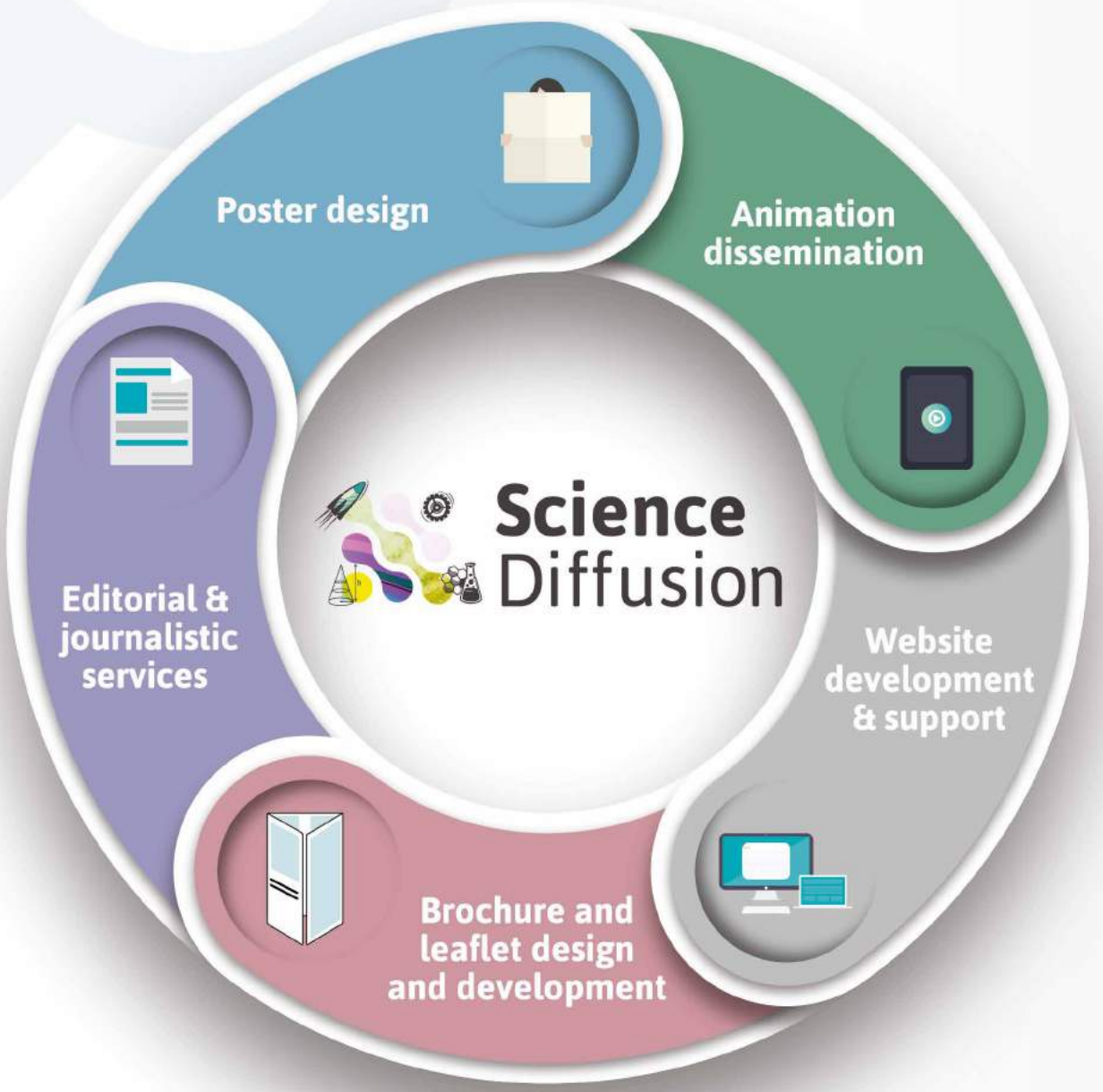

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