Scientia

STRENGTHENING THE STEM COMMUNITY THROUGH INCLUSIVE EDUCATION

HIGHLIGHTS:

- Closing the Gender Gap in Science
- The RADSS Program: Encouraging and Supporting Rural Students
- A Different Tangent to Teaching Trigonometry
- From Coast to Coast: Building Capacity in Ocean Science

EXCLUSIVE:

- The American Association of Physics Teachers

Issue: #127

Do you want to become a regular **READER OF SCIENTIA?**

Scientia's mission is to connect people: scientists and educators, policy-makers and researchers, and the public and private sectors. We communicate science into the wider world, providing **high-quality, engaging,** and **relevant information** to our audience of thinkers and explorers.

Register today for your **FREE** subscription at:

www.scientia.global/subscribe/

WELCOME...

In this critical issue of Scientia, we showcase an inspiring array of projects, each seeking to enhance science, technology, engineering and mathematics (STEM) education worldwide. Ranging from early childhood schooling to postgraduate training and beyond, this impressive collection of initiatives aims to guarantee a strong and diverse STEM workforce into the future – one capable of addressing humanity's greatest challenges.

To open the issue, we spoke with Dr Mel Sabella, president of the American Association of Physics Teachers (AAPT), a professional society dedicated to the pursuit of excellence in physics education. In this exclusive interview, Dr Sabella explains how the Association focuses on diversity, equity and inclusion to greatly enhance physics education in the US and further afield.

This leads us on to our first section in the issue, which explores a range of programs that aim to increase diversity within the STEM community. From exposing young people to relatable STEM role models from diverse backgrounds, to creating inclusive environments for underrepresented college students, we discuss several pioneering approaches that seek to widen opportunity and promote achievement in STEM across the broad spectrum of society.

In our second section of the issue, we focus specifically on new and innovative teaching methods. By encouraging active learning, facilitating student collaboration, and recognising the different needs and abilities of individuals in a classroom, the initiatives featured here are ensuring better academic outcomes for students, ultimately resulting in a stronger STEM community.

In the final section of this edition, we showcase a collection of targeted educational programs, each designed to address a shortage of highly skilled professionals in a specific area of STEM. From inspiring students to pursue careers in sustainable energy, to upskilling the global ocean science community, these pioneering projects are bridging critical skills gaps in the STEM workforce, allowing us to adequately address the growing challenges facing society.

Science Diffusion

CONTACT

Published in the UK, by Science Diffusion ltd

ISSN 2059-8971 (print)
ISSN 2059-898X (online)

E: info@sciencediffusion.com
W: www.sciencediffusion.com
W: www.scientia.global

@scientia_social
www.facebook.com/socialscientia
www.linkedin.com/company-beta/11065635

Meet The Team...

CONTENTS

ISSUE : #127

BRIDGING SKILLS GAPS

THE AMERICAN ASSOCIATION OF PHYSICS TEACHERS

Founded almost 90 years ago, the American Association of Physics Teachers (AAPT) is a professional society dedicated to the pursuit of excellence in physics education. The Association represents a diverse network of educators who all learn from each other about the most effective ways to teach physics, to reach all students. In this exclusive interview, we speak with AAPT's President **Professor Mel Sabella**, who tells us about AAPT's varied activities and goals. He also explains how the Association focuses on diversity, equity and inclusion to greatly enhance physics education in the US and further afield.

To begin, please tell us a little bit about the history of AAPT. Why and when was the Association established?

AAPT was established in 1930 with the goal of being the leading voice in the 'dissemination of knowledge of physics, particularly by way of teaching'. Homer L. Dodge, the first president of the AAPT and one of the co-founders of the organisation, emphasised the importance of community and recognised that physics teachers often 'had no means of intercommunication'.

Fostering community remains an important role for our organisation, and although the world is much more connected than it has been in the past, we often find physics teachers who suffer from different types of isolation. They may be the only physics teacher in their high school, they may be the only physics faculty member at their institution interested in active learning, they may be physics teachers from an underrepresented group in a field that suffers from a lack of diversity. Supporting our diverse network and fostering a community of educators, who share similar values and goals, remains an important part of our mission.

AAPT's first national meeting was held in New Orleans in 1931 with the American Physical Society and the American Association for the Advancement of Science. Many of the topics, such as laboratories and apparatus, discussed at the first AAPT meeting, over 75 years ago, are still being discussed by our membership today, although, as you would expect, the details of these discussions have evolved quite a bit.

Shortly after this first meeting, AAPT began its journal program which now includes *The Physics Teacher* and the *American Journal of Physics*. As the world changes and physics education adapts to changing demographics,

‘It’s amazing to part of such a diverse community where the expertise of educators at all levels is valued and leveraged.’

changing technology, and changing workforce needs, AAPT changes to reflect the values and interests of our membership. You can see this evolution in our journals, at our conferences, and in our programs and activities.

For instance, diversity, equity, and inclusion have become a cornerstone of AAPT’s work in recent years, with many in our membership thinking about the best ways to create effective physics classrooms *for all*. Two examples from recent national meetings are sessions on ‘Reducing the Gender Gap in Undergraduate Physics’ and ‘The Model Minority Myth and Disaggregation of Asian Student Data’. Another excellent example of this effort comes from a recent themed issue of *The Physics Teacher* that focused on Race and Physics Teaching. This theme issue brought together physics educators to think critically about the role race, gender, and culture play in the physics classroom.

While AAPTs mission and values have remained the same and the organisation remains committed to being ‘a professional membership association of scientists dedicated to enhancing the understanding and appreciation of physics through teaching’, the way we accomplish this has changed significantly from the early days of the organisation.

How many physics teachers (and therefore students) currently benefit from AAPT’s work?

There are roughly six thousand members of AAPT around the world, but the impact and benefits extend well beyond our membership, as students in classes taught by AAPT members benefit from innovative, active, research-based instructional materials. When you think about the impact the organisation has had and continues to have on physics teaching, it’s quite impressive. This impact extends well beyond the United States, as roughly 14% of our members are international, and many of our international members regularly attend the national meetings and play leadership roles in the organisation, serving on area committees and organising sessions.

AAPT is quite diverse with K-8, High School, Two Year College, Four Year College and University members. Student membership includes both undergraduate and graduate students with the majority of graduate student members in the field of Physics Education Research. It’s amazing to part of such a diverse community where the expertise of educators at all levels is valued and leveraged.

Because of this diversity in our membership, our organisation has this amazing breadth of expertise and experience. You always have access to a welcoming community focused on the specific topic that you are interested in. For instance, If you are interested in improving the laboratory experience for your students you can connect to our affiliate organisation, ALPhA; if you are interested in supporting students underrepresented in physics you can connect to our Committee on Diversity in Physics; if you are teaching physics in your High School for the first time you can connect to the Physics Teaching Resource Agents. These are just a sample of the breadth of work in our organisation.

How do you engage with physics teachers across the country and encourage them to collaborate with you?

There are many ways that our membership engages with the organisation and the way we foster collaborations is through offering high-quality instructional resources and supporting the implementation of these materials through peer-reviewed journal articles, workshops, and national meetings. Many in the organisation, in addition to running workshops at the national level, run regional workshops, through the AAPT Sections, to provide

access in different areas of the country. With less and less funds for professional development, it is important that AAPT has programs and activities to support membership who cannot always travel to a national meeting. As our national meetings move around the country, we always include special opportunities for local students and teachers.

Our K-12 Teachers' Day and Two Year College (TYC) Day, which have a deeply discounted registration, offer focused programming for these specific populations and are designed to provide access to AAPT resources to the local community. The reduced registration and small travel costs for the local community make attending one of our national meetings possible for those without significant funding.

In addition, the Society of Physics Students, one of AAPT's sister societies, organises a hands-on, interactive session with local students at each of our Winter meetings called Students Exploring Engineering and Science. AAPT provides lunch, transportation, career information, and science materials so these students experience an exciting day of physics.

Our members also collaborate with the organisation by engaging in leadership roles and many of our members choose to join one of our 19 Area Committees that focus on topics of interest to the physics and physics education communities. These committees tackle big picture issues in physics education, inform our strategic planning, and develop amazing sessions and workshops for our national meetings. These opportunities in leadership mean that any member of AAPT can contribute to the national dialogue around physics education and help guide the direction of the organisation.

How do you establish the efficacy of different approaches to teaching physics, and how do you encourage teachers to adopt such new and more effective strategies?

Developing new, effective instructional approaches to physics teaching is a central goal of our organisation. The overarching characteristic of these approaches is active engagement, based on what we know works best for students. There is a wealth of compelling evidence that instructional materials that are inquiry- and research-based result in larger gains in content understanding, as well as improved attitudes and expectations, when compared to the traditional lecture-based physics course.

The Physics Education Research community within AAPT has done significant work in establishing the efficacy of different instructional materials through both qualitative and quantitative research studies. This community consists of students, post docs, and faculty who take a scholarly approach to instruction and learning. When the field started, it mainly focused on studying content understanding and often involved analysis of interviews with students on different physics topics, analysis of written responses on exams, and analysis of research-based, validated diagnostic instruments.

‘There is a wealth of compelling evidence that instructional materials that are inquiry- and research-based result in larger gains in content understanding, as well as improved attitudes and expectations, when compared to the traditional lecture-based physics course.’

The development of a number of research-based curricula came out of this work, and while these materials emphasised active engagement, they also emphasised the importance of asking the right questions based on data on student learning. Two examples from this work that are still used widely today include Tutorials in Introductory Physics (focused on the college classroom) and Modeling Instruction (focused on the high-school classroom). But these are just two examples – you can find many more exemplary physics instructional materials on the AAPT website and on the AAPT PhysPort site.

Physics Education Research has evolved and diversified since it started and now includes topics such as developing inclusive classrooms, student epistemology, attitudes and expectations, self-efficacy and mindset, laboratory instruction, mathematical reasoning, and computational understanding. The Physics Education Research community holds a tandem meeting, PERC, at the end of each AAPT Summer Meeting that tackles important issues in Physics Education from diversity and inclusion to physics outside of the classroom.

Please tell us about the other resources that you provide for physics teachers, and how you help teachers to derive the most benefit from them.

AAPT and its members have a great deal of expertise on many topics and many of our members have and continue to contribute different types of resources to support teachers at all levels. One great resource for many of these materials is the ComPADRE Digital Library. This is a great site to find resources for K-12 and College classrooms.

For instance, on the Physics Front, in the K-12 resources, you can find an activity where students can integrate physics and biology through a high school diffraction lab that supports students in modelling the work of Rosalind Franklin in discovering the structure of DNA. In the college resources you can find the excellent work of the Partnership for Integration of Computation into Undergraduate Physics – a vibrant community of educators that organises a forum for open discussion, hosts collections of educational resources, strategies and tactics that support the development and improvement of undergraduate physics education through the integration of computation. These two examples just scratch the surface of what one can find in ComPADRE.

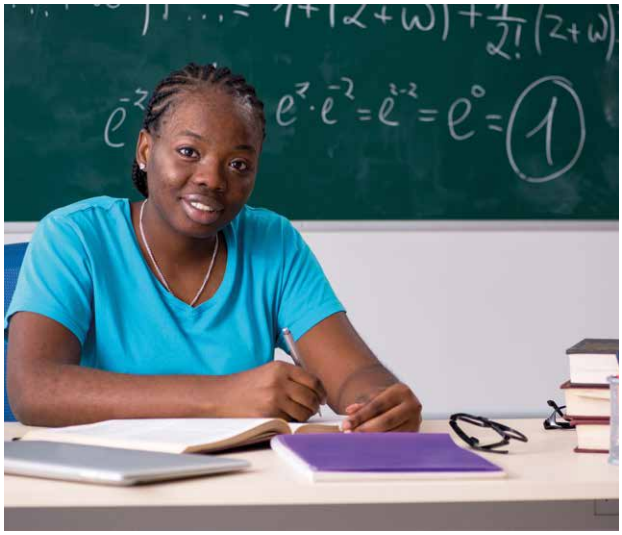
Another great resource is the AAPT K-12 Portal. Physics teachers who visit the K-12 Portal will find a wealth of information specifically designed for K-12 educators. For instance, K-12 teachers can read the AAPT report on how physics and physics education connect with the Next Generation Science Standards, or they can check out the collection of Digi Kits, which are hands-on, inquiry-driven activities that support student and teacher learning.

AAPT continues to develop more expertise in Policy and Advocacy work and has worked closely with the American Institute of Physics to strengthen these efforts. One great example of this effort, also on the K-12 Portal, is the Physics Master Teacher Leader Program, which recognises the role and expertise of teacher leadership and its potential for making major impacts on science education at the state and national level.

AAPT is also involved in a number of resources and programs that directly connect to students such as our work with the US Olympiad, the PhysicsBowl and the HS Photo Context. Each year, AAPT hosts a competition for high school students to represent the United States at the International Physics Olympiad Competition. The Olympiad is a nine-day international competition involving more than 60 nations. The PhysicsBowl is a contest for high school students that began in 1985, has always excited students and provides a great venue for students to review and test their physics knowledge. Photos of amazing physics phenomena always excite me and I always look forward to getting my calendar with the AAPT High School Photo Contest winners’ pictures. These pictures are an excellent example of how creativity, physics and art can complement each other and excite both scientists and non-scientists, who each bring a unique perspective when viewing these photos.

I really appreciate your question about how we help teachers derive the most benefit from these resources. I really think this highlights the importance of membership in a professional society and being part of a community. While Digi Kits are great, it is important to engage in workshops on how best to implement them and connect to a community where you can co-think and problem solve around effective strategies for implementation and sustainability. It’s so much more enjoyable, effective, and impactful when you are part of a learning community that shares common values and goals.

So, I think the AAPT best supports



members in utilising these resources by supporting connections within our community – this might mean engaging in workshops at national meetings, being part of our mentoring and alliance programs, having access to journal articles about a particular topic you are teaching, or connecting to an online learning community that is trying out the same instructional materials that you are trying. Effective teaching is incredibly challenging and it's important to have the support of a community.

Unfortunately, women continue to be severely underrepresented in physics, which is not only an equity issue, but also means that there is an untapped talent pool that could help in solving scientific challenges. What initiatives are AAPT involved in to increase the proportion of women who study and pursue careers in physics?

This is a major concern in the physics community and it's important that we push back on the common narrative that physicists are judged solely on their physics. We need to recognise that there is always bias and we need to acknowledge that the culture of physics is not always friendly. We also need to understand and value the contributions to science and physics from diverse communities. It's concerning that, although the number of women earning physics bachelor's degrees has increased over the last decade, the percentage of women earning these degrees has not increased.

As you mention, physics benefits greatly from diversity in who has access to physics and who does physics. We know that the physics and the physics education community benefit from diversity, but as we think about diversity in the field, we also need to think about inclusivity. If we don't create programs, classrooms and instruction that value all and invite all to participate then we won't be able to increase and sustain diversity in the field. To create these inclusive classrooms, physics educators need to understand the variety of obstacles that can impede success for women and underrepresented groups in physics, such as implicit bias and stereotype threat, and need to know how to hold members of our community accountable for actions that stifle the development of inclusive spaces. In a recent study that surveyed undergraduate female identifying physicists that participated in the annual Conference on Undergraduate Women in Physics, about 75% of those surveyed indicated that they experienced some form of sexual harassment during their academic career.

AAPT has a number of programs in place to support women in Physics. Two examples, that AAPT is a part of, are the eAlliances and the StepUp4Women projects. eAlliances is a National Science Foundation sponsored project that provides faculty development for women physics faculty and creates a peer-mentoring alliance with women who share similar values and experiences. The goal of StepUp4Women, also funded by the National Science Foundation, is to mobilise a large number of high school physics teachers to attract and recruit female students to physics-related careers using research-informed and field-tested classroom practice that improve female students' physics identity. Both these projects, focused on the college and high school level, respectively, are powerful ways we can support women in physics.

At the international level, AAPT has played a leadership role in the International Conference on Women in Physics, led by the International Union of Pure and Applied Physics. A number of AAPT members including our Executive Officer and current President Elect served on the US Delegation to the Sixth International Conference. This conference has resulted in a number of resources such as conference proceedings, HERStories which highlights female identifying physicists from around the world sharing personal knowledge and encouragement and also includes lesson plans, and the Gender Bias in Physics Forum which provides a space where women and people who are gender and sexual minorities can share experiences of gender and sexuality bias in physics, find resources, and report responses to bias.

These are broad collaborative efforts among many different people and professional societies. This is not work that professional societies can do alone – it's work that requires all hands on deck. AAPT recently joined the Societies Consortium on Sexual Harassment in STEMM which involves over 100 societies in science, technology, engineering, mathematics and medicine (STEMM). This is an excellent example of how societies can join forces to make STEMM a more welcoming place.

Many of the programs I described, such as the Societies Consortium on Sexual Harassment in STEMM, work toward changing culture and existing structures. It's problematic to encourage diversity in a culture that can be toxic to specific members of our community. This highlights the importance of thinking about diversity, equity, and inclusion together.

‘Supporting diversity, equity, and inclusion is one of four goals in AAPT’s new strategic plan – it is a goal that is a top priority for our membership, our staff, and our Board of Directors.’

As well as increasing female participation in physics, how are you working to achieve greater cultural, racial, sexual, socioeconomic and ability diversity, amongst both physics teachers and students? Describe one or two of your success stories.

AAPT recently released a policy statement on the importance of fostering safe and inclusive classrooms. This statement emphasises that ‘there is abundant evidence that a hostile environment places burdens and impedes success, disproportionately affecting those marginalised because of their identities. These communities include, people of colour, women, LGBTQIA individuals, those differently abled and those from lower socioeconomic backgrounds. The threat increases significantly for those with multiple historically excluded identities.’ Supporting diversity, equity, and inclusion is one of four goals in AAPT’s new strategic plan – it is a goal that is a top priority for our membership, our staff, and our Board of Directors.

In 2016, in the case of Fisher v. University of Texas, Chief Justice Roberts asked, ‘What unique perspective does a minority student bring to a physics class? I’m just wondering what the benefits of diversity are in that situation?’ The AAPT Committee on Diversity in Physics offered a powerful response to this question and affirmed the following: *(1) Racism and sexism exist in physics and physics education; (2) Homogeneity in physics is the by-product of racism and sexism; (3) Affirmative action is an important countermeasure to institutional racism and sexism in physics; (4) Making physics more inclusive and supportive of women and people of colour is important and necessary for doing the best possible physics; (5) Increasing diversity is a matter of justice; and (6) Women and people of colour do not need to justify their presence in physics classrooms.*

We have made a number of efforts in our community to foster inclusive spaces in Physics, whether it is at our national meetings or in the classrooms of our members. For instance, at our meetings we always have an LGBTQ meetup that is free and open to all. This is an opportunity for members of the LGBTQ community to have a safe open space to gather. At our recent meetings we have provided membership with free workshops throughout the meeting that focus on topics such as implicit bias, active bystander intervention, ally skills training, and racial microaggressions. These sessions have been well attended and membership has indicated that they greatly value opportunities to engage in these difficult discussions. We are also seeing that the number of sessions that focus on diversity, equity, and inclusion at our meetings has grown significantly and attendance at many of these sessions is often standing room only.

Our national meetings that occur in the winter and summer are one of the most valuable aspects of AAPT membership. This is often the place where physics educators learn about the cutting-edge efforts in instructional reform, it’s a place where practitioners can engage in interactive workshops, it’s the place to hear internationally renowned plenary speakers, and it’s the place to develop community and network. Because of this, it’s important to make sure these meetings are accessible to as many members as possible.

While our K-12 and Two Year College Day provide access to local educators, we also have funds to support travel for our diverse membership who sometimes have less funding resources or are juggling family commitments. Dependent Care and Disability Grants can be used to cover childcare costs and elder-care costs, as well as provide support to our members with disabilities to bring a caretaker to a national meeting or otherwise support their needs.

Our Special Projects and Philanthropy Committee has a dedicated fund to support travel for high school and TYC faculty who are from underrepresented groups or from institutions whose students are predominantly underrepresented. Both these funds help take some of the financial burden off traveling to the national meetings and help our membership not have to choose between family responsibilities and integration with their professional community.

Climate change and other forms of environmental degradation are perhaps the greatest challenges facing humanity, and today's science students will be key in building a sustainable future. Please tell us about how you are helping to prepare and encourage today's physics students in this regard.

Our membership is quite interested in this topic and in our recent meetings we have had a number of sessions and plenary speakers who have tackled the science of climate change and environmental challenges, as well as discussed best practices on how you might bring this topic into a classroom.

One great example is the work of our Committee on Physics in Two Year Colleges who organised a session at our San Diego meeting on climate change that involved speakers talking about clouds in a changing climate, evidence for global temperature change, and building climate intuition through classroom demonstrations. Our plenary at that meeting was Lynne Talley, a Distinguished Professor of Physical Oceanography in the Climate, Atmospheric Sciences, and Physical Oceanography division at Scripps Institution of Oceanography.

At the following meeting we had David W. Cash as our plenary. He is the Dean of the John W. McCormack Graduate School of Policy and Global Studies at UMass Boston and a founding Dean of the Sustainable Solutions Lab. In his talk, he focused on how science, scientific research, the science-policy interface, science education and scientific literacy are 'being defined, re-defined, re-cast, transformed, re-imagined, and re-conceived'. He spent much of his talk focusing on the work of the Environmental Protection Agency and the 'turbulent world we as science educators and practitioners find ourselves in'.

AAPT is a society partner in a Project Kaleidoscope Project focusing on better preparing students to relate to real-world issues such as energy, air and water quality, and climate change. This project has resulted in interesting resources on sustainability and the connection to physics. The topic of climate change is especially exciting because, in addition to being a contemporary issue, it also brings in a diverse set of disciplines. Incorporating interdisciplinary work into STEM instruction is a challenging, crucial direction we need to focus more resources on. AAPT has just launched a new books program and we would love to have contributions on how best we can bridge climate and environmental science to physics through interactive, research-based instructional materials.

We are finding that the world is changing rapidly: scientifically, technologically, and politically. It's crucial for professional societies, such as AAPT, to stay informed of these trends, listen and respect the views of our members, and provide essential information and resources to support our diverse communities of educators in navigating the always-changing instructional landscape. The best way to navigate this is through a community that shares similar values.

When you look at the diverse variety of AAPT activities, you see that the value in the organisation comes from its members, their expertise, and their service to their students and the broad community of physics educators. The ways in which AAPT supports our mission to 'enhance the understanding and appreciation of physics through teaching', continue to evolve as the organisation changes and the world changes.

www.aapt.org

AAPT
PHYSICS EDUCATION

DIVERSITY IN STEM

ENHANCING DIVERSITY TO STRENGTHEN THE STEM WORKFORCE

Humanity's greatest challenges, including climate change, pollution, energy shortages, food insecurity and antibiotic resistance, can be most effectively tackled by competent scientists and engineers. Therefore, as these threats continue to escalate, there is an urgent need for a strong and diverse STEM workforce. Unfortunately, the number of young people who are choosing to pursue STEM-related careers is not adequate to meet this growing demand for scientists and engineers.

So, why are so few students choosing to enrol in STEM degrees? Misconceptions held by young people and their parents about the types of people who 'fit in' in to the STEM community represent one major obstacle, with many people perceiving STEM careers as being for white, middle-class men. This perception is borne from long history of women and people from minority groups being actively excluded from scientific disciplines. The present dearth of diversity within the STEM community continues to exacerbate the issue, as many young people have no relatable role models to inspire them to pursue science or engineering.

Then, once enrolled in a STEM course, underrepresented students are often subjected to both conscious and unconscious bias from their peers and mentors. Such bias can lead to feelings of isolation and low confidence, resulting in poor academic performance and 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 pursuing STEM overall. Furthermore, homogeneity within the scientific community stifles scientific innovation.

In contrast, a STEM workforce rich in diversity, in terms of gender, ethnicity, culture, age and socioeconomic background, is essential for achieving true excellence in science. By combining the widest possible range of backgrounds, perspectives and experiences, diversity creates greater potential for thinking outside of the box and for driving forward new ideas.

Therefore, this section in the edition introduces several fantastic initiatives, aimed at both inspiring young people from diverse backgrounds to become interested in STEM, and supporting underrepresented students on their journey to careers in STEM.

In the first article of this section, we discuss *Voice of the Sea*, a science TV series aimed at people who would not typically be reached by traditional science outreach. By showcasing scientists of different ethnicities, cultures, genders and ages, *Voice of the Sea* aims to expose viewers to diverse voices and career paths in marine science. The show's producers hope that this will inspire young people to pursue careers in marine science, where there is an urgent need for a strong workforce to protect the ocean's threatened ecosystems.

Also providing relatable STEM role models is Soapbox Science, an amazing science outreach initiative that takes female scientists out of the lab and onto the streets, to talk to the public about their research. The second article of this section is authored by Dr Nathalie Pettorelli, co-founder of Soapbox Science, who explains how their popular outreach events inspire girls to pursue STEM careers.

The next article of this section also describes a fresh and innovative approach to science communication. Bright Club is a variety night that features researchers alongside professional comedians. In this opinion piece, Bright Club's organiser, Dr Jessamyn Fairfield, explains how these events aim to highlight the funny side of science, with all of its messiness, surprises and setbacks. By showing this human dimension of research, Bright Club's mission is to make science and scientists relatable to its diverse audience.

From here, we move on to highlight two amazing initiatives focused on introducing children from diverse backgrounds to the world of STEM, inspiring and empowering them to pursue further study in these areas. In the first of these, we meet Dr Jerrod Henderson and Ricky Greer of the University of Houston, who have developed an after-school academy to motivate underrepresented boys to become the next generation of scientists, engineers and mathematicians. The program

seeks to foster engagement by combining learning with interaction from students' parents and underrepresented STEM professionals.

In addition to children from underrepresented minority backgrounds, those from rural communities and low-income families are also faced with many obstacles when it comes to pursuing STEM fields of study. Therefore, Dr Susan Assouline, Dr Lori Ihrig and their colleagues at the Belin-Blank Center have developed the STEM Excellence and Leadership program. This academic program allows gifted students from low-income and rural families to take extra classes in math and science outside of school hours, putting them on a more equal footing to their urban, high-income counterparts when it comes to applying to university.

When the time comes to enrol in a STEM degree at university, many rural youths in the US lack the financial resources required. Addressing this issue is Dr J. Reid Schwebach and his team at George Mason University, who we meet in the next article. Here, we showcase the team's Rural and Diverse Student Scholars (RADSS) program, which seeks to remove the financial obstacles and other issues that rural youth face when pursuing studies and employment in STEM-related fields.

Another major hurdle that rural youth face when pursing higher education is the long distances between their homes and universities, which are typically situated in cities. While urban college students can often save the cost of accommodation by living with their parents and attending local universities, this is not an option for their rural counterparts. Therefore, one solution to providing equitable education is to increase the uptake and quality of online third-level education, such as that provided by the Open University.

Our next featured project does exactly that. Here, we showcase the SOONER research program, which aims to improve the quality of online learning, and tackle the negative perceptions about this education format. Ultimately, this project is about ensuring that more people have access to high quality and affordable education.

Next, we highlight Oregon State University's STEM Leaders program, which seeks to improve the success, retention, and persistence to graduation of underrepresented minority students in STEM disciplines. Such disadvantaged students are more likely to drop out of third-level education than their privileged counterparts, due to financial strain, low confidence and inadequate support networks. Students enrolled in the STEM Leaders program have the opportunity to engage in their own research projects, and present their results at meetings. These experiences have previously been shown to enhance students' engagement and confidence, and provide them with invaluable skills for future careers in research.

Undergraduate research experiences are also at the core of our next featured project. Here, we meet interdisciplinary researchers at Georgia Gwinnett College, who increase student engagement in STEM courses through embedded research experiences. Their goal is to increase the retention and graduation rates of students in STEM subjects and to support underrepresented students in their pursuit of research careers.

In addition to embedded research experiences, our next featured program, ASCEND, provides undergraduate students with leadership and networking opportunities, as well as the requisite training and support to become 'research entrepreneurs'. Just as entrepreneurs conceive business ideas, seek funding, and lead their ideas to fruition, successful researchers come up with research ideas, compete for funding, conduct their research, and disseminate the findings. To help undergraduate students to foster an entrepreneurial mindset, the ASCEND team has developed the Entrepreneurial Research Training Model, which provides a straightforward pathway for how to become research entrepreneurs.

In our next article of this section, we meet Dr Elahé Crockett and her colleagues at Michigan State University, who have developed the 'Research Education Program to Increase Diversity in health researchers' (REPID) program. REPID's aim is to train students from underrepresented, minority and disadvantaged backgrounds in the basic and advanced biomedical sciences. The goal of the program is to overcome the lack of diversity in biomedical research and clinical practice, to ensure a strong biomedical workforce in the future, while also reducing the stark inequality in this field.

Although biomedical science has a significant way to go in terms of achieving a diverse workforce, the field of physics has an even longer road ahead. For instance, in the US, women of colour received less than 4% of all physics degrees between 2004 and 2014, despite constituting 22% of all US citizens and permanent residents aged 18–24. To address this worrying statistic, Dr Apriel Hodari at Eureka Scientific and Dr Angela Johnson of Saint Mary's College of Maryland have been working on strategies to remove the obstacles that women of colour face in their pursuit of education and employment in the field of physics. Their solution involves significant cultural change within an institution, catalysed by strong leadership at the top.

VOICE OF THE SEA: INNOVATION IN SCIENCE COMMUNICATION

Communicating science to the public is a difficult undertaking; communicating it in a way that encourages people to change their behaviour is a rare achievement. With her television series *Voice of the Sea*, **Dr Kanesa Duncan Seraphin** has produced an innovative program that connects viewers with ocean science and scientists and encourages them to take action to protect our seas.

Reaching a Wide Audience

One of the greatest challenges in science communication is reaching the widest audience possible. It takes creativity to share often complex concepts in ways that connect with a broad audience. It also takes resourcefulness to package information in a form that has the potential to reach a large number of people, particularly when the desired demographic extends beyond those who would normally seek out science content.

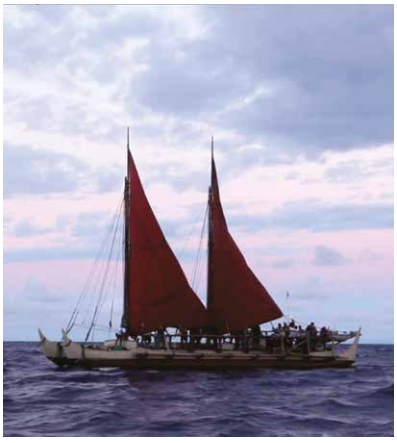
Both in print and online, science content is primarily accessed by people who either already enjoy learning about science or who are looking for specific information. When the goal is to drive community-wide changes in conservation behaviour, researchers need a platform that reaches the entire community. For University of Hawai'i (UH) professor and marine biologist, Dr Kanesa Seraphin, that platform is television. As producer and host of the television series *Voice of the Sea*, Dr Seraphin is using an ideal medium to share ocean science with her community and beyond.

A Fresh Take on Ocean Science

Voice of the Sea provides entertaining and informing marine science content that is not only relevant to Hawai'i residents and visitors but also encourages eco-friendly relationships with the ocean. Each episode revolves around a specific topic and features scientists, cultural leaders, public servants, or other ocean experts, sharing their research, knowledge, and relationship with the sea.

The series covers topics ranging from reef fish migration, to nutrient cycles, to unusual deep-sea creatures. *Voice of the Sea* makes a strong effort to explore lesser-known habitats, plants and animals, rather than focusing solely on large, charismatic species, such as whales and sharks. This approach helps to foster an appreciation for the broad complexities of marine ecosystems as a whole.

One of the series' primary aims is to help viewers identify and engage in behaviours that support healthier oceans and beaches. 'We are partnering with researchers to engage viewers in specific behaviours, such as water conservation and the preservation of nesting bird habitat,' Dr Seraphin explains.



'*Voice of the Sea* shares stories of scientific, environmental, and cultural work in local contexts. The series expands viewers' perceptions of how and by whom research is conducted, providing career connections and engaging the community in societal issues.'

Episodes also feature specific behavioural goals, such as avoiding disposable plastic containers, respecting seaside vegetation, choosing to eat at ocean-friendly restaurants, and finding value in the science, environment and culture tied to the ocean. As viewers learn about the balance of the ocean's ecosystems, they also learn about ways they can help preserve and protect it.

The 30-minute series began airing weekly on Sundays on a local Hawaiian channel in 2014, after Dr Seraphin and colleagues received institutional support from the UH Curriculum Research & Development Group and the UH Sea Grant College Program, which is dedicated to innovative marine science programs. Now in its fifth season, the series airs twice a week in Hawai'i and is also broadcast across numerous US territories in the Pacific.

Voice of the Sea is available to approximately 90% of the Pacific region's 1.8 million people, and episodes are available online, further increasing the series' potential reach. The series has also partnered with educational venues in Hawai'i, where it is played in exhibits, and clips are incorporated into the Exploring Our Fluid Earth (grade 6-12) and Sea-Earth-Atmosphere (grade 3-5) ocean science curricula, which provide free educational content online.

Engaging Viewers Across Demographics

As it has grown, *Voice of the Sea* has become a true science communication success story. Targeted at community members that would not typically be reached by traditional science outreach, the series is bringing marine knowledge to a wide audience, including a loyal following of Hawai'i residents. In questionnaires, viewers of all ages have indicated that watching an episode not only increased their understanding of and interest in the topic, but also increased their interest and likelihood to adopt suggested behaviours that support ocean health.

A viewer survey indicated that approximately 25% of the series' audience plans to engage in suggested actions, demonstrating that the series has potential to positively impact its viewers. The series is now seen as a trusted source of marine science and over the past four years has received 16 national Telly Awards for outstanding regional television programming. The series is such a shining success that Dr Seraphin has been invited to join the 2019 Telly Awards judges panel.

The series' quality is made further evident by its growing viewership. When *Voice of the Sea* first took to the air in 2014, it was watched by roughly 2,500–5,000 people per week in Hawai'i. In 2016 that number had grown to 8,000–10,000 weekly viewers, and in 2017 the series experienced massive growth, jumping to over 27,000 people watching the initial weekend airing. With at least four re-runs for each episode, it is estimated that over 100,000 people view each episode in Hawai'i alone. Further, each week the series also runs 30-second TV promos that are both enticing and informative, providing information even to people who never watch the full episode. Partner TV station broadcasts in the outer Pacific increase the series' potential reach by another 300,000.

Since *Voice of the Sea* was added to YouTube in March of 2017, it has garnered over 3,000 subscribers and 251,000 views. The series' online growth has been completely organic – no marketing has been employed to gain this online following. Dr Seraphin and her team have only recently begun exploring ways to market the series online, such as Facebook ads, and are working to develop a strategic marketing plan that can maximise this innovative science program's reach around the globe.

Dr Seraphin explains that, 'we would like to grow our TV audience into new markets and to grow our online audience in various platforms and formats.' As the series finds new viewers, the *Voice of the Sea* team hopes to increase understanding of marine environments and help viewers identify ways that they can help keep the ocean a little healthier.

Showcasing Diversity in STEM

Beyond the difficulties of effective science communication, another key science challenge currently facing the United States is finding ways to increase enrolment and diversity in science, technology, engineering and mathematics (STEM) careers. Students' choice of major when entering university studies is often limited by their awareness and perception of available professional options within a field.

Ocean science, particularly in areas of oceanography, physics and engineering, struggles to recruit a diverse range of students, due to factors that include (1) lack of scientist role models, (2) limited availability of career guidance from adults who are knowledgeable about ocean science careers, and (3) conceptions about scientists that don't match students' own culture or demographic. Public perceptions of scientists in general are flawed, with scientists commonly viewed as unrelatable and unbelievable.

Moreover, the portrayal of STEM professionals on network TV often does more to solidify stereotypes and misconceptions about scientists than it does to break them. Medical and criminal dramas frequently rely on situational plot twists or unnecessarily glamorised lab tests rather than hard data and logic to solve cases, inaccurately representing much of the science performed and portraying results as open to interpretation.

At other times, the science presented is entirely made-up, with lasting negative effects on viewers' perceptions of scientists and the process of science itself – as in the 2013 fake stories of Megalodon on Discovery and the 2012–2013 mermaid mocumentaries on Animal Planet (which represented both series' most watched episodes to date). Further, STEM TV characters are seldom diverse, with the majority portrayed as older white men or sexualised young women. As such, the limited representations of STEM portrayed on television do little to aid in closing the diversity gap in science.

On the other hand, when purposefully constructed, exposure to STEM careers through video and TV can enhance public awareness of what scientists actually do and can encourage students to pursue STEM careers. Showcasing scientists of numerous cultures, ethnicities, age and gender increases STEM interest in diverse populations. Thus, another major goal of *Voice of the Sea* is to expose viewers to diverse voices and career paths in ocean science and to provide grounded perspectives of marine science and related professions. The series aims to show that science can be engaged in by people of all combinations of ages, genders, ethnicities, cultures and levels of education.

The series' hope is that by demonstrating the diversity in ocean researchers and promoting real-life heroes, they can stimulate the next generation of scientists to be even more diverse. Dr Seraphin describes how, '*Voice of the Sea* expands viewers' perceptions of how and by whom research is conducted, providing career connections and engaging the community in societal issues.'

In a recent questionnaire study, Dr Seraphin's team found that viewers of the series expressed affinity for the experts featured, suggesting that episodes are successful in showcasing scientists as relatable and enjoyable people.

Full Steam Ahead

Voice of the Sea has become a beacon of science communication and outreach for the people of the Pacific, and Dr Seraphin and her team plan to leverage the series' current success for an even greater future. As they attract funding from sponsors, the team is planning to expand creative marketing and research efforts to not only reach more people but also to identify even more effective ways to communicate topics and encourage viewers to take action.

'We are looking to tell new stories in more engaging ways and to better the technical and artistic aspects of the series,' Dr Seraphin describes. 'We are working to increase audience engagement and to better understand the extent to which viewing *Voice of the Sea* influences knowledge, attitudes, and behaviour.'

Meet the researcher

Professor Kanesa Duncan Seraphin
Hawai'i Sea Grant College Program
Center for Marine Science Education
School of Ocean and Earth Science and Technology
University of Hawai'i at Mānoa
Honolulu, HI
USA

Dr Kanesa Seraphin is a professor with the University of Hawai'i (UH) Sea Grant College Program, in the School of Ocean and Earth Science and Technology, at UH Mānoa. She is also Director of the Sea Grant Center for Marine Science Education as well as the producer and host of the *Voice of the Sea* television series. In addition to a BS in biology, MS in zoology, and PhD in zoology studying scalloped hammerhead sharks, Dr Seraphin has received a post-baccalaureate education certificate in secondary science education, and a secondary science credential for the state of Hawai'i. Her work focuses on making ocean science education accessible to everyone, through her television series, free online curriculum and citizen science projects.

CONTACT

E: kanesa@hawaii.edu
W: voiceofthesea.org
@voiceoftheseatv

KEY COLLABORATORS

TV stations: KFVE/KGMB/KHNL (Hawai'i), KVZK (American Samoa), KUAM (Guam), OTV (Palau and Micronesia)
UH News, UH Communications
Currriculum Research & Development Group (CRDG), College of Education, University of Hawai'i at Mānoa
Kauai Sound and Cinema Media Corp.

FUNDING

National Oceanic and Atmospheric Administration
National Science Foundation
Hawai'i Community Foundation
Disney Foundation

FURTHER READING

K Seraphin, J Philippoff, T Seraphin, Using TV to Teach Ocean Science and Promote STEM Careers Across the Pacific: *Voice of the Sea*, Current, 2017, 31, 30–35.

CLOSING THE GENDER GAP IN SCIENCE

Opinion article by Dr Nathalie Pettorelli of Soapbox Science and ZSL (Zoological Society of London)

The Need for Female STEM Ambassadors

If you were to believe many advertising companies designing toys, T-shirts and science lab kit packaging, science isn't attractive to girls. Yet, in the UK alone, 50% of Science, Technology, Engineering and Mathematics (STEM) enrolments, including medicine, are female postgraduates and undergraduates, with 61% of biological science and 79.4% of medicine undergraduates being women.

The thing is, few of these women make it to become visible ambassadors for STEM professions, with most UK adults being unable to name a single living female scientist. Many of these graduates end up working outside of STEM: although women represent 47% of the UK workforce, only 13% of the STEM workforce is in fact female. Academia is a significant STEM employer in the UK; however, for those STEM female trainees who choose to work in academia, prospects of securing a high-profile position are low. For example, less than 20% of full-time STEM professors are women.

Is the lack of visible role models for women in science a problem? The short answer is yes, very much so. The lack of visibility continues to support the spread of stereotypes about science being a boy thing. For instance, a majority of parents hope for their sons to become engineers, scientists, professional sportsmen or tradesmen, while expecting their daughters to become teachers, nurses, fashion designers, doctors and hairdressers. This lack of visibility may also contribute to girls as young as six years old being less likely than boys to believe their own gender is the most brilliant.

Interestingly, the lack of visible women in science can moreover influence how the public perceive experts and information and the extent to which the public trusts the message delivered. For example, research suggests that women are more trustworthy than men and that women are more likely to trust and value information from women's communities.

On the other hand, visible role models can have a massive impact on self-confidence and career choice, with research showing that the number of girls interested in STEM almost doubles when they have role models (41%) compared to those who do not (26%). This means that visible role models can play a part in helping to close the global gender gap in the STEM workforce, thereby helping to address the shortage of qualified individuals needed to meet the burgeoning demand of technology jobs. By failing to develop and retain the talents of half of the world's population, economies around the world indeed miss out on a major growth opportunity.

Soapbox Science

So, how do you improve the visibility of women in science, and thereby provide the much-needed role models to girls around the world interested in STEM? The solution that Seirian Sumner and I came up with years ago is to bring women scientists directly to the general public, in places where they don't expect to see them, giving everyone a chance to strike up a conversation, ask questions, and realise that both men and women can advance knowledge, revolutionise the ways we do things, and push the limits of what humanity is capable of.

In 2011, we set up Soapbox Science as an annual public science communication event with a difference. By taking cutting-edge

‘By taking cutting-edge female scientists to busy streets and shopping centres, we transform public spaces into an arena for learning, exploration and scientific debate.’

female scientists to busy streets and shopping centres, we transform public spaces into an arena for learning, exploration and scientific debate. Our events are sustainable, cheap, highly reproducible, and flexible. Their common aim is simple: inspire people who never normally get exposed to science, and tackle stereotypes about what scientists look like.

For the past nine years, Soapbox has evolved from a localised initiative to a global phenomenon; this year, events will take place in 19 cities across the UK, as well as in 13 countries around the world including Canada, Germany, Tanzania, Nigeria, Ghana, Brazil, Australia, Argentina and the USA, making it the biggest set of annual events to date. The call for speakers closed a few weeks ago, with >900 women having applied to speak at one of these events.

A Vehicle for Change

Importantly, Soapbox Science isn’t just about organising events and putting women on soapboxes: the initiative is used to bring local organisers, speakers and volunteers together, helping connect scientists who may not know about each other, train participants in science communication and help them grow their confidence in public speaking, share experiences and tips about how to build a career in science, and improve the visibility of women in science and the work they do in their home institutions as well as in the media.

It’s a fantastic vehicle to talk about science and ethnicity, socio-economic background and social mobility, disability, sexual orientation and gender perception. It’s a place where issues such as the two-body problem, the impostor syndrome, stereotypes, or the Matilda effect can be discussed. Soapbox connects potential mentors with mentees, investigators with co-investigators, supervisors with students and reviewers with writers. Soapbox is thus, first and foremost, a social enterprise aimed at promoting overall diversity in science.

Soapbox Science is only one initiative among the many that are trying hard to promote and build a more diverse scientific community. We hope that Soapbox plays a role in acting as a vehicle for change in addressing the detrimental effects of gender bias in scientists’ visibility, as well as boosting the confidence of female scientists and their profiles among their peers.

However, much more is needed to address the cultural beliefs and stereotypes that underpin the gender gap in STEM. Only when it is socially acceptable for men and women to have an equal chance of staying in STEM, taking a career break or adopting a flexible work schedule, will women no longer be the largest component of the sunk cost in science.

CONNECTING SCIENCE AND SOCIETY THROUGH COMEDY

Opinion article by Dr Jessamyn Fairfield, of the National University of Ireland, Galway

Science's Funny Side

Sometimes, science can feel like a joke. Experiments don't work, simulations produce physically impossible outcomes, and a question that you thought would take two weeks to answer instead can take two years. All too often we hide the messiness of science, presenting progress as linear rather than admitting the missteps and follies along the way. But surprises and setbacks shape the story of science as a human endeavour, and if we are unwilling to share this side of science, to laugh at ourselves, we risk alienating society from science altogether.

You might be thinking, but science isn't funny, it's an important and serious business! In my view, that is exactly why we should find the humour in it. Scientific progress saves lives, and technological advances improve quality of life across the globe. This means that public understanding of and participation in science has never been more important, especially as scientific issues such as climate change and energy usage increasingly impact politics and people worldwide. Research in education tells us that playful approaches to learning information can actually aid in retention and understanding, so educators now encourage learners to generate their own content on a topic – to be able to tell a story. Or write a joke.

What is a joke, after all, but a surprising reversal, a change in viewpoint that completely reframes the information that came before? These sorts of reversals happen in science all the time, and scientists are used to having their viewpoints upended by new data. In fact, many of the skills that are important in science are also important in writing comedy: creativity, a willingness to upend the status quo, and indeed a subversive approach to authority in pursuit of a deeper truth.

But more importantly, consider the audience. When a person listens to a joke, they are waiting for the other shoe to drop and the punchline to be revealed: they are waiting to change their mind. In this era of polarised news and information bubbles, what other approach to communication of complex ideas could possibly be more powerful than comedy?

‘Surprises and setbacks shape the story of science as a human endeavour, and if we are unwilling to share this side of science, to laugh at ourselves, we risk alienating society from science altogether.’

Bright Club

It is this ethos that underlies Bright Club, a series of variety nights combining academic research and stand-up comedy. I have run Bright Club events in Ireland since 2015, training researchers from science, social science, and humanities and bringing them together with comedians and musicians for thought-provoking shows. The Bright Club format itself was pioneered in the UK by Steve Cross in 2009, and Bright Club events now take place in many European countries. Before each event, academics are trained in stand-up comedy techniques, a skill set which they often find useful in teaching and other science communication events.

In the 60+ events we have held in Ireland, which take place in informal spaces from pubs to music and comedy festivals, we have found an audience which is diverse and excited to hear from academics who reject the notion of the ivory tower. The interdisciplinary nature of the events helps connect science to the broader constellation of human knowledge, drawing in people from all walks of life.

We’ve also found that speakers who take part in Bright Club find comedy empowering: not only does it help them to communicate more accessibly, without jargon, but it helps them to communicate authentically, to find their own voices and their own unique perspectives on their own research. Participation in public engagement events like Bright Club often leads to a strengthened sense of agency and scientific identity, but the use of humour adds an extra level to this by allowing researchers to connect their professional selves to their personal selves. Audiences see researchers in their full humanity, and researchers often report that Bright Club is the first time they have felt that this humanity could be part of their work.

Science affects all of society, and hence it is of critical importance to bring researchers into public spaces to engage the public with what they do. Comedy is an invaluable tool for engagement, not least because the audience response adds the element of dialogue. Researchers report that the laughter and comments from the audience, as well as the process of writing jokes and reflecting on their own work, gave them new ideas and perspective on their research. And audiences reported great joy in hearing academic research presented so engagingly, in a fun setting, with a mix of different topics. Facts don’t speak for themselves – they need ambassadors. So, isn’t it time we all started taking ourselves a bit less seriously?

IT'S FULL STEM AHEAD IN AFTER-SCHOOL PROGRAMS

Underrepresented is not often the thought that comes to mind when describing males in science, technology, engineering and mathematics (STEM). However, there are striking gender and ethnic disparities across STEM fields as white males disproportionately occupy the sector in the US. In recognition of this, **Dr Jerrod Henderson** and **Ricky Greer** of the University of Houston developed an after-school academy to motivate underrepresented boys to become the next generation of scientists, engineers and mathematicians.

The Importance of Inclusive STEM Education

STEM is the fastest growing sector in the US economy, creating jobs that pay a higher wage relative to other sectors. STEM skills are vital for a healthy economy, but STEM employers are increasingly requiring at least a high school degree and other specialised skills. There is a stark ethnic divide as African Americans, Latinos, Native Americans and Pacific Islanders are underrepresented in STEM education and careers. The same is true of women and those with special learning needs.

For the sector to maintain innovation and growth, students from all backgrounds must learn the skills and expertise necessary to pursue a STEM career. Research also suggests that workplaces benefit from diversity because diverse teams bring multiple perspectives to the table and boost creativity. This is particularly relevant to the STEM sector because it thrives on turning fresh ideas into technological advancements.

The Case for Early Intervention Among Males

Research demonstrates that the problem of underrepresented male persistence in higher education, especially STEM, is a result of systematic neglect that starts in childhood. For example, black males are overrepresented in special education, and are disproportionately disciplined in school. Interventions during a student's teenage years might not be enough to reverse the trend of underrepresentation, as research suggests that student interest in science is high at 10 years old. Therefore, early exposure and engagement is likely to be a key intervention for developing interest in STEM careers.

STEM Academy Overview

In 2013, Ricky Greer and Jerrod Henderson created the St. Elmo Brady STEM Academy (SEBA) in Illinois. The academy targets fourth- and fifth-grade boys to combat the growing disinterest in STEM fields that traditionally occurs at that age. Two participating elementary schools nominated boys

that they felt could benefit from the academy. Both schools have similar diversity profiles – one of the schools is a STEM Magnet School, and the other is a typical elementary school.

The goals of SEBA are to expose, engage and empower underrepresented male students, and to motivate them to become the next generation of scientists, engineers, and

mathematicians. Students engage in SEBA activities three times each week, on a Saturday and two weekdays, for 16 weeks over the course of two school semesters. Students participate in the program for 75 minutes after school, and for two hours on Saturdays.

A typical week at the academy begins with a warm-up discussion from a professional in the STEM field, followed by a themed activity. It is then concluded by a review and reflection of the week's activities. An important aspect of the program is allowing students to learn-by-doing through partaking in hands-on experiments. The educators maintain engagement among the young learners by encouraging exploration and inquiry. Learning is not restricted to the classroom, as the educators also organise field trips that allow students to visit university labs, museums, and engineering open houses.

Role Models as Sources of Inspiration

The program seeks to foster engagement in STEM subjects by having students combine learning with interaction from their parents and other mentors. STEM professionals from underrepresented groups interact with the students each week and act as relatable role models. On Saturdays, fathers or other relatives of each student enrol in the academy, and are invited to actively participate in the program and conduct experiments alongside their children. In a typical week, the number of male role model attendees varies from five to ten.

Co-Founders (Greer and Henderson) have opened up opportunities to undergraduate and graduate students who are interested in volunteering as teaching assistants at the academy. Before the successful applicants are put to work, they first undergo training in classroom management, mentorship and teaching techniques. Undergoing a similar process, university students are selected to act as mentors for those elementary students that do not have relatives available to participate. Many of these student mentors are from the underrepresented groups that the academy targets.

Impact on Students

In the second year of SEBA, Dr Henderson, Greer and their colleagues measured the overall impact of SEBA by collecting feedback about the program design, implementation, content and outcomes from the school staff, parents, program coordinators, university faculty and participants involved in the academy.

The team collected student survey responses and conducted interviews during the final week of the program. The survey consisted of simple 'yes' or 'no' answers and follow up questions that allowed for explanation of the given answers. Of particular interest to the team is the impact of the STEM academy on student interest and engagement at school, career ambitions and confidence. 'Plainly put, we seek to understand how underrepresented fourth- and fifth-grade students (African American, Hispanic boys) become interested in STEM and the impact of fathers and mentors on those decisions,' explains Dr Henderson.

The survey results show that exposure to STEM activities in the academy increased engagement in STEM fields and confidence among boys to pursue future STEM education. Of the 24 boys surveyed in the final week of the program, 95.8% became more interested in science, 91.7% became more confident in their science and math classes at school, and 87.5% indicated increased participation in their science and math classes at school.

In the follow up questions, the boys explained that SEBA increased their participation in school classes and that the academy increased their confidence levels. One student stated that he 'didn't use to like science but when we did the activities at St. Elmo Brady [they] made me more confident to do it'.

A key feature of the SEBA program is the involvement of STEM professionals in educating the children on the career options available. Upon entering the SEBA program, 81.8% of students indicated interest in a STEM career, this increased to 87.5% at the end of the academy. One student praised this component of the program stating, 'I think the program helped me because you helped me introduce a part of what I wanted to do in life'.

Not only did the program increase interest among STEM fields, it also generated interest in specific STEM fields. For example, upon entering the program, a fifth-grade student indicated his interest in becoming an engineer, while on the exit survey he revealed interest in civil engineering and chemistry.

Because the boys and many of the professionals involved in the academy are both from underrepresented groups, the students were exposed to relatable role models working in STEM fields. A fourth-grade student in the SEBA program confidently exclaimed 'if they look like me then I can probably do what they did'.

The Importance of Fathers

During the program students learn a lot by engaging with their fathers. The exit survey at the end of the program's second year highlighted the important role of fathers during the boys' time at the academy, and their influence on student interest in science. 'The most important finding has been the impact of father engagement on participants in the program,' says Greer. 'It has been reported by participants that fathers help to cultivate their excitement and curiosity for STEM exploration.'

In the exit survey, 91.7% of students reported said they enjoyed and learned from having fathers involved with the program. Students commented on how the fathers involved acted as positive influences on their interest in science. Interestingly, the effect of participating fathers was not limited to their own child. For example, a fifth-grade student whose father did not participate in the program, indicated that the participating fathers, 'showed me how to act' in these types of environments.

The Academy's Ambitious Future

SEBA is now in its fifth year, and given the overwhelming success of the program, the team has big hopes for the future. Plans are in place to increase the number of students participating in the St. Elmo program, and to increase the amount of parental involvement. To facilitate these aspirations, the team is currently reaching out to benefactors for financial support and recruiting additional teaching assistants and mentors.

The team hopes that the approach they have developed is adopted by other locations, so that after-school academies are set up across the US.

Meet the researchers

Dr Jerrod A. Henderson
Cullen College of Engineering
University of Houston
Houston, TX
USA

Dr Jerrod A. Henderson is an Instructional Assistant Professor and Director of the Program for Mastery in Engineering Studies at the Cullen College of Engineering, University of Houston. Here, he is also Co-Founder of the St. Elmo Brady STEM Academy. He holds two BSc degrees, in Chemical Engineering and in Chemistry, an MSc in Chemical & Biomolecular Engineering, and a PhD in Chemical & Biomolecular Engineering. He joined the Cullen College of Engineering in 2016, after several years working as a Lecturer and Coordinator of design projects at the University of Illinois. While in university, he earned distinction as a NASA Harriet G. Jenkins Graduate Fellow. His research interests are in engineering identity formation and persistence among underrepresented students, especially African American males.

CONTACT

E: jahenderson5@uh.edu
W: http://firstyearexperience.egr.uh.edu/faculty/henderson

Mr Ricky P. Greer
Cullen College of Engineering
University of Houston
Houston, TX
USA

Mr Ricky P. Greer is a Co-Founder and Program Director of the St. Elmo Brady STEM Academy. He will soon complete his Higher Education MEd degree from the University of Houston. He holds a BA in History from Tuskegee University. Greer has a passion for helping students succeed at navigating the university experience. He strives to cultivate academic awareness, academic excellence and the development of leadership skills in students.

CONTACT

E: rickypgreer@gmail.com
W: www.linkedin.com/in/ricky-greer-5944a696

KEY COLLABORATORS

Mariam Manuel, University of Houston
Virginia Rangel, University of Houston
Blackshear Elementary School
Booker T. Washington STEM Academy
Garden Hills Elementary School
University of Houston Charter School

FUNDING

National Science Foundation, Award no. 1760311
Past funders: Chevron Phillips Chemical Company; Dr Francis Ihejirika; University of Illinois Urbana-Champaign Office of Public Engagement

PROJECT WEBSITE

http://stelmobrady.egr.uh.edu/

THE STEM EXCELLENCE AND LEADERSHIP PROGRAM

Recognising students with great potential and supporting them in their academic endeavours is of utmost importance, particularly for disadvantaged children from rural areas or low-income families. **Dr Susan Assouline** and **Dr Lori Ihrig**, at the University of Iowa's Belin-Blank Center for Gifted Education and Talent Development, which is part of the UI College of Education, have developed a program to support high-ability students in their transition to high school and completion of higher-level courses.

Recognising Gifted Children from All Backgrounds

While many perceive America as a land of opportunity, where all students can achieve great things irrespective of their background, statistics suggest that this is often not the case. In realty, factors such as parental income and the neighbourhood where a child is raised can have a significant impact on determining their academic progress and their chances of having a fulfilling career.

A 2014 White House report states that 'while half of all people from high-income families have a bachelor's degree by age 25, just one in 10 people from low-income families do.' Moreover, statistics suggest that compared to students from urban or suburban environments, rural students are far less likely to enrol in four-year post-secondary education courses. According to the National Center for Education Statistics, rural students in the US attend college at a rate of 29.3%, while the overall college attendance rate is 42.3%.

This education gap is not only profoundly unfair – it is also an enormous waste of talent. Often, the result is bright students giving up on their studies and ultimately failing to achieve their full potential.

Currently, approximately 60 million US residents live in rural areas, 13.4 million of which are children. Offering equal opportunities to this segment of the population and supporting disadvantaged students throughout their academic journey is of critical importance.

Therefore, Dr Susan Assouline, Dr Lori Ihrig and their colleagues at the Belin-Blank Center have been working on numerous programs and initiatives aimed at supporting students from low-income families and/or rural environments in their studies and professional endeavours. One of these is the STEM Excellence and Leadership program, an academic program that allows gifted students from low-income families to take extra classes in math and science outside of their standard school hours. STEM Excellence and Leadership includes a professional development component.

The Program

Past studies suggest that students who develop positive identities around science, technology, engineering and math (STEM) subjects are more likely to pursue further education and careers in related fields.

The STEM Excellence and Leadership program offers additional learning opportunities to disadvantaged students, which could enhance their skills, confidence and preparation, ultimately encouraging them to pursue further studies and careers in STEM-related fields. 'The STEM Excellence and Leadership program is a way for us to ensure that high-ability students in our rural communities are prepared to pursue advanced studies in STEM fields,' says Dr Ihrig. 'What we hope to do is lay the groundwork for their future success. We are deeply engaged with 10

‘The STEM Excellence and Leadership program is a way for us to ensure that high- ability students in our rural communities are prepared to pursue advanced studies in STEM fields.’

rural school districts across the state. Being able to have school-university partnerships allows us to reach more students to fulfil our mission.’

From 2003 to 2009, STEM Excellence and Leadership, which was initially funded by Federal Funds for the Improvement of Education, ran as a pilot program in five rural Iowa school districts. In 2014, the program was revitalised and expanded through a Talent Development Award from the Jack Kent Cooke Foundation to include 10 new rural districts in the state of Iowa. Subsequently, the program has continued to broaden its impact through a US National Science Foundation (NSF) Advancement of Informal Learning Sciences (AISL) grant. Within three years of its inception, over 500 high-ability middle school students had taken part in the extracurricular classes provided by the program.

‘The STEM Excellence and Leadership program is positioned to break down barriers and foster rural students’ developing identities as students with high STEM interest, exceptional potential to succeed, and social-emotional resilience when facing challenges,’ says Dr Assouline.

Extracurricular Classes for Gifted Students

The STEM Excellence and Leadership program is aimed at increasing students’ aspirations, knowledge and abilities in STEM disciplines. It particularly targets high-achieving students in 5th to 8th grades who come from rural areas, supporting them in their science and math learning. ‘In rural school districts, students don’t have the same opportunities available to them because of rurality,’ says Dr Ihrig. ‘This is an extracurricular program that operates mostly outside of the school day with students taking math and science courses before and after school.’

As part of the program’s selection process, disadvantaged middle school students in the 85th percentile, or above, complete a fairly challenging assessment as part of the identification process. In addition, teachers and parents can nominate other students who they believe would benefit from the program. ‘Collecting all the data together, the district determines who this program may be a good fit for and sends invitations to participate in the program,’ says Dr Ihrig.

Students participating in the program spend a total of 96 hours each school year taking additional science and math classes. These classes include both theoretical and practical learning experiences, which are designed to enhance students’ engagement and understanding of STEM-related topics. For instance, the students might be divided into small teams and asked to conduct investigations that incorporate advanced engineering and science concepts.

Teachers at schools involved in the program receive extra funding to purchase science and technology equipment or resources, such as supplies for experiments or classroom projects. Once a year, they are also invited to tour the UI campus along with their students. During these tours, rural students enrolled in the program can visit the science labs on campus and meet college students specialising in STEM subjects.

Evaluating the Program

So far, the STEM Excellence and Leadership program has yielded highly promising results. Although the program is relatively new, feedback from participating students and teachers has been overwhelmingly positive.

'I love being in STEM because I believe it is helping set me up for my future career path,' said one of the students who participated in the program. 'It teaches so many things while also being fun. I am so thankful that my school is able to have a STEM program and I hope it continues not only for me but also other students to come in the future.'

Teachers at participating schools have collected and examined their students' test scores, to document their performance in STEM subjects. Andrea Reilly, a science teacher at Atlantic Middle School, observed notable improvements in her students' scores on I-Excel, the main assessment tool for program identification, and ACT, a standardised test used for college admissions, which is administered to junior high students as a post-program instrument.

'I've seen some students make 180-degree turnarounds in terms of their classroom attitude and behaviour,' said Reilly. 'The program gives them access to opportunities they wouldn't have otherwise, as there are less resources in rural areas compared to cities. I have parents ask me how they can get their kids into the program. It's seen as a tremendous asset.' According to Reilly, the extra classes provided to participating students are a chance for them to build relationships that they would not develop in ordinary classrooms. Outside these classes, the students also benefit from one-on-one time with their teachers.

Atlantic Middle School's principal, Josh Rasmussen, feels that the program has helped students to recognise the benefits of college education from an early age. For instance, it has prompted greater conversation about the classes that they would like to take in high school, in order to meet college entrance requirements.

Supporting Students Throughout their Academic Journey

The STEM Excellence and Leadership program is a remarkable example of how academic institutions can support gifted children from all backgrounds in realising their full academic and professional potential. With the recent grant awarded by the NSF, Dr Assouline, Dr Ihrig and their colleagues hope to strengthen the impact of the program by examining its strength and limitations.

'The NSF is counting on us to build on our expertise in student programming, professional development and rural education to offer a template for other professionals involved in after-school programming,' says Dr Ihrig. 'We want to understand what threads of commonality exist among districts, including aspects that are unique and effective as well as those that pose special challenges. Talent in our rural communities is too important to neglect.'

According to Dr Assouline and Dr Ihrig, initiatives such as the STEM Excellence and Leadership program could help to significantly reduce the current disparities in education. In the future, their program could inspire other academic institutions to invest in new generations of gifted rural students, paving the way towards equal opportunities in education.

'You can compare increasing students' interests and aspirations to running a marathon,' adds Dr Ihrig. 'If you motivate and excite people to run a marathon, but don't prepare them for that task, you can imagine how they will not be successful.'

Meet the researchers

Dr Susan G. Assouline
Director
Belin-Blank Center
University of Iowa
Iowa City, IA
USA

Dr Susan Assouline is the director of the UI Belin-Blank Center for Gifted Education and Talent Development. She holds the Myron and Jacqueline N. Blank Endowed Chair and is also a professor of school psychology. One of her key research interests is twice-exceptionality, particularly gifted students with autism spectrum disorder or with a specific learning disability. Dr Assouline has worked on identifying academic talent in elementary students, as well as implementing academic acceleration interventions for advanced students. In collaboration with Nicholas Colangelo and Ann Shoplik, she developed the Iowa Acceleration Scale, a tool designed to guide educators and parents through decisions about grade-skipping students. In 2015, Dr Assouline and colleagues, Nicholas Colangelo, Ann Shoplik, and Joyce VanTassel-Baska, published *A Nation Empowered: Evidence Trumps the Excuses Holding Back America's Brightest Students*. She has received numerous awards for her work, including the National Association for Gifted Children (NAGC) 2016 Distinguished Scholar Award.

CONTACT

E: susan-assouline@uiowa.edu
W: https://education.uiowa.edu/person/susan-assouline

Dr Lori Ihrig
Supervisor for Curriculum and Instruction
Belin-Blank Center
University of Iowa
Iowa City, IA
USA

Lori Ihrig graduated with a BS in Science Education in 1999 from the University of Iowa and taught grades 7–12 science for the Williamsburg Community School District. She earned her MS in Science Education from the University of Iowa in 2002. In 2007, she began working at ACT, Inc, writing science curriculum and facilitating science teacher professional development for Quality Core, a project in partnership between ACT, the Gates Foundation, and the National Governors Association. In 2014, she earned her doctorate in Curriculum and Instruction from Iowa State University with an emphasis in Science Education. She is the program director for the STEM Excellence and Leadership program, lead administrator for the Secondary Student Training Program, co-administrator for the Invent Iowa program, and the co-director of the Iowa Junior Science and Humanities Symposium. Her research interests include STEM academic talent-development in high-ability rural students.

CONTACT

E: lori-ihrig@uiowa.edu
W: https://education.uiowa.edu/person/lori-ihrig

FUNDING

NSF award no. 1713123: 'Implementing the STEM Excellence and Leadership Program to Understand the Role of Local Agency in Broadening High-Potential, Rural Students' STEM Participation and Achievement'
Jack Kent Cooke Foundation

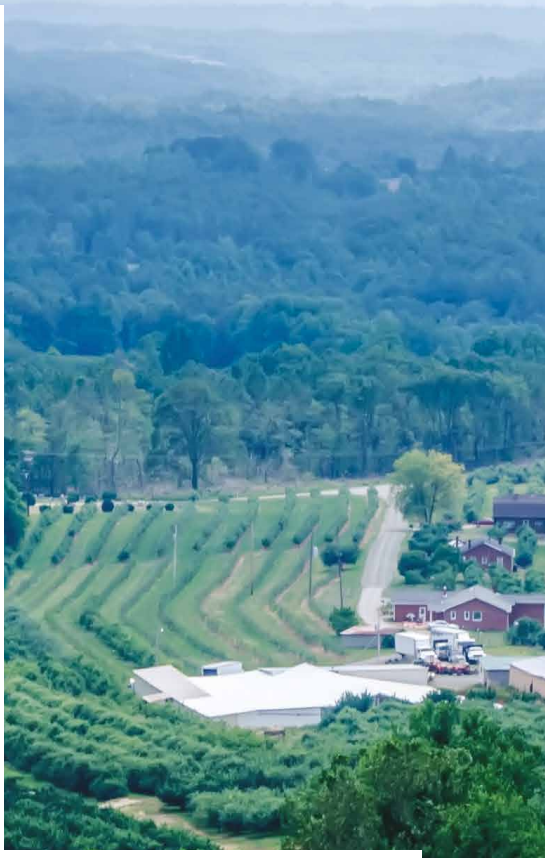
JACK KENT COOKE FOUNDATION

NSF

BELIN-BLANK CENTER
College of Education

THE RADSS PROGRAM: ENCOURAGING AND SUPPORTING RURAL STUDENTS

Rural youth often lack the financial resources needed to study at university. In fact, their path to higher education is brimming with obstacles. Through the Rural and Diverse Student Scholars (RADSS) program, **Dr J. Reid Schwebach** and his team at George Mason University are seeking to remove these obstacles and encourage students throughout rural Virginia to pursue further studies and employment in STEM-related fields.



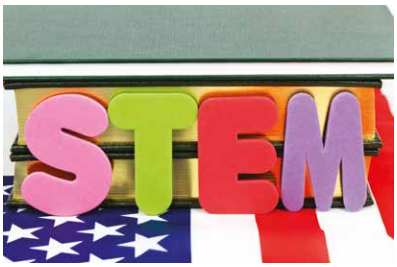
Accessing Education

Ensuring that young people have unhindered access to education continues to be a challenge. This is especially true in the case of students who have limited financial resources. The UNESCO Education Strategy for 2014–2021 acknowledges that, 'the gap in learning outcomes between rich and poor – within and between countries – is high and often growing.' It also relates that, because of limited access to education, 'unemployment and underemployment are too often experienced disproportionately by girls and women, the poor, the disabled and rural populations.'

Clearly, there is an ongoing need to encourage and support rural youth in their quest for a good education, especially those from diverse backgrounds and with limited financial resources. Furthermore, there is a need to encourage students who have a passion for STEM-related fields to pursue study and employment, to ensure a thriving STEM workforce into the future.

In response to this need, Dr J. Reid Schwebach from George Mason University created the Rural and Diverse Student Scholars (RADSS) program. RADSS aims to encourage academically talented students from rural areas in the state of Virginia to attend Mason's College of Science (COS). Specifically, the main objectives of RADSS are: (1) to strategically attract talented rural and diverse students to major in COS degrees, (2) to promote retention of talented rural and diverse students in COS majors, and (3) to directly support undergraduate scholarly activity in the COS. RADSS is supported with financial aid from the National Science Foundation (NSF). It is also supported by the 4-VA organisation – a collaborative partnership between six Virginian universities that is working to improve higher education across the state.

Through RADSS and associated research, Dr Schwebach and his colleagues are also collecting data and feedback to better understand the obstacles that rural students face in general, and how they can be assisted to overcome them. 'We are investigating how these rural students experience college and how university support mechanisms can help them succeed with their four-year degrees,' Dr Schwebach explains. The goal? 'Understanding the unique variables in these students' decisions to enrol and persist in undergraduate STEM has the potential to aid future recruitment and support of rural students,' he said. So, in addition to giving support to current RADSS participants, Dr Schwebach hopes to fine-tune his program and improve future recruitment efforts.



Obstacles Facing Rural American Students

Despite the United States having an excellent higher education system overall, talented rural students from various regions are still facing financial challenges and a lack of opportunity. A recent report prepared by the School Superintendents Association, entitled 'Levelling the Playing Field for Rural Students', highlighted that rural children face greater levels of poverty than their peers.

In 2015, child poverty rates were 24 percent in non-metropolitan areas compared with 20 percent in metropolitan areas. In

'We are investigating how these rural students experience college and how university support mechanisms can help them succeed with their four-year degrees. Understanding the unique variables in these students' decisions to enrol and persist in undergraduate STEM has the potential to aid the future recruitment and support of rural students.'

addition, rural school districts tend to be geographically large, adding increased costs for transport, technology, and learning materials. A lack of financial resources, in turn, affects enrolment rates, retention rates and students' motivation to engage with their studies. The report also highlighted that rural students are less likely to enrol in college and may lack the required role models and support to take up further studies.

The report concluded, 'the challenges students face in many rural places are staggering. Limited access to advanced coursework, medical care, food and employment opportunities, continue to daunt students in many rural communities.' Furthermore, as Dr Schwebach highlighted, research indicates that rural students in the United States are less likely to major in STEM subjects. As far as the state of Virginia is concerned, few rural students are headed to Mason to study at all, let alone to study at the COS. And so, the RADSS program was born.

About the RADSS Program

RADSS aims to encourage academically talented students from rural Virginia to attend Mason. The program does this by offering scholarships and research experiences to rural and diverse undergraduates with demonstrated financial need, and who wish to major in degrees such as astronomy, biology, chemistry, environmental science, mathematics, geology and physics. During their studies, these students also receive specialised support and mentoring to ensure that they remain positive about their learning.

In the initial stages, the RADSS program provides scholarships of 5000 USD for two cohorts of ten incoming freshmen who complete a summer bridge program before their first full academic year. Then, students complete a transition to a university course during their incoming semester. Students are mentored and supported by RADSS undergraduate Learning Assistants for four years. Provided students demonstrate that they are benefiting from the program, and provided they are in good academic standing, they receive an additional 5000 USD in scholarship funding for years two, three and four of their studies. Scholars can also participate in summer undergraduate research supported by academic and industry partners.

Fine-tuning the program and improving future recruitment strategies based on community feedback is also a central component of RADSS. Therefore, the program has two additional components. The first is to create and investigate a general, state-wide recruitment mechanism to attract rural students to major in a STEM subject at a college away from home. The second is to investigate how students from rural backgrounds form their identity and find their place in college, to understand how best to support these students' academic success. Of course, in collaboration with other institutions, the program will also provide a model for supporting recruitment and retention of students in STEM degrees throughout the rural areas of the United States.

Another notable feature of the RADSS program is that it builds capacity at Mason to form partnerships with regional laboratories and industries. These partnerships provide opportunities for students to gain research experience and to be mentored by those working in relevant fields. In addition to the skills and knowledge gained, these experiences will help students to network, likely increasing their employment prospects after graduating.

What the RADSS Program Tells Us

The program is currently in its early days. However, Dr Schwebach and his colleagues have accomplished much, and have reached several significant milestones. First, the recruitment method has been successfully implemented across 10 schools in Virginia. The team has identified an applicant pool and has already offered several scholarships

to selected students. Although there are still scholarships on offer for the first cohort, the team is processing applications from interested persons and will continue to select students and facilitate their transition to Mason.

As far as understanding the unique variables and challenges that rural youth face on their path to higher education, initial community feedback from the RADSS program has been most enlightening. Firstly, it has shown that rural students are indeed greatly influenced by family involvement, finances, and perceived opportunity, which in turn, affects their motivation to study at university. For example, some students commented how they felt that that their hometown lacked opportunity completely, or that opportunities were totally inaccessible.

Secondly, initial feedback has shown that financial and study support, as well as research opportunities, are critical to overcoming many of the obstacles facing rural youth and encouraging their academic pursuits. The comments and sentiments of students highlight that this is very much the case:

'I became interested in Mason because it was economically fit for both me and my parents. I wanted to enrol because I felt right at home as soon as I stepped foot on campus.' (Student C)

'I finally decided to enrol when I thought about the amazing undergraduate research opportunities and the proximity to DC (and away from home).' (Student E)

'I was accepted into many colleges, and offered various scholarships, but none compared to the RADSS program. It was not only the financial support of the RADSS program that was helpful, but the support team involved as well. The most important aspect I looked for when choosing a college was its science department and the amount of opportunity involved within the department.' (Student D)

Onwards and Upwards with RADSS

Dr Schwebach and his colleagues have much work to do. When asked about the next steps in their work, Dr Schwebach explained that, 'a rural student's identity as "rural" is unique to each rural student; being "rural" is not a singular definition. Hence, we are investigating "what works" for these students to be supported in STEM at university, with our theory being that the Learning Assistant program and support of these students as a cohort with additional faculty advising will significantly impact student success.' And of course, there is much work remaining to ensure that the rollout of RADSS is as smooth as possible, and to collect data and feedback from participants.

Nevertheless, RADSS is already having a positive effect. As implementation progresses, it will undoubtedly continue to assist rural students to follow their passion for STEM-related fields of study and employment. It is also shedding light on the obstacles faced by rural youth on their path to a quality, individualised education. Of course, the insights gained will further improve future recruitment efforts, and many other academic institutions could also benefit from the lessons learnt.

In conclusion, in light of ongoing issues related to accessibility, we applaud the efforts of researchers and educators from around the world to improve the situation. Indeed, there is a need to encourage and support rural youth, particularly from diverse backgrounds and with limited financial resources, into STEM-related fields of study and employment. Programs such as RADSS aim to do exactly that and will continue to ensure that equity in education is improved and maintained.

Meet the researcher

Dr J. Reid Schwebach
College of Science
George Mason University
Fairfax, VA
USA

Dr J. Reid Schwebach received his PhD in in microbiology and immunology from the Albert Einstein College of Medicine in 2002. He also holds an EdM degree in secondary science education and an MA degree in international education development. Before coming to George Mason University, he taught high-school chemistry and independent student research at The Beacon School, New York. He also worked for the Board on Science Education at The National Research Council as a program officer and study director. From 2007 until 2008, he was a Science and Technology Policy Fellow at the National Science Foundation in The Division of Research and Learning. He currently serves as Assistant Professor at Mason's Department of Biology, Program Manager of Teacher Engagement and High School Partnerships at Mason's College of Science, and Coordinator of The Governor's School, Innovation Park – a dual-enrolment public high-school at Mason.

CONTACT

E: jschweba@gmu.edu
W: https://biology.gmu.edu/j-reid-schwebach/

KEY COLLABORATORS

Additional colleagues on the project deserve acknowledgement for their contributions to the RADSS Program: Dr Rachel Cleaver and Dr Rebecca Jones of George Mason University, and Dr Mary Emenike of Rutgers University.

FUNDING

National Science Foundation (NSF)
4-VA
George Mason University's Office of Student Scholarship, Creative Activities, and Research (OSCAR)

Dr Schwebach would like to thank 4-VA (https://4-va.org/) for support to fund the publication of this article. We acknowledge NSF #1564989 for supporting the RADSS Scholars and the RADSS Program.

Dr J. Reid Schwebach is transitioning to a new position at the American Association for the Advancement of Science (AAAS) effective 8/27/2018, and future interest in the RADSS program at Mason should be directed to Padmanabhan (Padhu) Seshaiyer, email: pseshaiy@gmu.edu.

SOONER – FUNDAMENTAL AND APPLIED RESEARCH ON OPEN ONLINE EDUCATION IN THE NETHERLANDS

The number of individuals engaging with open online learning is rapidly growing because this form of learning is a flexible means of education that can be adapted to a wide range of different circumstances. Through the SOONER (www.sooner.nu) project, Prof. Dr Marco Kalz, affiliated to the Heidelberg University of Education and holder of the UNESCO chair of Open Education at the Open University of the Netherlands is working with colleagues at the Open University of the Netherlands, Utrecht University and Maastricht University to gain a better insight into how open online education can be developed in the future. SOONER or the 'Structuration of Open Online Education in the Netherlands' is a five-year project financed by the Netherlands Initiative for Educational Research (NRO), the Netherlands Organisation for Scientific Research (NWO) and the Dutch Ministry of Education that is supported by SURF – the collaborative ICT organisation for Dutch education and research.

Towards Enhanced Open Online Education

Open online education is growing in popularity. In many cases, this is due to the format's ease-of-access, flexibility and affordability. Considering the time constraints and financial burdens placed upon many citizens in modern society, it is quite easy to see why so many are turning to this flexible mode of education delivery. The growth of open online education has not gone unnoticed by the larger, established universities and they are responding to this trend. They too are utilising online learning to deliver their academic programs to a wider audience. Distance education institutions, such as the Open University of the Netherlands, focus not only on the rollout of open online education but also on improving its quality.

The purpose of the SOONER project is to gather empirical and robust evidence to support the validity and effectiveness of open online education, particularly in relation to higher education in the Netherlands. With a firm theoretical basis and development of teaching and learning practices, the quality of this form of learning can continue to improve, and challenges to negative perceptions about its use can be addressed.

The SOONER project consists of four PhD projects that focus on three levels that include the learner, the course and the organisational level. At the learner level, the project is investigating two key areas. One is the role of self-regulating behaviour in open online education. Reneé Jansen is a PhD candidate at Utrecht University and she is investigating self-regulated learning behaviour in open online education and ways to facilitate it.

The second key area, at the learner level, is the nature of intention and behaviour in relation to the measurement of success in open online learning. Maartje Henderikx is a PhD candidate and teacher at the Welten Institute at the Open University of the Netherlands. She is investigating the intention and behaviour of Open Online Course-learners and the barriers they encounter while learning what can hinder or impede learning success.

At the course level, SOONER is investigating how to scale student support and feedback provision, whilst maintaining the quality of learning. Julia Kasch is working on a PhD project at the Welten Institute at the Open University of the Netherlands. She is investigating solutions for scalability within

Open Online Education for support and assessment.

Finally, on an organisational level, the SOONER project aims to understand the major challenges and opportunities associated with the implementation of open online education within higher education institutions in the Netherlands. Martine Schophuizen is a PhD candidate at the Welten Institute of the Open University of the Netherlands. She is working to determine the organisational conditions that lead to success, the effect of Open Online Education on the organisation and the contribution it has towards the quality of education and educational innovation.

‘SOONER is delivering knowledge about the conditions and the impact of open online education on the individual, course and organisational level.’

Developing the Much-needed Skills of Self-Regulation

The term ‘self-regulated learning’ refers to a student’s ability to actively plan out their work and study schedule, set goals, and monitor their own study habits. Self-regulation is a pre-requisite for success in open online programs. As Renée Jansen and colleagues explain in one of their research papers, ‘due to the autonomy of students in this type of education, students in Massive Open Online Courses (MOOCs) are required to regulate their learning to a greater extent than students in traditional, face-to-face education.’

Because self-regulation is vital for success in these programs, it is important to explore self-regulation in open online education and to look for ways to support students’ in their self-regulated learning. It is hypothesised that there is a relationship between self-regulation skills and drop-out. Student drop-out in online education is due to many factors in addition to problems with self-regulation. Supporting student’s self-regulation will, therefore, help them to optimise their potential to make the best possible use of open online education.

To gain further insights into the issue, the team at Utrecht University developed a thorough and all-encompassing self-regulated learning questionnaire, specifically designed for the online learning environment. The questionnaire addresses different aspects of self-regulated learning, namely, metacognitive skills, time management, environmental structuring, help-seeking and persistence. A later refinement split the assessment of metacognitive skills into activities students engage in before, during, and after learning. Therefore, the questionnaire can be used to measure these activities separately, increasing the usefulness of the information obtained.

The questionnaire is a starting point for further research. The team clustered MOOC students based on their responses to the questionnaire into four groups with different self-regulated learning behaviours. The self-reported self-regulated learning of the students was found to be related to students’ behaviour in the online course environment, groups for instance, differed in their forum activity and the order in which they worked their way through the course materials. The results brought the team to believe that to support students in their self-regulated learning, support must be integrated within the course online learning environment: The students that are most in need of self-regulated learning support, are the least likely to go looking for it themselves.

The team also looked at existing research testing the effectiveness of self-regulated learning interventions in higher education to determine what makes an intervention effective and what characteristics are important. They aim to combine this information to test a self-regulated learning intervention in the fall of 2018 in several MOOCs. The goal is to improve students’ self-regulated learning and their learning experience – as failing to finish your work on time is a stressful experience – and their behaviour in the online learning environment.

Redefining Success in Open Online Education

While many enrol in open online education courses (MOOCs), providers report failure rates to be as high as 98 per cent. However, these providers consider getting a certificate and completion as defining success, and when they do so, failure rates are indeed incredibly high. In contrast, Maartje

Henderikx and her colleagues state that measuring success in a completion-centric manner is flawed. Such a metric does not take into consideration the perspectives, intentions and circumstances of the learner. Taking the view that measuring success in a completion-metric manner is flawed and has its consequences. In a recent research paper, the team highlighted that, 'framing success from a certificate- and completion-centric view will nurture a false understanding of success and dropout in MOOCs, which may subsequently lead to unnecessary interventions and unjustified negative reviews.'

In reality, a learner may not intend to follow the program to completion in the first place, especially if their desire is simply to acquire a certain skill and not a certificate. Therefore, once that skill has been acquired, then they may choose to withdraw from the course. That can hardly be deemed a failure. Furthermore, some learners may simply be satisfied with the knowledge gained sometime before the actual endpoint of the program. This illustrates how open online education providers need to redefine success. The perspectives of students need to be considered when evaluating dropout rates and also the perceived efficacy of the training. In line with this, this approach to measuring success focuses on the student's initial intentions as the reference point for assessment. Indeed, learners enrol in open online programs for various reasons. For example, some may simply wish to browse, or only passively participate. Therefore, determining the learner's intentions is vital in measuring success.

Dr Kalz and his colleagues from the Open University of the Netherlands have developed two MOOCs (Massive Open Online Courses) on marine litter and the adolescent brain. Within the MOOCs, success was measured in different ways. The first was traditional in its approach, measuring success by acquisition of a certificate upon completion, without consideration of the learner's initial intentions. The second, considered the learner's intentions and related that to their actual study behaviour.

If one considers those who do as they intended or do more than they intended as successful, then this paints a completely different picture. In the study, the success rates of MOOC-takers in the traditional measure was between 5.6 and 6.5 per cent. Where the intention-behaviour parameter was used as a measure of success, success rates increased to between 59 and 70 per cent. As Maartje Henderikx and her colleagues stated, 'this small change in the way we look at assessing MOOC success and dropout may have a large impact on future research on MOOCs.' While a more traditional, institutional approach does have its merits, changing the way we view success in open online education-based programs and factoring in the viewpoint of the learner will, at the very least, complement current practice.

Scaling Up Student Support and Feedback in Open Online Education

Due to the sheer number of enrolments in most open online courses, providing students with elaborate feedback challenges the teachers. As in regular, face-to-face education teacher time is limited and the provision of elaborate feedback on students' performance is limited or non-existent in courses with large student enrolment. According to Julia Kasch, Dr Van Rosmalen and Dr Kalz, the challenge is how to enable educational scalability. This means how to provide high-quality education, to large student numbers with low teacher costs. To reach scalability, MOOC designers and teachers should focus on the educational design of their course.

To support them Julia Kasch and colleagues developed and published an educational scalability scan, which helps to identify examples of best practice in MOOC designs. They used the scan to analyse the educational design and the potential scalability of different MOOCs. Their study revealed that, in particular, the use of scalable feedback and student support is scarce or inefficiently used. For example, poorly designed student-teacher and student-student discussion fora, ill-structured use of peer feedback, or automated feedback that was too simplistic led to unstructured interactions of limited use.

As the research highlighted, 'simply providing discussion fora, which in theory supports large-scale interactions, does not lead to high-quality interactions that students can benefit from, unless the educational design provides information and feedback criteria.' In relation to the goal of delivering large-scale yet high quality open online education, this is an important consideration. Interesting examples of scalable student support were a weekly sum-up video and a live hangout session. Teachers would discuss frequently asked questions, provide examples and include exercises. That way, the teacher could provide large numbers of students with valuable feedback in an efficient way. Following up on the scan and its findings the team is now studying what factors enable a successful design and take-up of peer feedback in an open online setting. Students' perceptions towards peer feedback and their role as a student will be asked within the context of a MOOC. Accompanying interventions will be used to study how best to prepare and instruct a heterogeneous population of students to give and use peer feedback.

Open Online Learning in Dutch Higher Education

In the Netherlands, the government is actively advocating open online learning, especially in higher education institutions. In a recent research paper, Martine Schophuizen and her colleagues stress that the ultimate mission is to, 'create more expedient, accessible and personalised learning experiences that contribute to an improvement of the quality of education and study success.' However, many higher education institutions are struggling to fully implement open online education.

It appears that attitudes and beliefs about online teaching are hindering such implementation of open online education. Furthermore, many educators lack the skills to design an online learning space and teach within that structure. Some educators also mention a lack of institutional support as the reason for fears and doubts about open online education implementation. For example, it was found that not having the needed ICT support was a concern for many educators. They also highlighted that defined organisational goals, visions, and support mechanisms are required for success. Despite these inherent challenges, educators also detailed the many opportunities associated with open online education. For example, many see the potential of open online education to offer time- and place independent learning and flexible and personalised learning paths. They also recognise that higher education institutions could use the format to appeal to and recruit new student groups.

In conclusion, the SOONER research project aims to inform the community about the inherent opportunities and benefits associated with open online education. It also seeks to improve the quality of online teaching and learning and tackle the negative perceptions about the format. Ultimately, it's about ensuring that more people in the Netherlands, and the world, have access to high quality and affordable education. This is, after all, a basic human right.

Meet the Team

Prof. Dr Marco Kalz received his PhD from the Open University of the Netherlands in Education Technology. He is currently Professor for Technology-Enhanced Learning at the Heidelberg University of Education and is affiliated to the UNESCO Chair of Open Education at the Open University of the Netherlands. He also serves as president of the European Association of Technology-Enhanced Learning (EATEL). His research examines the use of open education, pervasive technologies and formative assessment to support self-directed lifelong learning.

CONTACT

E: Marco.Kalz@ou.nl
W: http://www.sooner.nu

Prof. Dr Liesbeth Kester is Professor of Educational Sciences and chair of the Division of Education at Utrecht University. She is also Educational Director of the Dutch Inter-university Centre for Educational Research (ICO). Her expertise includes multimedia learning, hypermedia learning, personalised learning, cognitive aspects of learning and designing and developing flexible learning environments.

Dr Peter van Rosmalen is Associate Professor and chair of the Taskforce on Instructional Design and E-learning at the Department of Educational Development and Research of the Faculty of Health, Medicine and Life Science at Maastricht University. He has also been a consultant within international corporate environments and a (co-) initiator of a variety of national and international research projects around the use of educational technology in education and knowledge management.

Dr Jeroen Janssen is Associate Professor of Education at Utrecht University. His current research focuses on collaborative learning and the use of ICT in education. In 2008, he successfully obtained his PhD and is currently co-coordinator of the ICO theme group Education and ICT. He is also involved in the undergraduate and graduate Educational Sciences programmes offered by Utrecht University.

Dr Ir. Karel Kreijns is Associate Professor at the Welten Institute of the Open University of the Netherlands. His research interests are the social aspects of computer-supported collaborative learning and networked learning. He is also interested in the application of Self-Determination Theory and the Reasoned Action Approach framework on teachers' use of technology/Open Educational resources, enrolling in MOOCs and teachers' professional development activities.

Dr Anouschka van Leeuwen completed her PhD at the department of Education at Utrecht University in 2015 and continued her employment in Utrecht as Assistant Professor. Her PhD project concerned teacher regulation of collaborative learning. The topics of her current research projects include collaborative learning, blended learning and open online education.

Renée Jansen (MSc) recently obtained her Master's degree in Human Technology Interaction at Eindhoven University of Technology where she gravitated towards the learning sciences by focusing on the use of technology to take notes. She is currently a PhD-candidate within the SOONER project at the Education department at Utrecht University. In her project she focuses on self-regulated learning behaviour in open online education.

Julia Kasch (MSc) completed her Master's studies at Twente University and then worked at Bartiméus, as a researcher on a project focused on supporting text comprehension, recall and information searching in blind and visually impaired high-school students. She is now working as a PhD candidate for the SOONER project at the Welten Institute at the Open University in Heerlen. Her research is focused on scalability solutions within Open Online Education regarding several aspects such as support and assessment.

Maartje Henderikx (MSc) obtained her Master's degree in Management of Learning at Maastricht University. During this study she developed a fascination for Online Learning Environments. She is currently a PhD candidate and teacher at the Welten Institute at the Open University in Heerlen. Her research is centred around the intention and behaviour of MOOC-learners and the barriers they encounter while learning in MOOCs that hinder or impede learning success.

Martine Schophuizen (MSc) holds a Bachelor's degree in Cognitive Psychology, and a Master's degree in Management of Learning (Maastricht University). She is now a PhD candidate at the Welten Institute at the Open University in Heerlen. Her research will mainly focus on the organisational (pre)conditions that lead to success, the effect of Open Online Education on the organisation, and the contribution it has towards the quality of education and educational innovation.

Open Universiteit
www.ou.nl

DIVERSIFYING AND RETAINING STEM LEADERS FOR THE FUTURE

The growing significance of science, technology, engineering and mathematics (STEM) is not currently being matched by an appropriate level of variation in student demographics. **Professor Kevin Ahern**, **Chelsea Wolk** and **Stephanie Ramos** of Oregon State University are working to facilitate more diversity in STEM subjects and cultivate an environment that helps students persist in their studies and to pursue interests unique to each student.

Addressing a Wasteful Discrepancy

With our expanding dependence on technology and increasing need to combat emerging scientific problems, fields in science, technology, engineering and mathematics (STEM) are in more need than ever of a diverse intake of new students. However, many potential science students face obstacles that prevent them from pursuing their interests.

Professor Kevin Ahern, Stephanie Ramos and Dr Chelsea Wolk of Oregon State University (OSU) are implementing the OSU STEM Leaders Program that seeks to address the disparity between students willing to pursue STEM careers and those with the means to realize them. The program is designed for students from populations with historically high rates of attrition and underrepresentation, with a goal to increase the number and diversity of STEM students at OSU.

The OSU STEM Leaders Program is a highly-structured STEM development program involving 276 students – 126 students supported by the National Science Foundation, 150 by OSU. Professor Kevin Ahern serves as the Program Director, overseeing the program's operation and interfacing with students, peer mentors and faculty.

Professor Ahern works with his dedicated team, Stephanie Ramos as the Program Coordinator and Dr Chelsea Wolk as the workshop creator and Instructor for U-Succeed, a first-year orientation course that forms part of the program. 'The OSU STEM Leaders program aims to improve the success, retention, and persistence to graduation of under-represented minority students in STEM disciplines,' Professor Ahern explains.

Through the program, Professor Ahern, Dr Wolk and Ms Ramos are helping students transition from high school and community colleges to STEM careers. Building skills is a priority of the program, including making use of campus resources, basic research design, processes and ethics, communication, resumes and applications.

Also emphasized are academic success, student retention, career clarification, the pursuit of graduate studies, cultivating enthusiasm and professional access. The team wants to combine all of these practices into a program for first-year students and new transfer students.

CREDIT: Sophie Pierszalowski

Intake of students into the program is filtered for eligibility. Only incoming freshmen and transfer students from community colleges are eligible to apply. The program aims to support students that are underrepresented in STEM, such as those at an economic disadvantage, or rural based, or those who are the first generation of their family in college.

‘The OSU STEM Leaders program aims to improve the success, retention, and persistence to graduation of under-represented minoritized students in STEM disciplines.’

CREDIT: Sophie Pierszalowski

Turning Undergraduates into Researchers

The program also allows for undergraduates to engage in STEM research areas. The research takes place under faculty mentorship with students presenting their research at the end of the project. Professor Ahern, Dr Wolk and Ms Ramos believe these opportunities for undergraduates to participate in research have previously been found beneficial to building academic skills. These faculty-mentored undergraduate research projects during the second academic quarter build on U-Succeed and the program’s workshops.

Students meet individually with Professor Ahern to discuss research interests and possible projects and mentors. He serves as the matchmaker between students and mentors. Students conduct six to seven hours of research per week. They are paid US$700 per academic quarter. This is intended to reduce the number of students dropping out due to the financial pressures associated with STEM research.

The research projects are supported by the grant for at least three quarters, after which students have the option to seek another funding source. Students may continue doing research for credit or support themselves with federally-provided part-time jobs. The students then meet quarterly for assessment and progress reports.

Students eventually present their research to a large audience at either the STEM Leaders Symposium in January each year or the Celebrating Undergraduate Excellence symposium in the spring. Funding also allows for students’ research to be presented regionally or nationally. After their research projects, students become alumni and can apply to become peer mentors.

Seminars and Workshops to Succeed

The program includes peer mentoring, supporting undergraduate research beginning in the second term of the students’ first year and orientation in a U-Succeed course for all new students. There are also professional development workshops, providing advice for the students’ first three terms at OSU, an annual symposium for students to showcase research results and an annual retreat.

Professor Ahern argues that large introductory STEM classes do not generate as much excitement as smaller, more focused seminars. The team believes that evidence suggests that socialization and connection programs have proven more successful and should be implemented more widely. The first year STEM orientation course and workshops that are part of the program have resulted in increased first to second-year retention and improved academic and social integration.

The program includes a year-long cohort-based workshop series with three workshops each term (fall, winter and spring) that are attended by the students. Workshops cover a wide range of topics including: how to effectively communicate and present their research, resume and application writing, and career panels with industry leaders and expert faculty.

CREDIT: Sophie Pierszalowski

U-Succeed

Taking place over the autumn of the first year, the U-Succeed seminar orients first-year students to STEM. The team argues for the positive impact of STEM-focused first-year orientation courses, citing that they help students develop early, positive identities as STEM students and researchers, and that they remain in STEM disciplines.

Other first-year orientation seminars have been conducted previously by OSU in the capacity of disciplines outside STEM, and it was found that student retention rates were over 7% higher for students who participated. In this project, the team wanted to create a first-year experience course that was specific to the needs and culture of STEM. They are intent on getting more students familiar with research and scientific processes.

U-Succeed covers professional practices of science and engineering research, research ethics, making use of scientific journals, locating areas of interest in research, communicating with research and PI mentors and study and test-taking skills.

In order to reduce 'transfer student shock', transfer students take the seminars alongside first-year students. This can potentially mitigate the reduction of the grade point average of a student transferring from community college to university.

Mentoring the Future of STEM

An effective component of the program includes one-on-one peer mentoring meetings from upper-division students as mentors. Peer mentors help students connect with tutors, advisors and financial aid, meet bi-weekly with students to discuss the program, monitor and report to Ms Ramos about the progress and wellbeing of each student and coordinate weekly workshops. These intensive interactions are also assisted by periodic meetings with Ms Ramos and Professor Ahern.

In addition, faculty mentors agree to provide at least seven hours of mentoring per week, provide orientation to the project, monitor the work of students through regular meetings and discussion of their progress, to include students in meetings of their research groups and submit evaluation reports to the program leaders.

Results and Sustaining the Momentum

The first cohort retained 37 of the 40 program students (92.5%) and the second retained 50 of 52 (96.2%). The program has also had demonstrable success in diversifying the STEM student body and aims to improve the graduation rate of students who participate. 'The retention rate of our students completing their first year at OSU is higher than the student population as a whole, despite the fact that the majority of our students are at risk,' explains Professor Ahern.

The next steps for the work include the completion of the fifth and final year of the grant, obtaining continuing funding from OSU that will extend the program and analyzing and reporting the results of the team's efforts for publication. In the future, the team aims to develop new materials and recruit more students from community colleges – a number that has already increased from the first two years of the program.

The OSU STEM Leaders team believes their methods could be extended to other schools, other programs and other groups of students. The entire team is working to make the structure of the program highly visible, creating videos to help students worldwide learn about OSU and STEM research and careers.

Videos from the workshops are produced by the program and uploaded to YouTube in order to reach a vast number of those who may benefit from being exposed to the methods being used. In this way, Professor Ahern, Dr Wolk and Ms Ramos are maximizing not only the direct impact of the program, but also allowing wide access to the means to achieve it.

CREDIT: Gildha Cumming

Meet the researchers

Professor Kevin Ahern
Department of Biochemistry and Biophysics
Oregon State University
Corvallis, OR
USA

Kevin Ahern is Professor of Biochemistry/Biophysics at Oregon State University and has been a member of the faculty since the mid-1990s teaching undergraduate and graduate courses in biochemistry and serving as head advisor of the department. He obtained his Ph.D., in 1986 from Oregon State University and served as the university's first Director for Undergraduate Research from 2012–2015. He is best known for his popular YouTube video lectures on biochemistry that have been watched over 4 million times by students worldwide. He has published over 700 articles and along with Indira Rajagopal, has also co-authored two popular electronic textbooks, *Biochemistry Free and Easy* (2012) and *Biochemistry Free for All* (2016), which together have been downloaded over 260,000 times.

CONTACT

E: ahernk@onid.orst.edu
W: http://stemleaders.oregonstate.edu
W: http://www.davincipress.com
@ahernk1

Dr Chelsea Wolk
College of Science
Oregon State University
Corvallis, OR
USA

Dr Chelsea Wolk oversees program development and instructs for the College of Science and STEM Leaders program at Oregon State University. Dr Wolk uses impactful teaching strategies that bring professional and science experience into the classroom. With a Ph.D. in biochemistry as well as biotech start-up experience, Dr Wolk synergizes academia and industry in her current position. She has a strong belief that learning is a lifelong process and that everyone can become an independent, empowered and successful professional.

CONTACT

E: chelsea.wolk@oregonstate.edu

Stephanie Ramos
Department of Biochemistry/ Biophysics
Oregon State University
Corvallis, OR
USA

Stephanie Ramos is a native of Texas and a first-generation college graduate. She is passionate about supporting the success of underrepresented students pursuing science degrees in higher education. Stephanie is the STEM Leaders Program Coordinator at OSU and works directly with STEM Leader Program participants. Before joining the OSU, she was the Academic Coordinator for a student center at the University of California, Santa Barbara. She has a B.S. and M.Sc. in Chemistry and is currently working on her Ph.D. in Science Education. Stephanie is an Associate Member of the Younger Chemists Committee for the American Chemical Society and a lifetime member of the Society for the Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS).

CONTACT

E: stephanie.ramos@oregonstate.edu

KEY COLLABORATORS

Scott Ashford
Dan Arp
Roy Haggerty
Cynthia Sagers
Kameron Kadooka
Milo Koretsky
Devlin Montfort
Sophie Pierszalowski

Oregon State University

FUNDING

National Science Foundation Grant #1432810
College of Science, OSU
College of Engineering, OSU
College of Agricultural Sciences, OSU
OSU Research Office

ENGENDERING FACULTY AND STUDENT ENGAGEMENT IN STEM EDUCATION: AN INSTITUTIONAL MODEL

An interdisciplinary team at the School of Science and Technology, the School of Education, and the School of Liberal Arts at Georgia Gwinnett College (GGC), are increasing student engagement in Science, Technology, Engineering, and Math (STEM) courses, through embedded research experiences. Their innovative systems-level approach employs bidirectional interactions between students and faculty and High Impact Practices (HIPs) to increase graduation rates and prepare students for their future STEM careers.

The STEM Education Innovations Program

Past research has highlighted the need for educational institutions to integrate practices that have been found to be effective in training students in STEM subjects, ensuring that the skills they learn are retained and that they are well-equipped to pursue a career in the field they are preparing to enter.

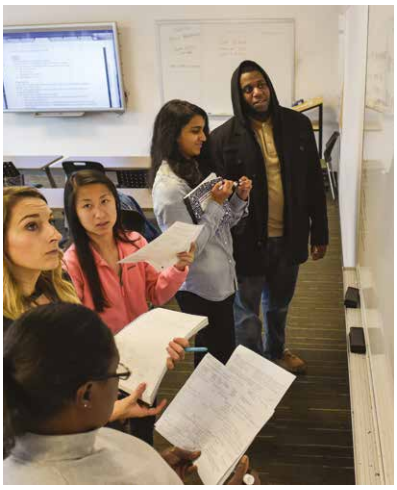
To address this, a team at Georgia Gwinnett College (GGC), in Lawrenceville, Georgia, has developed and applied a new institutional model of teaching STEM disciplines that is centred around extensive research experiences aimed at improving learning and increasing student engagement. Their aim is to increase the enrolment and retention of students in STEM subjects and to support under-prepared and under-represented students to pursue careers in science and engineering.

The institutional model at GGC includes four key High Impact Practices (HIPs), teaching and learning methods that have been found to be particularly beneficial for college students. These HIPs, now recommended by the Association of American Colleges and Universities, include Course-embedded Undergraduate Research Experiences (CUREs), Peer Supplemental Instruction (PSI), Faculty Learning Communities and Service Learning.

In developing their model, the researchers at GGC adopted a systems-level approach. Systems-thinking is a relatively new approach to educational reform, designed to bring about institutional change that leads to more engagement among students, faculty and staff.

Systems-level approaches take the different contexts and cultures within an institution into consideration, including departments, the college, the institution as a whole, and other external groups collaborating with the institution. This approach also focuses on other elements that could facilitate or prevent change, including evaluation/reward systems, workload allocation, professional development opportunities, and leadership practices and how different factors can influence faculty choices related to teaching practices.

The team at GGC has identified several key levers for change, including faculty and student support at the micro-level,



curriculum at the meso-level, and institutional support at the macro-level. Their institutional model entails key HIPs and activities that have been found to be particularly effective for each one of these levers (see figure one).

Curriculum

At a meso-level, the model provides rigorous research-based curricula designed to foster STEM competencies. It includes Course-embedded Undergraduate Research Experiences (CUREs), a HIP that has been found to effectively increase student engagement and student learning in STEM disciplines.

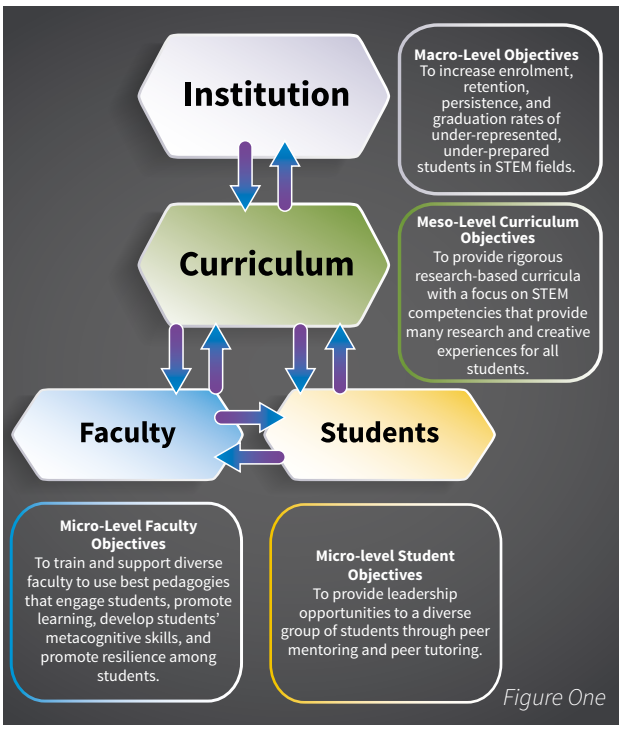


Figure One

The CURE model developed by the team, in which students participate in research and creative experiences, is the *Four-year Undergraduate Research and Creative Experience (4YrURCE) Program*. Initially, faculty members in biology, chemistry, information technology, mathematics and exercise science prepared a list of discipline-specific research or creative skills that they considered essential for the students to succeed. Faculty then identified specific courses in each year of a four-year degree program in which research and creative experiences would be embedded.

Thus, in a four-year degree program, students are provided repeated opportunities for students to acquire STEM work-force skills and competencies which builds students' confidence in their ability to pursue a career in STEM and ultimately translates into greater student retention in STEM degrees (see figure two). For example, the biology faculty at the college designed a course-embedded research experience that integrates ecology (juniors) and cell biology (sophomore) courses using taxonomy and bar-coding to identify insect species.

Students

On a micro-level, GGC's model includes evidence-based activities and initiatives targeting students and faculty. A key component of the STEM education initiative at GGC is Peer Supplemental Instruction (PSI), a collaborative study practice in which peer student leaders facilitate structured study sessions for students who are taking gateway courses in biology, chemistry, mathematics and information technology. In these sessions, peer leaders help students practice course material using a variety of active-learning strategies.

These peer leaders are students who have already succeeded in these courses and are trained in how to prepare lesson plans that incorporate STEM skills and active learning strategies. In this practice, leaders have the opportunity to develop their soft professional skills including, STEM communication, leadership, and teamwork, which will undoubtedly prepare them for the transition to post-baccalaureate education or STEM careers. Past research has found that individuals who perform tasks cooperatively performed 66% better than those learning alone.

Most students participating in PSI sessions at GGC give very positive feedback for these sessions, saying that they find them useful and that PSI helps them to develop better study skills, improve their understanding of course material, and strengthens their confidence in their abilities. Preliminary data also shows a correlation between student grades and attendance at PSI.

The Service Learning component of the model provides STEM majors with leadership opportunities to use their STEM knowledge and skills to run inquiry-based hands-on labs for fifth-grade elementary students. To do this, GGC partners with local elementary schools, where undergraduate students lead science lab activities that enrich the fifth-grade science curriculum and are aligned with Science and Engineering Practices (Next Generation Science Standards). This allows undergraduate students the chance to gain valuable public-speaking experience as well as serve as role models in the community to engage and motivate a younger generation of students in science.

Faculty

The STEM initiative at GGC was also designed to encourage collaboration between faculty from different disciplines, through the formation of Faculty Learning Communities. At GGC, implementing their institutional model encouraged greater collaboration between different faculties. For instance, the information technology and biology faculties worked to bring their students together to develop apps and animations that could help biology students to better understand different topics.

Responses collected using a faculty attitudinal survey found that over time professors developed a better understanding of the initiative, initiating greater interdisciplinary collaboration, participating in other STEM initiatives and feeling increasingly motivated to include other pedagogical approaches in their classrooms.

In addition, the model also promotes and supports student-centred learning, encouraging faculty to engage their students and tailor their teaching around them, so that they remain motivated and acquire greater confidence in their STEM-related skills. The model is designed to foster continuous faculty development, encouraging teaching staff to adopt pedagogies

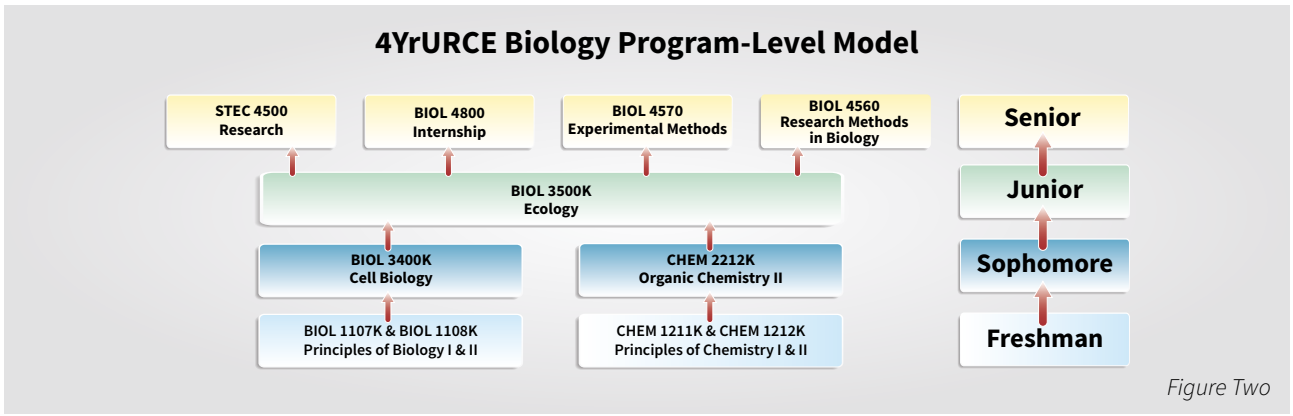


Figure Two

that have been found to be particularly effective to engage students, develop their metacognitive skills, and foster their resilience.

Institutional Support

A comprehensive, systemic approach such as that employed at GGC also requires commitment and involvement at a macro-level that focuses on the institution as a whole community and at the level of the School of Science and Technology.

Resources are devoted to increasing enrolment and retention of under-represented students in STEM fields through faculty development and research at the human resources and institutional level. This is supported by the involvement of the Center for Teaching Excellence (CTE) and commitment from the institution's administrators. Institutional Research, Grants and Sponsored Research, Budget and Planning, and administrative support from the School of Science and Technology, all play a key role in ensuring the success of the model and the approach, building a solid foundation for its development.

A Promising Approach to Institutional Change

The institutional model developed by the team has already been integrated at GGC, with highly promising results. Total enrolment of STEM majors has increased from 2527 (Autumn, 2012) to 3524 (Autumn, 2017). Evaluations of the model found it had a direct positive impact on students' academic performance, leading to improvements in their grade point average and greater retention of material covered.

Within the School of Science and Technology, the annual grade point average of STEM students increased from 2.68 in Autumn 2011, to a high of 2.96 in Autumn 2013. Over the last three years, grade point averages have remained above 2.8. Moreover, in the years after the introduction of the 4YrURCE model, STEM students were found to be retained at a higher rate than the general student population at GGC.

The average retention rate for STEM students was 84.3%, considerably higher than the 57.5% retention rate among GGC's general student population and the 64.7% retention rate overall for underserved populations. Preliminary data also indicates that underrepresented and minority groups (Hispanics, Blacks, and Multi-Ethnic students) were retained within the School of Science and Technology at a higher rate than White students for the last two years, suggesting that the model's high student engagement activities may play a role in retention rates of under-represented groups.

The researchers found that early participation in research during freshman and sophomore years played a part in students deciding to stick to a STEM major. In addition, student enrolment in STEM courses increased, as compared to overall enrolment at GGC. In the future, the researchers' systems-level approach could provide a valuable guideline for other institutions, fostering greater engagement in STEM disciplines on behalf of both students and faculty.

In a recent article in the *Council of Undergraduate Research Quarterly*, the researchers write: 'While our model appears to be ambitious, we believe that it has the potential to be replicable, scalable, and attainable at different types of institutions. Results of our studies have been presented at various national conferences and they have generated much interest. Many institutions have requested information on our model, and a few have started similar pilot projects.'

Meet the Team

Dr Judy Awong-Taylor is Professor of Biology at Georgia Gwinnett College (GGC), Lawrenceville, GA, USA. She obtained her PhD in environmental microbiology from the University of Florida. Before joining GGC, Dr Awong-Taylor was a professor and interim department head at Armstrong Atlantic State University (AASU), as well as the director of the University System of Georgia's STEM Initiative. Her interests include system-level approaches to improving undergraduate STEM education.
E: jawongta@ggc.edu
W: http://www.ggc.edu/academics/schools/school-of-science-and-technology/stem-education-innovations/

Dr Clay Runck is Assistant Professor of Biology at GGC. He obtained his PhD in biology from Northern Arizona University. Dr Runck's teaching interests include CUREs designed for campus-based outdoor classroom settings for introductory biology, ecology, and limnology.
E: crunck@ggc.edu

Dr Thomas Mundie is Professor and Dean of the School of Science and Technology at GGC. He holds a PhD in biomedicine from the Medical University of South Carolina. His teaching interests include anatomy and physiology, and immunology. His research interests are varied including pulmonary pathophysiology, STEM retention and progression, and the role of high-impact practices on STEM RPG.
E: tmundie@ggc.edu

Dr Allison D'Costa has focused her research in STEM education to developing laboratory curriculum that provides students with research experiences while building essential STEM skills. She earned her PhD in Molecular and Cell Biology from Hahnemann University, Philadelphia.
E: adcosta@ggc.edu
W: https://commons.ggc.edu/adcosta/about/

Dr David Pursell served world-wide for 25 years in the US Army before joining higher education. He is currently Professor of Chemistry with research interests in environmental chemistry and chemistry education. Dave earned his PhD in Chemical Physics from the University of Pennsylvania under the direction of Hai-Lung Dai.
E: dpursell@ggc.edu
W: https://commons.ggc.edu/dpursell/
Twitter: @DrDavePursell

Dr Tirza Leader has a PhD in social psychology and specialises in methodology and analysis. She has designed, implemented, and analysed various assessments for government agencies and for private business.
E: tleader@ggc.edu
W: http://www.ggc.edu/academics/schools/school-of-science-and-technology/stem-education-innovations/

Dr Cindy Achat-Mendes earned her PhD in Neuroscience at the University of Miami School of Medicine and trained as a Psychiatry Fellow at Harvard Medical School. She utilises cell and animal models to teach and engage undergraduates in neuroscience. She is particularly interested in identifying strategies that best promote student learning in college.
E: cachatme@ggc.edu
W: https://commons.ggc.edu/cachatme/
Twitter: https://twitter.com/achatwithme

Dr Chantelle Anfuso earned her PhD in Physical Chemistry from Emory University. Since joining the faculty at Georgia Gwinnett College, her research interests have focused on developing low-cost spectroscopic experiments for physical chemistry courses and investigating methods for supporting students in STEM courses.
E: canfuso@ggc.edu
W: https://commons.ggc.edu/canfuso/

Dr Nathan W. Moon is a Senior Research Scientist at the Georgia Institute of Technology, Atlanta, GA, and Director of Research for the Center for Advanced Communications Policy. His research interests include broadening participation in science education, accessible education, information and communications technology access, and educational evaluation.
E: nathan.moon@gatech.edu
W: http://cacp.gatech.edu/nathan-moon

FUNDING

This work is funded and supported by grants from the Board of Regents of the University System of Georgia (STEM-EIP Grant), and the National Science Foundation under NSF Award No. 1623779. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or the University System of Georgia.

FURTHER READING

J Awong-Taylor, A D'Costa, G Giles, T Leader, D Pursell, C Runck, T Mundie, Undergraduate research for all: addressing the elephant in the room, Council on Undergraduate Research Quarterly, 2016, 37, 11–19.

JE Russell, AR D'Costa, C Runck, DW Barnes, A Barrera, J Hurst-Kennedy, EB Sudduth, EL Quinlan, M Schlueter, R Haining, Bridging the undergraduate curriculum using an integrated course-embedded undergraduate research experience (ICURE), Cell Biology Education Life Sciences Education, 2015, 14, 1–10.

A Heinz, X Xu, A D'Costa, Web-animations: An interdisciplinary approach for biology and information technology students, Integrated STEM Education Conference (ISEC), 2015, 33–37.

BEGINNING THE ASCENT

Diversity of outlook is essential for any scientific endeavour. Improving this diversity is the goal of the **ASCEND Program**, led by Professors Farin Kamangar and Payam Sheikhattari at Morgan State University, USA. Here, we showcase their work aiming to improve the experience of undergraduates by embedding them firmly in the fascinating world of scientific research from the very beginning of their careers.

Progress and achievement in scientific research rely on curiosity, persistence, and a willingness to listen to differing viewpoints. Many of the most important discoveries throughout history have come from researchers with radically different opinions to the majority. Yet the diversity which we strive for in research often fails to reach the levels which it could. Indeed, the world of scientific research is often more homogenous than we could expect.

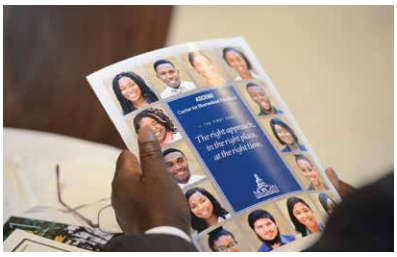
In the USA, the majority of faculty research positions are held by those with Caucasian or Asian backgrounds. Less than 10% of leading research roles are held by African Americans, Hispanics, Native Americans, or Pacific Islanders, despite these groups comprising more than 30% of the American population. The major onset of this disparity appears to occur between undergraduate and graduate degrees – although the groups will earn around 22% of the science or engineering Bachelor's degrees in any particular year, the percentage for doctoral degrees is far lower at only 13%.

What causes this drop? There are many causes, but a major one is the significant change in environment between undergraduate and graduate studies. Students are no longer provided with the information they need, so they must now go out and do the research themselves – they become masters of their own fate. Surviving this transition is a difficult act, one in which previous experience and support networks are vital for success.

This is where the researchers Drs Farin Kamangar and Payam Sheikhattri enter the picture. As principal investigators of the ASCEND program at Morgan State University, USA, they have set out to bring undergraduates fully into the scientific life – from planning their own experiments through to writing their own funding proposals.

Students as Research Entrepreneurs

The ASCEND program is currently implemented at Morgan State University, which is located in the biomedical research hub of Baltimore, Maryland. The university is open to all but has historically had a higher proportion of African Americans in the overall student population. Many of the students receive government assistance due to financial need, and many are the first generation in their family to go to college. Financial stress and limited support networks increase the risk of dropping out of academic studies, making training and a supportive environment a high priority for the university. Over 150 years old, the university has grown significantly in recent times and is currently attempting to build a solid base of research programs. The ASCEND program is seen as a vital part of this mission.



The ASCEND program provides undergraduate students with leadership and networking opportunities, as well as the requisite training and support to become 'research entrepreneurs'. Just as entrepreneurs conceive business ideas, seek funding, and lead their ideas to fruition, successful researchers come up with their own research ideas, compete for funding, conduct their research, and disseminate the findings. To facilitate this for undergraduate students, the ASCEND investigators have developed the Entrepreneurial Research Training Model (ERTM), which provides a navigable pathway for students to become research entrepreneurs. The model has four stages: attraction and inspiration, ideation and innovation, implementation, and growth (Figure 1). As we can see, activities, outcomes, types of interactions, and evaluation methods have been defined for each stage.

The ASCEND Entrepreneurial Research Training Model

Stages	Attraction & Inspiration	Ideation & Innovation	Implementation	Growth
Activities	**Extra-curricular** community & family engagement events, organizational & club leadership **Co-curricular** workshops, scientific clubs, training	**Research Training** Introductory methodology & skills, active learning, interdisciplinary seminars, team building **Coaching** peer & near-peer, academic	**Entrepreneur-Style Research** submission of proposals and applications (IRB, grant, etc.), conducting faculty-mentored student-owned research projects, interpreting research data	**Dissemination** presentations, publications **Transformation** professional networking, resume building, graduate school application
Outcomes	increased interest in biomedical research, enhanced peer & social support	developing entrepreneurial thinking skills, increased science communication, enhanced science self-efficacy	developing research knowledge and skills, increased leadership and teamwork competency, enhanced science identity	developing communication skills, enhanced scientific writing and analytical competency, pursuit of graduate biomedical training
Networking & Mentoring	**Peers** near-peers, faculty	**Near-Peers** peers, faculty	**Faculty** peers, near-peers	**Scientific Community**

The ASCEND program has several initiatives that use elements of the ERTM: the Student Research Center (SRC; a student organisation), an annual Summer Research Institute program (SRI; a research training camp), and a two-year ASCEND Scholars program (an extended research training program). In all of these initiatives, student leadership and entrepreneurial mindset is emphasised.

The SRC has been found to be very cost-effective. The SRC is a registered student-led organisation which focuses on health research – it is open to any undergraduate with reasonable academic achievement. The members organise research clubs, smaller groups each with a focus on a particular area of health science and hold regular discussions with interested faculty members on upcoming science or recently published work. An incentive program awards points based on club involvement and academic excellence, which in turn allows the students to reach higher 'ranks' within the centre. These, in turn, provide valuable academic privileges, whether it be free printing or paying graduate school entry fees. SRC involves nearly all stages of ERTM by attracting large numbers of students, engaging them with networks of like-minded peers who want to do research, forming research clubs and choosing research topics, and conducting student-led research under the guidance of faculty.

The SRI is a training camp, held every year for around 30 students. Over eight weeks the students are introduced to scientific methods and the science underlying health research. Working in teams and guided by faculty members and student mentors, the student groups select their own research topics and write preliminary research proposals. Eight weeks is too short for completing the research that the students have conceived. Therefore, the SRI primarily covers the early stages of ERTM, i.e., attraction and inspiration, and ideation and innovation.

To complete the final stages of ERTM, i.e., implementation of research and dissemination of the results, a select group of the SRI members are enrolled into a two-year ASCEND Scholars program. During this time, the ASCEND Scholars improve the preliminary research proposals, apply for study approval, and then submit the proposals for research funding. As in the real world, only the most competitive and well-planned proposals are accepted – those who fail to receive internal funding at this stage may continue on with another training program if they so desire. Those who succeed receive faculty mentorship, additional training, the chance to visit scientific congresses, and other additional career-boosting activities.

A Sense of Purpose

As Dr Kamangar notes, ASCEND can be thought of as developing scientific entrepreneurs, because those who develop their own scientific program are responsible for its success. By doing so, the program organisers tap into several of the most important factors involved in job satisfaction: a sense of purpose, autonomy, progress, and belonging. The ASCEND program attempts to bring all these factors into play.

Autonomy and progress are two of the areas in which the ASCEND program excels. The organisers are clear on the need for students to take the lead – students choose research programs, run the university club, do the research, write the applications, analyse the data, and write up the results. This avoids a common pitfall in which more established researchers see student workers as a mere source of cheap labour, capable of performing the boring work but who should be kept away from the 'loftier' roles of writing up and hypothesising. Instead, the students take part in the entire process, from beginning to end, preparing them for the real world of scientific research.

Furthermore, the program heavily emphasises collaboration. The SRC brings like-minded students together, the SRI requires groups to work together, and mentorship and peer support is never far away. All of these factors build a sense of membership both within the group and as part of the wider scientific community.

Sense of purpose is also an area of focus, as students choose to be part of the ASCEND program because it matches their interests. ASCEND builds upon a significant body of work which shows that scientific development is best improved by providing scientific training to those involved and then simply letting them get on with it. Those who are trained, whether they be minority students or health workers in low-income countries, will know what problems are of most importance to them. As such they will naturally be motivated to perform research in those areas – this builds a sense of purpose in the development of their research careers.

The Scientific Groundwork

The ASCEND program has been running since October 2014, and in that time has seen a significant level of success. The first cohort of attendees finished the two-year training program in 2017 and several of these students have now completed their undergraduate degrees. Many of these students have been accepted into graduate school programs or are in the application process. Nearly all of the ASCEND Scholars have been accepted into summer research internships at prestigious research institutions, including Johns Hopkins University and Columbia University.

The organisers also surveyed the members of the SRC. They found that membership was associated with a significant increase in peer support for research and science, as well as a large boost in the sense of scientific identity and favourable attitude towards research. Importantly for the scientific future of the students, the attendees also showed an improvement in their self-sufficiency in academic and research settings. The longer they were part of the program, the more these attributes were improved – showing clearly the benefits the ASCEND program brings to students. This was matched by a high level of satisfaction with the organisation, with most SRC students stating that they were 'extremely satisfied with their SRC experience, and they would not change anything about it.'

These impressions were further confirmed in individual surveys with ASCEND Scholars. Many participants noted that although the SRI and two-year programs are very intensive, they are worth the challenge. Indeed, the first cohort confirmed that they believed they would not be where they are today without ASCEND.

Future Heights

One of the litmus tests for any initiative is that of sustainability – it must continue to run beyond the initial funding period. ASCEND is well aligned with the goals of the university, which hopes to strengthen its research programs. Some components of the program are relatively inexpensive – for example, running the SRC student organisation requires only a few part-time staff, and the research proposals tie into the work of the faculty. Other components, such as the SRI, can be sustained by transforming it into two student-centred courses offered by the university during the academic year.

As such, the ASCEND program looks highly likely to continue into the foreseeable future. Thanks to the efforts of the ASCEND team, ever-more generations of students will involve themselves in the program, learning the realities of science, and preparing themselves for scientific careers. By targeting our upcoming generations of scientists, this work will serve to broaden the scientific workforce of the future.

Meet the researchers

Professor Farin Kamangar
Department of Biology
Morgan State University
Baltimore, MD
USA

Professor Payam Sheikhattari
Department of Behavioral Health
Morgan State University
Baltimore, MD
USA

Professor Farin Kamangar completed his PhD in epidemiology at the world-renowned Johns Hopkins University in 2005, then progressed through a series of academic positions in the United States. As a cancer epidemiologist, Professor Kamangar has received several prestigious awards for academic and research excellence and has obtained large competitive research grants. He has also published over 190 peer-reviewed journal articles, written several textbooks, and mentored students at various stages of academic study. Currently at Morgan State University, USA, Dr Kamangar uses his role as Director of the ASCEND centre to improve scientific knowledge and enthusiasm for research in a diverse student population, thereby preparing them for success in their own scientific careers.

CONTACT

E: farin.kamangar@morgan.edu
W: www.morgan.edu/research_and_economic_development/ascend/about_ascend/ascend_faculty_and_staff/kamangar.html

Dr Payam Sheikhattari is a Professor of Public Health at Morgan State University. He has over 20 years of experience in conducting research both in the United States and internationally. Professor Sheikhattari received his MD and MPH from Iran, then became a post-doctoral fellow at Johns Hopkins University. Dr Sheikhattari has been the principal investigator of competitive research grants in the areas of community-based participatory research, tobacco-use prevention and treatment, and the training of students from underrepresented backgrounds. As the director of the Prevention Sciences Research Center at Morgan State University, he partners with underserved communities of Baltimore City to lead research studies aimed at identifying solutions to urban health disparities.

CONTACT

E: payam.sheikhattari@morgan.edu
W: https://www.morgan.edu/research_and_economic_development/ascend/about_ascend/ascend_faculty_and_staff/sheikhattari.html

KEY COLLABORATORS

Dr Christine Hohmann (Department of Biology, Morgan State University)
Dr Cleo Hughes-Darden (Department of Biology, Morgan State University)
Dr Shiva Mehravaran (ASCEND Center for Biomedical Research, Morgan State University)
Ms Gillian Silver (ASCEND Center for Biomedical Research, Morgan State University)
Dr Jocelyn Turner-Musa (Department of Psychology, Morgan State University)
Dr Hongtao Yu (Department of Chemistry, Morgan State University)

FUNDING

A Student-Centered, Entrepreneurship Development (ASCEND) Training Model to Increase Diversity in the Biomedical Research Workforce; National Institutes of Health

FURTHER READING

F Kamangar, et al, Empowering undergraduate students to lead research: The ASCEND Program at Morgan State University, in (ed.) Broadening Participation in STEM (Diversity in Higher Education, Volume 22), pp 35– 53, 2019, Emerald Publishing Limited.

F Kamangar, et al, An entrepreneurial training model to enhance undergraduate training in biomedical research. BMC Proceedings, 2017, 18, doi: 10.1186/s12919-017-0091-8.

THE REPID PROGRAM – INCREASING DIVERSITY IN BIOMEDICAL RESEARCH

Dr Elahé Crockett and colleagues at Michigan State University have developed the Research Education Program to Increase Diversity in health researchers (REPID) program to train students from underrepresented, minority and disadvantaged backgrounds in the basic and advanced biomedical sciences. The goal of the program is to overcome the lack of diversity in biomedical research and clinical practice.

Minority Representation in Biomedical Research

There is a startling difference in the proportion of underrepresented groups in the healthcare industry. Several ethnic groups, specifically African Americans, Hispanics, Native Americans, and Hawaiian/Pacific Islanders and socioeconomically disadvantaged individuals, such as women and people with a disability, are repeatedly underrepresented in biomedical and clinical research and clinical practice.

Although there is a clear need for a diverse taskforce in biomedical science, the current scenario represents one of a homogeneous group and this lack of diversity is particularly apparent in postgraduate education. The number of doctoral degrees awarded to underrepresented students in the US is significantly less than the number of bachelor's degrees.

This disparity continues along the academic ladder – the National Institutes of Health (NIH) estimated in 2012 that only 5% of principal investigators who received grants in 2010 belonged to underrepresented groups. In order to create a diverse healthcare workforce that is culturally inclusive, it is imperative to encourage and train a diverse student population in basic and clinical research.

A Grassroots Program to Improve Diversity in Biomedical Research

Dr Elahe Crockett, the project director of the Research Education Program to Increase Diversity in health researchers (REPID) at Michigan State University (MSU), is dedicated to addressing this problem.

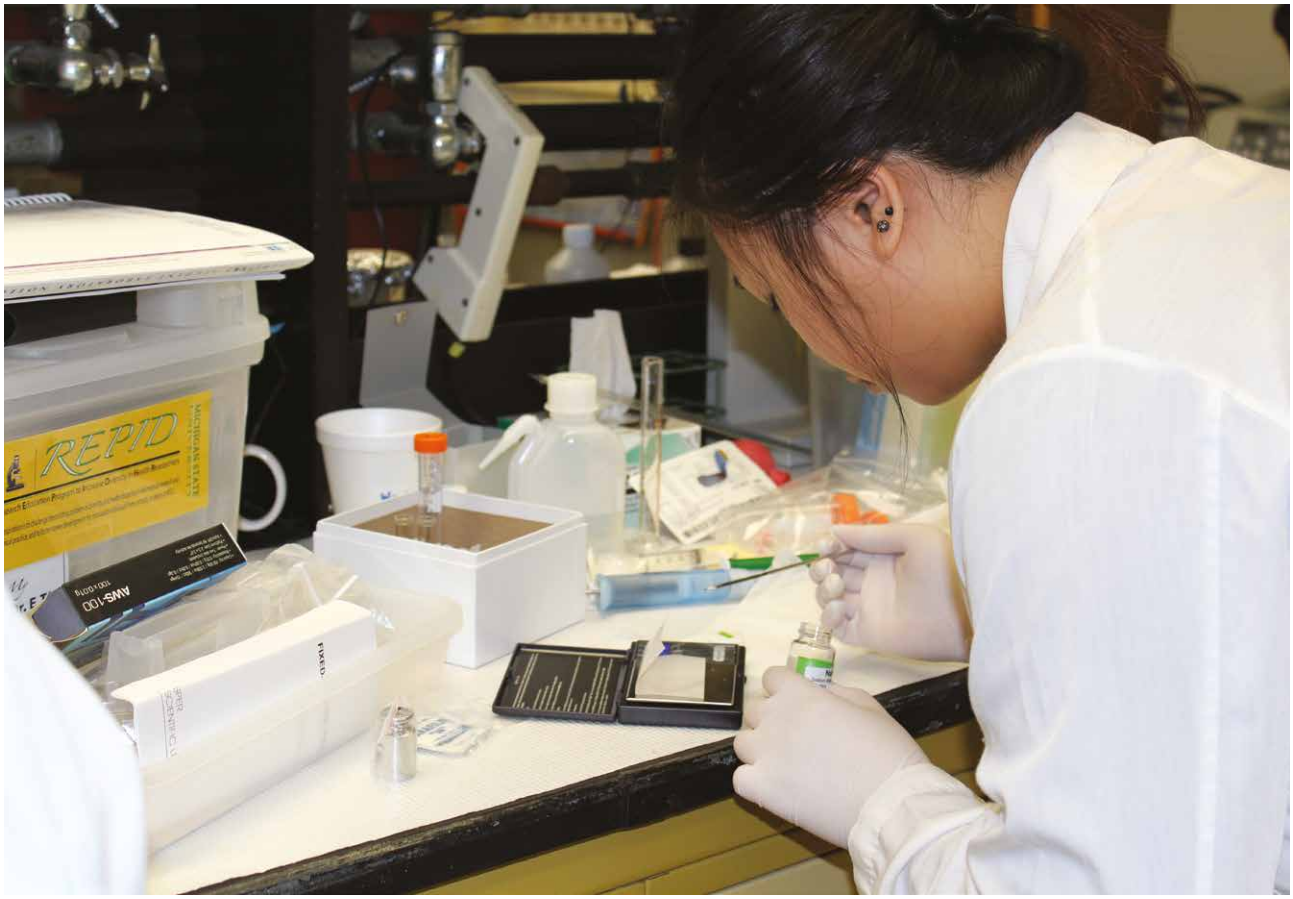
Since 2011, Dr Crockett has been working with a team of highly qualified faculty at MSU that has successfully mentored and trained over 100 students from underrepresented, minority and disadvantaged backgrounds in basic and advanced biomedical science disciplines, with the goal of overcoming the lack of diversity in biomedical research. The REPID program aims to provide comprehensive research training and enrichment experiences for students from underrepresented groups to inspire them to pursue careers in health-related research.

The REPID program includes an introductory course in biomedical research basics and a summer research project that provides hands-on

research experience to REPID scholars in a biomedical science laboratory or clinic. The program is specifically designed to focus on the dissemination of information on basic science and translational and clinical research in biomedical science, especially in cardiovascular, pulmonary, and haematologic disease research.

Through regular seminars and the use of the excellent educational resources available at MSU, the program teaches concepts that are common to all biomedical research disciplines such as integrity, literature review, critical thinking, experimental design, research laboratory skills, data collection and analysis, and modes of scientific reporting such as manuscript preparation and effective oral and poster presentations.

‘I would like to expand my training online to reach students and learners in remote areas or towns that don’t have access to university and research institutions. In particular, I am interested in teaching biomedical science to girls. They should know that girls are smart and can be great scientists and even get the Nobel Prize!’



Moreover, by promoting direct interaction of the REPID scholars with their mentors, graduate and medical students and faculty clinicians, and by encouraging scholars to present their research findings at symposiums, meetings and conferences, the program instils self-confidence and cultivates positive attitudes toward learning and professional development.

The scholars come away with an understanding of current research issues and identify career paths in which they can make a contribution to advance research and improve public health. REPID scholars have access to several resources that are tailored towards their successful entry into advanced medical and/or graduate programs.
Scholars are given an individualised developmental plan, which identifies barriers to success and provides personalised suggestions by the mentors and the advisory committee. The program fosters the development of professional skills and good research and clinical practice, all of which greatly helps students to establish and launch successful careers in the biomedical sciences.

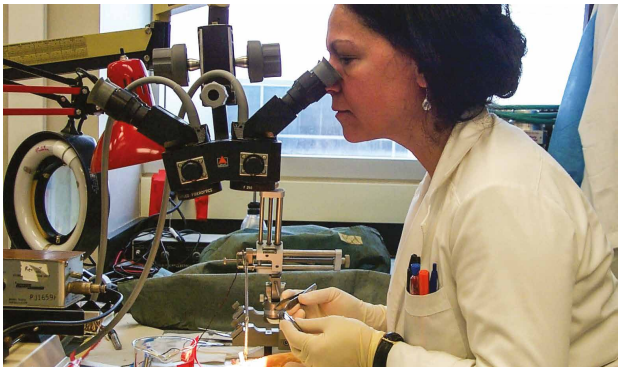
Unity in Diversity, Diversity in Society

Since 2011, Dr Crockett has helped mentor over 100 REPID scholars in a wide variety of topics including but not limited to heart, lung and blood disease disciplines. Funded by the National Institutes of Health and the National Heart, Lung and Blood Institute (NIH – NHLBI), the REPID program builds on the foundation provided by existing supportive structures at MSU, such as the premedical/human biology undergraduate and biomedical/medical graduate programs.

MSU provides a vibrant environment for student career development, with a strong emphasis on inclusiveness and diversity. With dedicated talented mentors whose research spans a wide spectrum of biomedical science, REPID scholars experience highly interdisciplinary research that is aimed towards solving global health issues.

These scholars acquire in-depth knowledge into basic biomedical techniques including the growth of isolated cells in the laboratory or cell culture, molecular biology techniques, microscopy and reagent preparation, setting them up for a successful career in research and clinical practice.

Dr Crockett has also developed a mobile laboratory kit that students can use to practice their laboratory skills and assignments remotely with online faculty guidance. All students



also get the experience of presenting at the annual summer undergraduate research conference at MSU, with some also going on to give national and international oral and poster presentations.

Focus on Health Research Problems

Dr Crockett's research focuses on understanding the molecular and cellular mechanisms of the inflammatory response to injury of different tissues such as the liver. Through the use of mouse models, her research has provided several insights into Hepatic Ischemia Reperfusion Injury (HIRI). This type of injury, which occurs in the liver, is caused when a tissue that has been damaged regains its blood and oxygen supply.

Paradoxically, this injury is often more severe than the original injury and may lead to several complications such as increased postoperative recovery time, multiple organ failure and even death. Dr Crockett and her mentees, who are often undergraduate or graduate students from underrepresented backgrounds, have shown how developing a new form of therapy, called anti-adhesion therapy, might be a useful method to improve survival outcomes and decrease organ injury in HIRIs.

Their research showed that this likely works through the regulation of inflammatory mediators called cytokines/chemokines. The team's research has also shown that due to differences in the levels of hormones, female mice are more capable of responding and resolving tissue injury compared to male mice. They have also identified that the best method of blood collection from mice is from the heart and that gender differences and the location of blood collection could significantly affect the interpretation of results that are generated in different studies.

In addition to her research into tissue injury, Dr Crockett engages in research that aims to improve the health conditions of minority groups. For instance, a recent study carried out by REPID scholars under the mentorship of Dr Crockett and Dr Won Song, published in the journal BMC Public Health in 2016, identifies the role of the nutritional attitudes of childcare providers of Migrant and Seasonal Head Start Programs (MSHS) in determining their health status and its association with migrant childhood obesity.

The study showed that childcare providers who practised weight loss methods and were dissatisfied with their weight were more likely to be obese/overweight compared to those who displayed healthy eating behaviours. Given that migrant children spend a considerable amount of time with non-family childcare providers, they fall in a high-risk category for developing health conditions such as obesity. The research suggested that the nutritional health status of young children enrolled in MSHS programs can be improved through offering nutrition education to the childcare providers that work in these programs.

The REPID program encourages scholars to pursue meaningful healthcare-related research. Accordingly, REPID alumni have gone on to excel in careers related to biomedical science. Dr Crockett and her team report that out of 66 REPID scholars that had been recruited over the first four years of the program, 24 continued to pursue their undergraduate program at MSU, 15 went into medical schools across the US, 11 pursued graduate programs across the US and nine scholars proceeded to take on careers in a health profession.

Looking Towards a Diverse Future

Programs such as REPID ensure that the future of healthcare research and the healthcare industry is in safe hands, with a focus towards cultural inclusiveness and sensitivity. The REPID program was awarded the '2015 Association of the American Medical Colleges building bridges and spanning boundaries award' for their innovation in research and research education. They have been nationally recognised several times as a successful program that fosters diversity and inclusiveness.

Dr Crockett has plans to expand the REPID program in the coming years. Armed with NIH funding until 2021, she plans to develop the program even further to include more underrepresented minority students. 'I would like to expand my training online to reach students and learners in remote areas or towns that don't have access to university and research institutions. In particular, I am interested in teaching biomedical science to girls. They should know that girls are smart and can be great scientists and even get the Nobel Prize!'

Meet the researcher

Dr Elahé Crockett
Department of Medicine
Michigan State University
East Lansing, MI
USA

Dr Elahé Crockett has served as a research scientist, educator and administrator throughout her career. She received a BS degree in Medical Technology, and after working for the WHO (World Health Organization), she pursued a Master's degree in Clinical Laboratory Pathology. After obtaining her PhD in human anatomy at Michigan State University (MSU), she pursued a National Institutes of Health Post-Doctoral Fellowship, training in Immunopathology at the University of Michigan (UM) Medical School. She worked for ten years at UM as Assistant Research Professor and currently serves as a Professor in the Department of Medicine at MSU where she researches leukocyte biology, inflammation and tissue injury. Since 2011, she has also been serving as the director of the REPID (Research Education Program to Increase Diversity in Health Researchers) program and has trained many undergraduate/graduate students, and medical professionals in biomedical research.

CONTACT

E: ecrocket@msu.edu
W: www.repid.msu.edu

FUNDING

NIH – National Heart Lung and Blood Institute
Michigan State University Offices of Provost and VP for Research

MICHIGAN STATE
UNIVERSITY

MITIGATING CHALLENGES FACED BY WOMEN OF COLOUR IN PHYSICS

Women of colour face many obstacles in their pursuit of STEM education and employment, especially in the field of physics. **Dr Apriel Hodari**, Principal Investigator at Eureka Scientific, and **Dr Angela Johnson** of Saint Mary's College of Maryland, have been working on strategies to remove these barriers. Their solution involves significant cultural change within an institution, catalysed by strong leadership at the top.

Shortfall of Women of Colour in Physics

A document prepared by the US National Science Foundation in 2017 reported on the current situation for minority groups in STEM-related fields of study and employment. In summary, the report highlighted that women, persons with disabilities, and three racial and ethnic groups – African Americans, Hispanics and Native Americans – are significantly underrepresented. While the number of individuals from minority groups receiving university degrees has increased, there is still a major shortfall, especially in the STEM workforce.

Consider, for example, the area of physics. Women of colour received less than 4% of all physics degrees between 2004 and 2014, despite constituting 22% of all US citizens and permanent residents aged 18–24, and 16% of all bachelor's degree recipients. As far as the physics workforce is concerned, even though the number of women earning degrees in physics is increasing, the proportion of women in this field (20%) is the lowest of all the physical sciences. These are, indeed, worrying statistics.

Two of those taking action to remedy this situation are Dr Apriel Hodari, Principal Investigator at Eureka Scientific, and Dr Angela Johnson, Professor of Educational Studies at Saint Mary's College of Maryland. Both are experts in the field of STEM educational research, especially that pertaining to equity and workforce diversity, and the culture of STEM disciplines. The focus of their recent work has been understanding the institutional cultures and environments that are contributing to the disparities between white and black, male and female, in the field of physics. Their ultimate goal is to improve the representation, progression and success of minority ethnic staff and students within higher education.

Moving Away from the Deficit Model

On a fundamental level, Dr Hodari and Dr Johnson feel that educational institutions need to move away from what is known as the 'deficit model' of education. One source explains that the deficit model of education is a perspective that attributes poor achievement to a lack of effort or a deficiency in the individual, rather than to failures of overarching social

and educational systems. Locating deficiencies in the students who drop out, rather than the institution, makes it difficult for institutions to take any actions to correct the problem. This approach essentially treats the symptoms of college dropout, not the actual cause.

To correct this, there needs to be greater emphasis on the broader cultural elements within an academic community, especially those that are negatively impacting the study and work experiences of women of colour in physics. Up until now, however, it has been easier to shift scrutiny and blame from the failures of educational institutions themselves to the student. Many issues arise when the finger of blame is pointed based on superficial, biased or inaccurate assumptions about the racial and cultural backgrounds of the individual student. A recipe for disaster, indeed.

On the other hand, as Dr Hodari and Dr Johnson point out, people from different ethnic backgrounds have different experiences during their journey through higher education, and they connect with it in different ways. All individuals have multiple identities, and the intersection of those different identities should be considered wherever possible, especially when analysing data and developing strategies to promote the retention and success of women of colour. In summary, we need individualised support, not assumptions. An understanding of the challenges that women of colour face is also paramount.

Exploring the Challenges Faced

In research of 2017, Dr Hodari, Dr Johnson and their colleagues highlighted that between 2002 and 2012, only 1% of graduating physics majors were Black women and another 1% were Latinas. Moreover, only 61 Native American women completed degrees in physics in those years (out of 48,000 physics majors). So, to address this, the team wanted to find out the specific challenges faced by women of colour in physics education. They hoped that this would, in turn, inform cultural and institutional-wide remediation efforts.

The team's approach involved looking at real-life instances where women of colour were both struggling and thriving, and the characteristics of the department and study environment that was contributing to this. Their method of choice was qualitative: including open-ended interviews and ethnographic field notes. Given their disciplinary overlaps with physics, the studies included participants from fields with similar underrepresentation of women of colour, namely, astronomy and astrophysics. Additionally, the work benefitted from previous research in mathematics, computer science, and engineering.

Stereotypes, Isolation and Microaggression

Prior research by Dr Hodari and Dr Maria Ong into the experiences of women of colour in physics revealed a challenge: the activation of stereotypes and resulting feelings of isolation. Put simply, academics and fellow students tended to associate science with white males, not women of colour. While that may seem to be rather callow reasoning, it permeates the attitudes of many in educational institutions and the STEM workforce today. This attitude, in turn, affects the way professors and fellow students unconsciously view the potential of women of colour for success, and they treat them accordingly.

These stereotypes perpetuate feelings of vulnerability and isolation in the student. It snuffs out their self-belief. The research team found that many students felt judged on their appearance and background – that they had no right to be studying physics. Many also expressed being afraid to ask questions in class or go to professors for help, for fear of reinforcing negative stereotypes towards women of colour. To further compound the issue, as those interviewed were often the only women of colour in their physics class, they could not even turn to their peers.

Many participants in the study also reported that they had been subject to instances of what Dr Hodari and Dr Johnson refer to as 'microaggression'. Sue and colleagues define microaggression as 'subtle indignities, slights or insults directed

at individuals, consciously or unconsciously, because of their race or gender'. In most cases, the hostility stems from bigoted and racist beliefs on the part of the aggressor. Researchers have found that women of colour who had been subjected to this treatment experienced feelings of loneliness and inadequacy. Needless to say, these experiences negatively affected their engagement with their studies.

Evidence-based Solutions

Many of the participants in Dr Hodari and Dr Ong's study highlighted that having a counterspace – a setting where they could find validation, vent frustrations about racism and sexism, and express both their identities as scientists and as women of colour – was vital to overcoming the challenges they faced. Counterspaces can take many forms – from student groups and mentor relationships, to conferences and enrichment programs. Essentially, counterspaces are any locations, events or forums that give women of colour a voice.

It is also important to note that these counterspaces can be found within departments. In prior research, Dr Johnson has found that professors who focus on developing an inclusive community can turn feelings of isolation into feelings of belonging. They can do this by creating opportunities for students to interact outside of class time and to work together. In a more direct sense, faculty can directly address microaggressions that come to their attention, by rejecting any stereotypes that are brought up, directly affirming that women of color belong in their departments and insisting that microaggressions end. And finally, the teaching strategies of educators can do much to address negative stereotypes and anti-social behaviour. It is vital that professors create learning environments designed around the needs of those from underrepresented minority groups.

Conclusion

The shortfall of women in physics and the physics workforce certainly is a cause for concern. Dr Hodari and Dr Johnson's research has shed light on many of the challenges faced by women of colour that are contributing to this shortfall. Primarily, women of colour face active stereotypes, isolation and acts of microaggression from both teaching staff and fellow students. This hinders their success because it tears down their identity and self-esteem. It negatively impacts upon their confidence and self-belief. Many give up. Or worse still, many young women feel discouraged from beginning their studies in physics in the first place.

Two of the main solutions to these problems include providing counterspaces and making faculty adjustments to stimulate an inclusive community. All of this is underpinned, not by the deficit model of education, but rather, turning the spotlight on STEM institutions and what they are doing to promote diversity and acceptance.

To this end, Dr Hodari and Dr Johnson have teamed up to locate universities where women of colour are thriving, to study how these institutions have created counterspaces or taken action to reduce the isolation and microaggression experienced by women of colour. They have already identified several institutions that are graduating surprisingly high numbers of women of colour in physics, and are currently identifying institutional policies and practices at these institutions. In the future, they hope to identify more of these exemplars and form a network of physics departments committed to becoming exemplars themselves.

In conclusion, the research of Dr Hodari, Dr Johnson and their colleagues has found that women of colour, over the course of their careers, face a consistent set of difficulties related to their race and gender. However, where supervising professors supported their learning and careers, and implemented measures to adjust the culture within the department, many of those challenges were mitigated.

Meet the researchers

Dr Apriel Hodari
Eureka Scientific Inc.
Oakland, CA
USA

Dr Angela Johnson
Department of Educational Studies
Saint Mary's College of Maryland
Saint Mary's City, MD
USA

Dr Apriel Hodari received her PhD in Physics from Hampton University in 1998. Following this, she was appointed as Postdoctoral Fellow of STEM Education with the US National Science Foundation (NSF). After several posts in industry, she was appointed Principal Investigator at Eureka Scientific, Oakland, California in 2014, where she currently serves. There, she co-leads research collaborations investigating the inherent cultures of inclusive STEM departments and seeks to learn from the experiences of women of colour in the fields where they are most underrepresented.

CONTACT

E: akhodari@gmail.com
W: https://www.eurekasci.com/cwcs/

Dr Angela Johnson received her PhD in Social Foundations of Education from the University of Colorado in 2001. Dr Johnson is an experienced physics teacher and researcher. After teaching physics and later teacher education at both school and college level for many years, she was appointed Associate Professor of Educational Studies, at Saint Mary's College of Maryland. She was later promoted to Professor and Department Chair of Educational Studies at that same institution, as well as Director of Teacher Education. Like Dr Hodari, her research focuses on addressing the challenges that women of colour face in physics education and the STEM workforce.

CONTACT

E: acjohnson@smcm.edu
W: http://www.smcm.edu/directory/faculty-profile/angela-johnson/

ACKNOWLEDGEMENT

Our profound gratitude to Maria Ong for co-leading several projects that preceded the work highlighted in this article. The current work is supported by the National Science Foundation under Grant No. DUE-1712531; as well as the Fulbright Scholars Program. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation, Fulbright United States-United Kingdom Educational Commission or the Council for International Exchange of Scholars.

FURTHER READING

A Johnson, M Ong, LT Ko, J Smith and A Hodari, Common Challenges Faced by Women of Color in Physics, and Actions Faculty Can Take to Minimize Those Challenges, The Physics Teacher, 2017, 55, 356.

INNOVATIVE TEACHING

HOLISTIC APPROACHES TO TEACHING STEM

Science, technology, engineering, and mathematics (STEM) underpin technological progress and discovery, and many of humanity's greatest challenges, such as climate change and the energy crisis, can only be addressed by a strong STEM workforce. Ensuring a strong workforce into the future depends upon effective and inclusive education in STEM subjects, from school to university and beyond.

However, many schools and universities still use outdated teaching methods, which rely on students simply memorising information and recalling it later in an exam. Although this form of teaching can be effective in certain situations, helping students to develop a knowledge baseline, it often fails to develop their critical thinking, problem solving and decision-making skills, which are all essential attributes for being a competent scientist or engineer.

Many modern teaching methods, on the other hand, encourage active engagement and facilitate student collaboration. Examples of such active learning include students taking part in research projects, and classroom-based problem-solving workshops. These activities allow students to explore and understand a given subject on a much deeper level, while also better preparing them for future careers in research. Modern educational practices also place greater emphasis on recognising the different needs and abilities of individuals, rather than assuming that all students have the same level of understanding.

In this section, we meet researchers who are committed to improving the quality of education by developing new, evidence-based and holistic approaches to teaching. These initiatives ensure better academic outcomes for students, which will ultimately lead to a stronger and more diverse STEM workforce. From infusing creative thinking into STEM education, to teaching students how to apply knowledge from one scientific discipline to another, we showcase an impressive range of initiatives.

We open this section by introducing Dr Jean-Luc Patry and Barbara Fageth at the University of Salzburg, and their collaborator Dr Angela Gastager at the University College of Teacher Education Styria in Austria, who are helping teachers to cultivate 'pedagogical tact', to improve outcomes for students. In this context, a 'tactful' teacher would be able to accurately assess the needs of individual learners in a classroom, and make appropriate decisions that allow students to get the most out of the lesson. Here, we showcase the researchers' endeavours to create a well-defined theoretical framework of pedagogical tact, and their ongoing investigations into its validity in school and university settings.

Our second article introduces an initiative that fosters problem-solving skills in young children. Dr Mia Dubosarsky and Dr Melissa-Sue John of Worcester Polytechnic Institute, along with their collaborator Dr Florencia Anggoro of the College of the Holy Cross, have developed an innovative curriculum called Seeds of STEM, which provides preschool children with the skills they need to pursue STEM-related studies in the future.

Next, we introduce Dr Korbinian Moeller and his team at the Leibniz-Institut für Wissensmedien, who are working to identify the cognitive and neuronal processes underpinning children's mathematical ability. Intriguingly, bodily actions, such as counting on one's fingers, appear to play a critical role. We read how Dr Moeller's work in 'embodied numerosity' is informing advances in the teaching of numeracy to children. Developing numeracy skills at such an early stage in a child's life sets the foundation for their future education in STEM subjects.

Continuing with the theme of childhood numeracy, we meet Dr Jessica Hunt of North Carolina State University, who focuses on developing an understanding of mathematics in children with learning disabilities. By considering each student's perspective, Dr Hunt has shown how continued cycles of observation, interaction, and lesson tailoring assist students in increasing their understanding of complex mathematical concepts. Through her work, Dr Hunt has also identified teaching strategies and exercises that could benefit all students.

Although critical to many STEM fields, high-school students often struggle with higher order mathematics such as trigonometry. Therefore, Dr James McClelland at Stanford University is working to identify effective ways of making complex mathematical concepts more meaningful and accessible to students. With initial evaluations showing that three-quarters of all students demonstrate successful learning outcomes as a result of his approach, Dr McClelland now seeks to identify the factors that will allow students get fully to grips with mathematics.

We then meet Dr Eugenia Etkina from Rutgers University, who developed the 'Investigative Science Learning Environment' ('ISLE'), a novel method for teaching physics. Now, along with a team of experienced scientists, this approach is being refined further with the goals of teaching students to think like scientists and encouraging them to learn independently.

Moving on to initiatives in biology, we read about the 'Partnership for Undergraduate Life Sciences Education' ('PULSE'), which was founded in 2012 as part of a collaboration between the US National Science Foundation, the Howard Hughes Medical Institute, and the National Institute for General Medical Sciences. The PULSE working group is a team of educators and administrators who work to progress the quality and content of courses delivered by biology departments, in order to ensure the development of highly trained graduates.

Stepping beyond subject-specific knowledge, Drs Rebecca Matz, Sonia Underwood, and Kristin Parent, along with their collaborative research team at Michigan State University and Florida International University, seek to improve students' ability to make connections between different scientific disciplines. Their two-year project, 'Creating Assessments for Student Understanding of Core Chemistry Ideas in Introductory Biology', aims to foster a multidisciplinary approach to science learning.

On an even broader level, Dr Raphael DiLuzio at the University of Southern Maine infuses creative thinking into STEM education through research, workshops, and creativity courses. Here, we read about the seven stages of the creative process, and of the importance of continuously capturing ideas regardless of how small or useless they might initially appear.

Continuing on the theme of creativity in science, the next article showcases an interdisciplinary training program that teaches graduate students to apply digital media and graphic design to communicate their research to general audiences. Here, we meet the program's creators, Dr Daniel McGarvey and Sarah Faris at Virginia Commonwealth University, who hope that this arts-based approach will prepare budding scientists to be effective science communicators.

In addition to creativity, entrepreneurial thinking is also an essential part of being a successful researcher. In this section, we meet Dr Caesar Jackson, Dr Alade Tokuta, Dr Tanina Bradley, and Clarrisa Grady, all at North Carolina Central University (NCCU), who are pioneering new approaches to developing students' sense of scientific identity and entrepreneurial mindset. Their program, 'Driving Research, Entrepreneurship, and Academics through Mastering STEM', has already increased enrolment, retention and graduation rates in STEM degree programs at NCCU, producing highly skilled STEM graduates.

Collaboration is yet another vital component of being a modern-day researcher. Thus, providing students with opportunities to collaborate on various projects prepares them for a successful career in STEM, particularly in today's team-focused research world. In the next article, we meet Dr Susan Cozzens at Georgia Tech and her interdisciplinary team, who

develop and implement evidence-based curricula for STEM graduate students, with a particular emphasis on collaborative research. Dr Cozzens and her colleagues have created a flexible and complementary team science curriculum that can be delivered to audiences beyond academia, and plan to develop a nationwide program that will make a significant contribution to graduate STEM education in the USA.

In the final article of this section, we take a step outside of the classroom, where we introduce the work of Dr Katie Davis and colleagues at the University of Washington. Achievements outside of formal schooling are rarely given credit by educational institutions or employers, but may nonetheless hold considerable academic value. Through the development of a digital badge system that represents students' informal learning outside of the classroom, Dr Davis and colleagues are increasing the visibility of non-traditional, STEM-related achievements, progressing their future educational and career goals.

IMPROVING EDUCATION THROUGH CULTIVATING PEDAGOGICAL TACT

Pedagogical tact is broadly defined as a concept that addresses how teachers transfer educational theories to their teaching practice, in order to achieve their educational goals (which include students' learning) most successfully. Although this concept has been widely referred to in past research, it remains very complex and difficult to define. To better delineate this concept, researchers at the University of Salzburg and the University College of Teacher Education Styria have developed a new theory of pedagogical tact and explored its validity in school and university settings. By better conceiving this concept, the researchers hope to help educators to cultivate pedagogical tact, enhancing the academic development of their students.

A Complex Theoretical Concept

To teach effectively, educators must be able to translate the educational theories they learned during their training into their teaching practices in the classroom. This ability is far from insignificant, as past research has highlighted a considerable disconnect between theory and practice. This disconnect has been addressed in the works of numerous pedagogues in the late 18th and early 19th century, including Ernst Christian Trapp, Johann Friedrich Herbart, and Friedrich Schleiermacher.

First introduced by Herbart in 1802, 'pedagogical tact' is one of the most widely discussed concepts when it comes to transferring educational concepts or theory into practice. In order to do this effectively, educators need to adopt a certain 'tact', which ultimately allows them to adapt a given educational theory to meet the requirements of individual learners or classrooms. For example, a tactful teacher would be able to accurately assess the needs of individual learners in a classroom, and make appropriate decisions to allow the students to get the most out of the lesson. Such tactful decisions would be based on educational theories, among other things.

Although Herbart's notion of 'tact' is widely cited and discussed in education studies, his work only provides a few vague theoretical elements to describe it. Other notable experts in the field, such as Herman Nohl and Jakob Muth, presented more sophisticated approaches to define this idea of 'tact', yet they also failed to provide a satisfactory and comprehensive account of it.

Dr Jean-Luc Patry and Barbara Fageth at the University of Salzburg, along with their collaborator Dr Angela Gastager at the University College of Teacher Education Styria in Austria, have built on these approaches to develop a theory of pedagogical tact that capitalises on

previous concepts, including empirical research in psychology and education. The team hopes that their new theory will guide educators in effectively transferring educational theories in the classroom, which will ultimately enhance the preparation and academic development of trainee teachers and students.

Theory and Practice

To develop their theory of pedagogical tact, Dr Patry, Dr Gastager and Fageth first set out to achieve a thorough understanding of the relationship between educational theory and teaching practice. The researchers

found that there are several reasons why educational theories are difficult to transfer in the classroom, some of which are outlined below.

Firstly, theories comprise statements, while practice involves action; thus, there cannot be a direct relationship between them. Despite the absence of a direct link, actions can be guided by theories, if the latter are incorporated into an educator's system of subjective theories. 'This incorporation will never fully match the corresponding [educational] theories,' the researchers explain in one of their papers. For example, a teacher might only learn certain parts of a given educational theory, and these parts may be simplified compared to the original theory.

Secondly, as highlighted by the researchers, theories have a certain degree of generality, which allows them to be applied in a variety of different situations. However, the more general a statement is, the less likely it is to provide concrete or detailed instructions for action.

In addition, to achieve different goals simultaneously, a teacher might need to combine different theories, some of which might not be compatible. A fourth reason is that social behaviour, such as that taking place in a classroom, is often situation-specific, while most educational theories do not address the specifics of different educational settings. These are just a few of the problems addressed by the researchers in their work.

Existing Theories of Tact

Countless researchers have attempted to address the transfer from theory to practice in their work, yet Herbart's has been the most influential approach so far. According to Herbart, the effectiveness of a teacher depends on 'how well tact forms within him or her'.

Herbart, Nohl, Muth and others suggest that tact can only be attributed to an action if it is aligned with some ethical reference standards. However, it is unclear whether these standards are defined by authorities (such as the school principal or parents) or by the teacher's own value system. Moreover, none of these approaches indicates whether situation specificity plays a role in tact, and if it does, then how.

Other frameworks, dubbed 'action theoretical models', integrate tact with other pedagogical concepts, such as the Cognitive-Affective Personality System (CAPS), which is a personality theory proposed by Walter Mischel and Yuichi Shoda in 1995. Although many adaptations of Herbart's notion of tact provide valuable insight into this fairly elusive concept, all of them are incomplete, as they fail to adequately address the key issues with translating educational theory into practice.

A New Theory of Pedagogical Tact

The new theory of pedagogical tact developed by Dr Gastager, Fageth and Dr Patry revisits some of the concepts introduced by Herbart, Nohl and Muth, and tries to better conceive the ways in which pedagogical tact can help teachers to translate educational theory into practice. According to the researchers, a theory of tact should take a number of elements into account, including the theories used

by a particular teacher and his or her non-verbal expressions, sensitivity, intuition, experiences, empathy and authenticity. 'These elements need to be put into a theoretical framework that addresses the relationships between them,' the researchers explained in one of their papers.

In their work, the team identified CAPS as the best theoretical framework for developing a theory of tact. The CAPS framework lists six dimensions that can account for situation-specific behaviour: competence, perception categories, expectations, goals, self-regulatory strategies and emotions.

Each of these dimensions comprises several elements, hence the CAPS framework accounts for the pursuit of very different educational goals simultaneously. In addition, the framework can easily be adapted to fit different cases, as different dimensions can be activated according to the requirements of a particular situation. The researchers found that CAPS can be easily adapted into a theory of pedagogical tact, particularly by focusing on how its different dimensions interact when a teacher is deciding how to act in a particular situation.

Testing the Theory

Although the units of the original CAPS framework are pretty straightforward, when applying it to tact, one might need to consider others tact-specific elements or relationships between different dimensions. To develop an exhaustive theory of tact, therefore, the researchers decided to test different hypotheses in a series of studies carried out in Austrian secondary schools, universities and kindergartens.

In a first study, they recorded and transcribed a counselling session between a counsellor and her client, then analysed the thoughts presented in it using a framework containing some elements of their theory of tact. In another study, students at the University of Salzburg completed practical and interactive exercises, and were then asked to analyse the content of these tasks using a coding handbook based on the theory of tact. In yet another study, the team video recorded experienced kindergarten teachers as they taught in various situations, and analysed the teachers' accounts of the interactions with the children based on the recordings.

Then, in a pilot study, the researchers evaluated aspects of their theory at a secondary school in Austria, by investigating the teaching practices and the related teacher thoughts of three mentors and five of their trainee teachers. Subsequently, 13 senior teachers and 21 trainee teachers were analysed with the same method as above, yet using a qualitative-quantitative mixed analysis approach. This study allowed the researchers to compare the ways in which novices and experts are able to translate educational theories into their teaching practices, using an assessment tool based on the team's new theory of pedagogical tact. This helped them to evaluate the validity of their framework and assess its tact-relevant dimensions under the assumption that senior teachers act more tactfully than trainees.

The studies carried out by Dr Patry and his colleagues are not yet conclusive; thus, further testing is needed to ascertain the validity of their theory. Nonetheless, these studies provided valuable insight and allowed them to test some elements of their framework. For instance, the researchers found that their CAPS framework might be applicable in a variety of situations, as different dimensions can be activated according to the requirements of the situation at hand. This sets their theory apart from previous approaches to pedagogical tact, which did not address situation-specific requirements.

A More Useful Vision of Pedagogical Tact

The theory proposed by Fageth, Dr Patry and Dr Gastager offers an account of pedagogical tact based on empirical and detailed analyses of actions in situations, hence pinning down a concept that has remained elusive for years and rendering it accessible for empirical research. In the future, the researchers hope to test different aspects of their theory further in a variety of educational settings.

For instance, they would like to use their theory to study how educational theories can be effectively translated into practice, as well as to develop instruction frameworks that could help to better understand and assess an educator's teaching practices. In years to come, the researchers will also use their theory to develop a practice-oriented book that can guide educators in fostering more 'tactful practices'.

The overarching goal of this project is that of improving the practice of professionals in the field of education. To share their vision with other educators, the researchers published a book and many articles and presented their findings at various education conferences, including the EAPRIL (European Association for Practitioner Research on Improving Learning) and EARLI (European Association for Research in Learning and Instruction) conferences.

Meet the researchers

Dr Jean-Luc Patry
Department of Education
University of Salzburg
Salzburg
Austria

Dr Jean-Luc Patry holds a PhD in science and a certificate for teaching biology from the Swiss Federal Institute of Technology (ETHZ). Before completing his degree, he worked as an assistant at ETHZ, and then taught at the University of Fribourg for almost ten years. He also worked as a visiting scholar at Stanford University and Lehigh University, before joining the Department of Education at the University of Salzburg in 1993. In addition to his teaching posts, he has been an active member of several committees and associations, including the Swiss and Austrian Associations for Research in Education.

CONTACT

E: jean-luc.patry@sbg.ac.at
W: https://www.uni-salzburg.at/index.php?id=21788

Dr Angela Gastager
Institute for Educational Sciences
University College of Teacher Education Styria
Graz,
Austria

Dr Angela Gastager began her career in 1982 as a primary school teacher – a post that she covered until 1994. Between 1992 and 1994 she pursued studies in Gestalt Educational Counselling in Salzburg and Graz. She then attained a Master's degree and a PhD in Education from the University of Salzburg. She worked in several research and teaching assistant positions at the University of Salzburg and University of Education in Weingarten in Germany, where she was also certified in adult education. In 2009 she became a staff member and professor at the Institute for Educational Sciences at the University College of Teacher Education Styria, Graz, where she currently works.

CONTACT

E: angela.gastager@phst.at
W: https://www.phst.at/phst/organisation-leitung/institute-praxiswerkstaetten/institut-fuer-bildungswissenschaften/hs-prof-mag-dr-angela-gastager/

Barbara Fageth
Department of Education
University of Salzburg
Salzburg
Austria

Barbara Fageth has been involved with FWF project 'Pedagogical Tact' since 2015 and is mostly responsible for the collection and analysis of data within elementary education settings. She has taught in elementary schools for several years and currently works at the Private Pedagogical University of the Diocese of Linz. Before that, Fageth was a member of the team managing the University of Salzburg's Elementary Education course. Between 2012 and 2014, she also worked as a junior researcher at the Federal Institute for Educational Research (BIFIE). She is set to complete her doctoral studies in 2019.

CONTACT

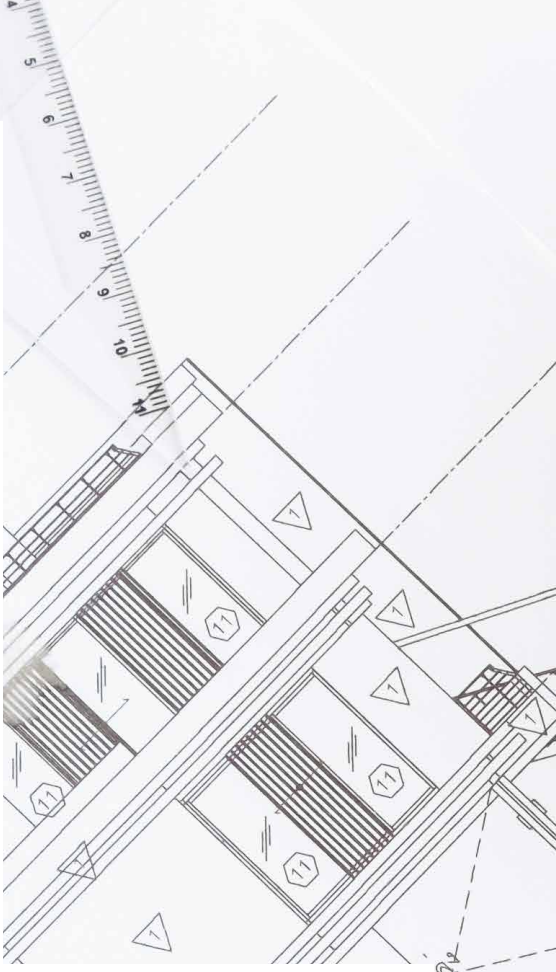
E: barbara.fageth@ph-linz.at
W: https://uni-salzburg.elsevierpure.com/de/persons/barbara-fageth-5

FUNDING

Austrian Science Foundation

SEEDS OF STEM: DEVELOPING AN INNOVATIVE EARLY CHILDHOOD CURRICULUM

Introducing science, technology, engineering, and mathematics (STEM) to younger generations has become a key priority for many researchers, educators, and policy makers. **Dr Mia Dubosarsky** of Worcester Polytechnic Institute (WPI) in Massachusetts, **Dr Florencia Anggoro** of the College of the Holy Cross (Worcester, MA), **Dr Melissa-Sue John** of WPI, and colleagues, in partnership with the Worcester Head Start program, have developed an innovative curriculum, *Seeds of STEM*, aimed at fostering problem-solving skills associated with STEM-related disciplines in preschool children.



Introducing Young Children to STEM Subjects

Continuous advances within the fields of science and technology are increasing the need for skilled workers that can meet the demands of modern society. Researchers, educators, and policy makers worldwide are trying to improve science, technology, engineering, and math (STEM) education, to ensure that future generations are introduced to these fields early on in life and are provided with the skills necessary for them to pursue related studies or careers in the future.

Most efforts to improve STEM education in the US have so far been limited to mathematics, science, and sometimes technology, all of which are generally included in the learning curriculum used by primary and secondary school teachers. In addition, engineering education has also received attention, with many US states adopting engineering education standards.

Early learning serves as a foundation for children's future learning, as the first five years of life are extremely important for cognitive and skill development. Past research has found that during these years, children not only acquire language at a rapid rate, they also actively explore their environments and form concepts and theories about the world. These fundamental structures are a basis for later academic learning and for a child's development of skills, strategies, and more complex constructs.

Introducing STEM-related concepts and skills to preschool children can, therefore, enhance their interest towards and engagement in these disciplines, prompting them to broaden their understanding of scientific fields in later years. As a result, early childhood educators have been exploring ways to introduce STEM-related topics and skills to preschool children, particularly those associated with engineering.

Engineering is a context-based subject that has real-life applications and often connects well with other areas of children's lives and experiences. While it sometimes overlaps with science, technology, and math, some of the skills used by engineers are unique. Children are sometimes described as 'born engineers', as they naturally tend to reason, define problems, build prototypes, and then test them or share them with others. Research has found that when teachers expose children to the *engineering design process*, children's motivation and interest in the subject tends to increase.

Studies suggest that there are considerable benefits to integrating engineering concepts

into the preschool curriculum, as they can enhance children's problem-solving skills, critical thinking, and scientific knowledge, while also fostering a positive attitude towards the field.

Despite evidence highlighting the benefits of early introduction to engineering ideas, instruction related to these topics is still very limited within pre-kindergarten classrooms. One of the reasons for this lack of instruction is that many teachers do not feel confident teaching STEM, partly due to a lack of preparation in these areas, and also due to shortages in early childhood STEM curricula and the resources available to them.

A group of researchers at Worcester Polytechnic Institute, in collaboration with the College of the Holy Cross and the Worcester Head Start program, are trying to address these issues by developing innovative and integrated STEM teaching material for preschool children: *Seeds of STEM.*

‘The *Seeds of STEM* project was funded to answer a critical need – to develop high-quality STEM curricula for preschool classrooms that is authentic and easy to follow by teachers.’

The *Seeds of STEM* project

In collaboration with pre-kindergarten teachers from Head Start in Worcester, MA, the research team has created *Seeds of STEM*, a high-quality STEM curriculum designed to enhance problem solving and critical thinking in preschool children aged three to five years. *Seeds of STEM* is a three-and-a-half-year project funded by the Institute of Education Sciences (IES) at the US Department of Education, that focuses on developing and testing a STEM-oriented curriculum for children attending pre-kindergarten.

The Principal Investigator leading the project is Dr Mia Dubosarsky, current Director of Professional Development at WPI’s STEM Education Center, a hub that provides STEM-related professional training, licensure, and degree programs for educators. ‘The *Seeds of STEM* project was funded to answer a critical need – to develop high-quality STEM curricula for preschool classrooms that is authentic and easy to follow by teachers,’ says Dr Dubosarsky.

For more than two years, the *Seeds of STEM* team partnered with teachers from the Worcester Head Start program to develop a set of eight curricular units, aimed at guiding both children and their teachers in problem solving using the *engineering design process*. Teachers who taught the curriculum in their classrooms were asked to complete a detailed feedback form that was used to improve the units before further testing. This process was then repeated for three groups of teachers.

‘The units were developed through an extensive iterative process – the team of researchers and teachers created the unit draft, which was then tested by the teachers in their classrooms. The process repeated itself two more times, with each group of teachers testing and providing feedback on an improved version of the curriculum,’ explains Dr Dubosarsky. During the development process, the team of researchers also carried out professional development workshops for all Worcester Head Start teachers that focused on the *engineering design process* and diversity in STEM.

Preschool Activities to Enhance Problem Solving

The different units of the *Seeds of STEM* curriculum are all built around the *engineering design process,* a set of steps that engineers follow when solving a given problem. The *engineering design process* generally consists of the following steps: defining the problem and criteria for a successful solution, brainstorming, selecting

a solution that meets the criteria, testing and improving this solution, and communicating the end result to others.

An imaginary character, Problem Panda, presents children with a different problem for every unit of the curriculum, asking them to engage in the process of understanding the problem, brainstorming ideas, selecting and creating a possible solution, revising the solution, and sharing it with others.

The units are carefully designed in a way that teaches children to solve problems, while also addressing key scientific concepts aligned with standards for preschool science. These concepts include topics such as natural habitats, the five senses, forces and motion, light and shadow, and more. For instance, in Unit Two, Problem Panda asks children to devise solutions to recover a ring that has been frozen inside an ice cube, asking children to apply concepts related to ice, water, solids and liquids for solving the problem.

The units are presented in a developmentally appropriate way that allows children to learn the problem-solving skills through experimentation, movement, and literacy. The first part of each unit engages children in experiences related to the science concepts, for example, stories about solids and liquids, melting and freezing experiments, going on a liquid/solid hunt, as well as singing and dancing. The second part of each unit brings Problem Panda, asking the children for help in solving a problem related to the science concepts they have just unpacked.

Teachers guide the children in brainstorming ideas to tackle the problems posed to them, emphasising that there are multiple solutions to every problem. Children are also asked to define the criteria for successful solutions – such as melting the ice fast and not breaking the ring – and then they sort the solutions as either testable or non-testable in a classroom setting. Finally, the children vote to identify the solution they would like to test first.

Evaluating the Project Outcomes

The *Seeds of STEM* curriculum was devised with two main student outcomes in mind. Firstly, children participating in the activities should demonstrate an improved ability to use problem-solving vocabulary. Secondly, their ability to carry out every step of the *engineering design process* and apply it to everyday problems should also improve.

During the third year of the project, the curriculum was pilot-tested in 16 classrooms at five preschool centres in central Massachusetts, as part of an experimental study evaluating the curriculum's outcomes. Eight of these classrooms were taught the full *Seeds of STEM* curriculum, while the other eight were used as a comparison group to determine whether the main goals of the project have been met.

Teachers from the intervention classrooms took part in three professional development sessions that provided useful background information about the *engineering design process* and explained how to teach problem-solving to young children. The teachers of the comparison classrooms were asked to stick to their usual curriculum, teaching only the last unit of the *Seeds of STEM* curriculum, which was used as an authentic performance assessment, gauging differences between children from both groups.

All teachers participating in the pilot study were asked to complete questionnaires assessing their prior knowledge regarding STEM and problem-solving, as well as their self-efficacy in teaching STEM-related topics to young children. The teachers were asked to comment monthly on children's learning, vocabulary, and the ability to apply the *engineering design process* steps throughout the day. The final unit of the curriculum, which serves as a summative assessment, also helps determine whether the children have mastered the main *Seeds of STEM* learning outcomes.

At the end of the pilot study, video recordings and questionnaires will be analysed to determine whether the main outcomes of the *Seeds of STEM* project have been met. The research team expects to observe changes in both teachers and students in the eight intervention classrooms. 'We expect to see an increase in teachers' self-efficacy, with regard to teaching STEM in preschool, as well as in content knowledge and pedagogy about teaching STEM to young children.' explains Dr Dubosarsky.

The study will also evaluate children's use of STEM-related vocabulary and their ability to follow the *engineering design process* steps, applying them in real-life situations, using a measure developed by Dr Anggoro and her students at Holy Cross. 'We expect to see children use the problem-solving vocabulary often and in context,' says Dr Dubosarsky. 'It is our hope that as a result of being engaged with the curriculum the children will internalise the problem-solving process, which will guide them to be critical thinkers and problem solvers in every aspect of their lives.'

Fostering STEM-related Skills in New Generations

As we approach a future marked by huge scientific and technological innovation, introducing children to STEM-related skills is of vital importance in order to start building the foundations that will help them to succeed in their future academic and professional endeavours. In our evolving society, education could play a substantial role in encouraging new generations to approach STEM-related fields, preparing them to meet the demands of what is expected to be a science and technology-fuelled future.

Engineering-related skills have so far been largely excluded from early education. Yet researchers, educators, and policy makers, are now recognising that fostering these skills could aid children's academic and character development. The *Seeds of STEM* curriculum is an innovative and engaging way of introducing STEM-related concepts to young children, while helping them to develop valuable problem-solving skills from their early years of life.

The project, funded by the Institute of Education Sciences (grant # R305A150571), should come to an end in 2019, but the researchers plan to further develop and test their curriculum in other US classrooms. Meanwhile, they also plan to carry out follow-up studies on children who were first exposed to the curriculum, to assess its long-term effects on their academic success.

In the future, the *Seeds of STEM* curriculum and professional development workshops may be made available to all preschool teachers, with some of the teachers who helped develop and test the curriculum coaching new educators who wish to introduce the learning material into their classrooms.

Meet the researchers

Dr Mia Dubosarsky
Director of Professional Development
The STEM Education Center
Worcester Polytechnic Institute (WPI)
Worcester, MA, USA

Dr Dubosarsky is the Director of Professional Development at WPI's STEM Education Center. She has a BA in Biology from Israel's Institute of Technology and a PhD in Curriculum and Instruction (Science Education) from the University of Minnesota. Dr Dubosarsky has been a STEM educator for more than 20 years and has conducted research in the areas of language development, STEM education, teacher professional development, culturally responsive curriculum development, and STEM in early childhood.

CONTACT

E: mdubosarsky@wpi.edu
W: https://www.wpi.edu/people/faculty/mdubosarsky
@seedsofstem

Dr Florencia Anggoro
Associate Professor
Department of Psychology
College of the Holy Cross
Worcester, MA, USA

Dr Anggoro is an Associate Professor of Psychology at the College of the Holy Cross, in Worcester, Massachusetts. She attained a BA in Psychology from the University of Wisconsin-Madison, as well as an MA and PhD in Cognitive Psychology from Northwestern University. Dr Anggoro has carried out extensive research related to language and conceptual development; science learning; spatial and relational thinking; and culture and cognition.

CONTACT

E: fanggoro@holycross.edu
W: https://www.holycross.edu/academics/programs/psychology/faculty/florencia-k-anggoro

Dr Melissa Sue John
The STEM Education Center
Worcester Polytechnic Institute (WPI)
Worcester, MA, USA

Dr John is a Research Associate at the WPI's STEM Education Center. She has a BA in Psychology from City University in New York, as well as an MA and PhD in Social Psychology from the University of Connecticut. Dr John has substantial teaching experience and has carried out research into academic achievement of ethnic minorities, immigration and intergroup behaviour.

CONTACT

E: melissasuejohn@gmail.com

Susmitha Wunnava
PhD Candidate
Worcester Polytechnic Institute (WPI)
Worcester, MA, USA

Susmitha Wunnava is currently completing a PhD in Data Science at WPI. She has a wide academic background in areas related to computer science, analytics, mathematics and software engineering. Her research interests include data-mining, text-mining, machine learning, and STEM education.

CONTACT

E: swunnava@wpi.edu

Dr Bernadette Sibuma
Research Scientist in STEM Education
The STEM Education Center
Worcester Polytechnic Institute (WPI)
Worcester, MA, USA

Dr Sibuma is a Research Scientist in STEM Education at WPI. She completed a BSc in Educational Psychology from Cornell University, as well as an MA and EdD in Instructional Technology and Media from Teachers College, Columbia University. Dr Sibuma has carried out extensive research and evaluation exploring learning in technology-based environments and in STEM education both in and out of school.

CONTACT

E: bsibuma@wpi.edu

PROJECT WEBSITE

https://seedsofstem.org/

FUNDING

Institute of Education Sciences (IES), 2015, Grant #R305A150571

KEY COLLABORATORS

The research team would like to thank its partners in curriculum development, Amy Herman, Colleen Bostwick, Christine Grudoff, Elizabeth Rogers Wright, Kathleen Kraemer, and Suchira Channoi, who helped create Seeds of STEM and were the first to test each unit in their classroom.

The research team is also indebted to its Advisory Board members for their feedback and guidance: Dr Martha Cyr, Dr Sarah Michaels, Dr Jeanine Skorinko, Dr Carlene Sherbourne, Dr Greg Mullaney, Dr Jody Figuerido, and Mr Bill Wolfson. The team thanks all its current and past research assistants.

WPI STEM Education Center · College of the Holy Cross · Head Start

THE BRAIN, THE BODY AND MATHEMATICS

Dr Korbinian Moeller and a team of researchers at the Leibniz-Institut für Wissensmedien are endeavouring to identify the cognitive and neuronal processes underpinning an individual's mathematical ability, by exploring the concept of embodied numerical training.

The Importance of Numeracy

The ability to perform and comprehend even the most basic of numerical calculations underpins many of the activities involved in daily life. Estimating the amount of money in your purse to determine whether you are able to make a necessary purchase, or perhaps calculating the number of nights to book your hotel when staying away from Friday to Wednesday, or the number of hours you have left at work – these are all day to day examples of processing number magnitude information.

However, what is perhaps less obvious is the fact that when conducting such calculations, bodily actions are often involved. Finger counting is one example – a process often utilised by children in their early numerical development but also observed in adults. For instance, when determining the number of nights to stay in your hotel, did you use your fingers? Why is this so?

A research field called 'embodied numerosity' explores the link between motor and sensory experiences and numeracy. An expert in this field is scientist Dr Korbinian Moeller. Since December 2012, Dr Moeller, who has expertise in Developmental Psychology, Neuropsychology and Cognitive Science, has headed the junior research group of Neurocognitive Plasticity at The Leibniz-Institut für Wissensmedien (IMW).

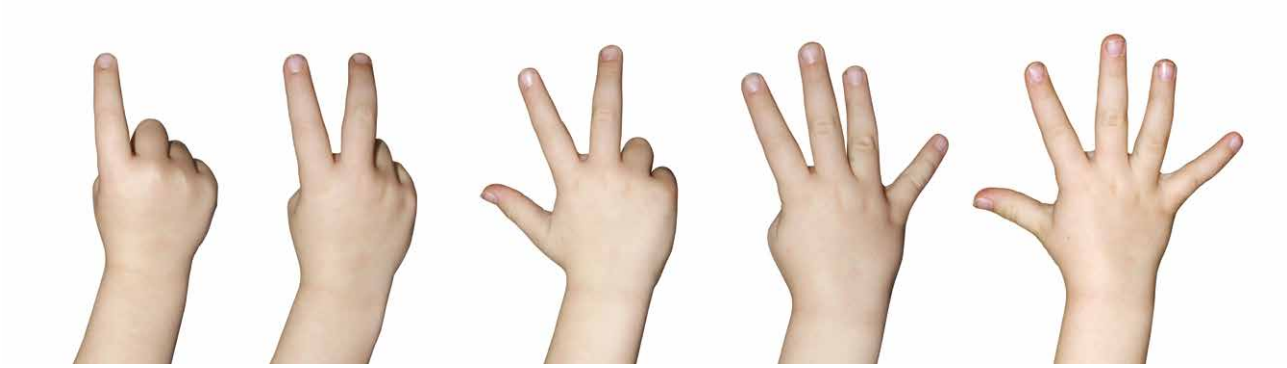
His team conducts in-depth research into the cognitive and neuronal underpinnings of the development of numerical and mathematical competencies. 'I pursue these interests employing the latest neuro-cognitive techniques such as fMRI and the consideration of neuro-functional models that allow us to associate numerical competencies to brain function and structure,' says Dr Moeller. By identifying such neuronal processes, Dr Moeller aims to create novel media tools that involve the entire body to enhance and promote numerical and arithmetic learning in children.

Fingers: Tools of Learning in Children

Entering into the research field of embodied numerosity, Dr Moeller, in collaboration with Dr Mirjam Frey and Dr Hans-Christoph-Nuerk, conducted an intervention study that aimed to address conflicting opinions regarding the value of finger-based numerical training in children. Previously, many countries adopted a syllabus for early mathematical teaching that largely dismissed the use of finger-based strategies in early math instruction.

This was viewed as a bid to prevent the adoption of counting-based computational strategies that had often been observed in children that were mathematically challenged. However, numerous neuropsychological research studies challenged this opinion, arguing that finger-gnosis (the ability to differentiate between fingers without visual feedback) and also fine motor

‘My work is driven by the idea that basic numerical abilities, such as counting and understanding number magnitude, serve as building blocks for later numerical and mathematical achievement. As such, these basic numerical competencies deserve special attention and promotion, for instance through new digital media that easily allows for the use of bodily experiences of numerical concepts.’



skills were a valid predictor of future numerical ability.

What remained inconclusive, however, was a distinct causal relationship. Dr Moeller and colleagues thus created a comprehensive study based on an earlier model of early numerical development. More than 100 children in the study sample group received 18 sessions of training in finger-gnosis, finger-counting and finger-based arithmetic strategies in their first year of primary school, whereas a similar-sized control group of children did not attend the finger-based training, and only took regular math classes. One example of finger-gnosis training adopted in the study was the assignment of different colours to different fingers, and asking the children to navigate their way through a labyrinth with a specific colour.

Before and after the training, the children were given a battery of mathematical tests that assessed their performance in different evaluation tasks, including mental arithmetic and number line estimation. Additional tasks were administered to control for influences of general cognitive abilities and working memory.

Dr Moeller and the team devised two hypotheses. Firstly, they proposed that finger-based training should specifically increase the understanding of numerical quantity and number relations, and therefore increase performance in mental arithmetic compared to the control group’s performance. This is because the concept of addition and subtraction can easily be conveyed by finger-based strategies.

Their second hypothesis was that finger-based training should not influence a child’s performance on tasks such as number line estimation. This hypothesis was formed on the basis that the idea of a mental number line, a spatial representation of number magnitude in which numbers increase from left to right, is hard to convey using finger-based strategies.

The team’s preliminary analyses revealed no negative effects of finger-based strategies and seemed to corroborate their hypotheses. This suggests that using fingers in primary mathematics instruction may not be harmful to children’s numerical development, and might actually be beneficial. However, more in-depth analyses are needed to substantiate this claim. The research efforts of Dr Moeller and his colleagues thus provides further evidence for the concept of embodied numerical training, paving the way for exciting subsequent studies.

Dancing to the Beat of Numeracy

‘Fingers are the most obvious embodied representations of numbers,’ states Dr Moeller. ‘However, our intention was to go beyond fingers and use full-body movements.’ And that they did. In 2011, the research team used a digital dance mat that allowed them to evaluate embodied training for developing number processing skills using whole-body responses.

In the study, kindergartners were presented with a number line that increased in size from left-to-right in correspondence with the metaphorical mental number line. The children were then asked to jump to the left or right field of the digital dance mat depending on whether they classified a number that they were shown as larger or smaller than the standard on the number line.

In contrast, the control training required children to simply tick on the larger of two numbers presented on a tablet PC using an electronic pen. The team’s findings revealed that children improved more strongly in number line estimation and counting after completing the embodied training on the dance mat, compared with the control group.

Figure 1: The game-based app

In 2013, Dr Moeller and colleagues took this work one step further. The research team endeavoured to extend the whole-body experience of numerical concepts from simply taking one step to the left or right, to continuous movements along a number line. In the study, first-grade children walked up to 3 metres along a number line, ranging from 0 to 100, that was taped to the floor, until they reached the estimated position of a target number that they were provided.

The team used a novel Kinect sensor to detect and record children's movements in 3D space. In this study, the control training involved the same estimation task on a tablet PC, which therefore did not provide an embodied physical experience of walking on the number line. Similar to Dr Moeller's previous research, the results indicated that embodied training led to increased performance in number line estimation.

Subsequent studies have also alluded to the success of embodied training in a range of age groups, from kindergarten to second grade, utilising varying digital media formats, and through different numerical training contents. There are consequently numerous avenues for future research, for which the team has suggested it would be exciting to evaluate the range of movement necessary to create beneficial embodied effects in numerical training.

In previous studies, children were required to move their whole body, or simply their fingers. Might training involving smaller physical movements, perhaps involving the arms or legs, be as efficient? Virtual reality is another research direction that excites the team, as it may also allow for the identification of distinct physical movement from perceived movement, for example on a number line.

Digits Grasp Digits – the Next Step

The increasing availability of modern digital touch-sensitive devices, such as tablets and digital dancing mats, has provided

a unique opportunity for Dr Moeller's research findings to be brought into practice. In their current work, Dr Moeller's team is developing an app for finger-based numerical training that can be utilised in an educational environment for kindergarten children. In the game-based app (see Figure 1), children help a little alien named Finn, who has been stranded on Earth and needs to collect stars to fuel his spaceship and fly back home. Because Finn has no hands or fingers, children have to 'grab' the stars by placing their fingers on the screen either sequentially for training finger counting or simultaneously for fostering cardinality knowledge.

The app will provide novel insight, as it will address the contribution of finger training to the development of different basic numerical skills such as counting, quantity understanding, and initial calculations. It is anticipated that immediate feedback provided on the basis of a correct or incorrect answer will encourage interaction with the game and hence interaction with numeracy.

'My work is driven by the idea that basic numerical abilities, such as counting and understanding number magnitude, serve as building blocks for later numerical and mathematical achievement. As such, these basic numerical competencies deserve special attention and promotion, for instance through new digital media that easily allows for the use of bodily experiences of numerical concepts,' says Dr Moeller. The research team hopes that their latest project will shed yet more light on the complex cognitive processes underlying a child's numerical development, whilst also providing a freely available learning tool.

Dr Moeller's fascinating research undertakes a unique, dynamic and fun approach to applying scientific findings in the context of education that is most certainly relevant and exciting in our technologically advancing society.

Meet the researcher

Dr Korbinian Moeller
Leibniz-Institut für Wissensmedien
Tübingen
Germany

Dr Korbinian Moeller is the head of the junior research group Neuro-cognitive Plasticity at the Leibniz-Institut für Wissensmedien (IWM). In addition, he is professor for applied learning and knowledge psychology at the University of Tuebingen. Dr Moeller studied psychology at the RWTH Aachen University and the University of Dundee in Scotland before pursuing his PhD (awarded in 2010) at the Paris-Lodron University in Salzburg, Austria and the Eberhard Karls University in Tuebingen, Germany. He is a faculty member of the LEAD Graduate School – Learning, Educational Achievement and Life Course Development, funded by the Excellence Initiative of the German federal government. A specific focus of his work is on the investigation of the development and acquisition of numerical competencies and corresponding changes on the cognitive as well as the neural level.

CONTACT

E: k.moeller@iwm-tuebingen.de
W: https://www.iwm-tuebingen.de/www/en/personen/ma.html?uid=kmoeller

KEY COLLABORATORS ON THE EMBODIED NUMERICAL LEARNING PROJECT

Professor Hans-Christoph Nuerk
http://www.uni-tuebingen.de/en/faculties/faculty-of-science/departments/psychology/research-groups/diagnostics-and-cognitive-neuropsychology/research-group/staff/hans-christoph-nuerk.html

Professor Ulrike Cress
https://www.iwm-tuebingen.de/www/en/personen/ma.html?uid=ucress

Professor Ursula Fischer
https://www.sportwissenschaft.uni-konstanz.de/forschung/entwicklung-und-foerderung-in-der-fruehen-kindheit-prof-fischer/

FUNDING

Moeller & Roesch (2019–2022), *How digits help digits grasping numbers*, ca. 350,000 EUR, funded by Deutsche Forschungsgemeinschaft (DFG).

Cress, Nuerk, & Moeller (2014 – 2019), *Embodied learning of numerosities – Math with the dance mat*, ca. 430,000 EUR, funded by Deutsche Forschungsgemeinschaft (DFG).

Moeller, Huber, & Gawrilow (2017 – 2019), *Development and evaluation of a digital app for self-regulated training of finger-based numerical strategies*, ca. 175,000 EUR, funded within the Leibniz-ScienceCampus Tübingen on Cognitive Interfaces.

Nuerk, Engel, Fischer, Moeller, & Cress (2011 – 2014), Movements in 3D space to improve numerical learning ca. 55,000 EUR, funded within the joint graduate school *Effektive Lehr-Lernarrangements: Empirische Evaluation und Intervention in der Pädagogischen Praxis* of the Eberhard-Karls University Tuebingen and the University of Education Ludwigsburg.

Moeller, Martignon, Nuerk, & Trautwein (2011 – 2014), Beneficial or negative effects of finger-based strategies on numerical learning in primary school ca. 55,000 EUR, funded within the joint graduate school *Effektive Lehr-Lernarrangements: Empirische Evaluation und Intervention in der Pädagogischen Praxis* of the Eberhard-Karls University Tuebingen and the University of Education Ludwigsburg.

IWM Leibniz-Institut für Wissensmedien

ILLUMINATING FRACTIONAL REASONING FOR STUDENTS WITH LEARNING DISABILITIES

Making sense of fractions can be challenging for students with learning disabilities. **Dr Jessica Hunt** of North Carolina State University studies how these children think and learn and is developing novel teaching methods that facilitate mathematics learning for this underserved population.

When many people look back on their early school years, mathematics is at the top of the list of subjects they remember struggling with. While different people struggle with different mathematics concepts, for many students, fractions are among the most difficult.

This is often particularly true for students with learning disabilities, who may not connect well with traditional methods of teaching fractions. Elementary school students with learning disabilities in the US commonly begin their fourth and fifth grade (aged nine to ten years old) study of mathematics at a disadvantage due to different incoming understanding that they use to think and learn.

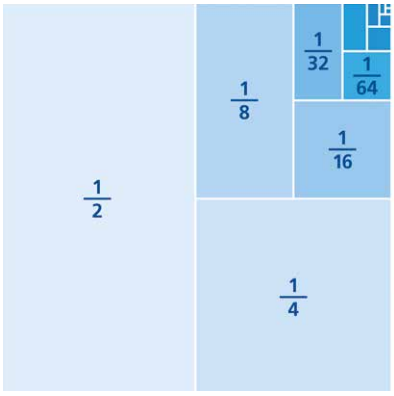
Dr Jessica Hunt is an Associate Professor of Mathematics Education and Special Education at North Carolina State University in Raleigh, NC. Her research focuses on identifying how students with learning disabilities think about and learn mathematics and identifying teaching strategies that support these students to grow their understandings, particularly of fractions, by understanding and building upon their unique cognition.

Rethinking Knowing and Learning in Fractions

Understanding fractions is beneficial in all areas of life and is fundamentally connected to reasoning proportionally and thinking relationally. Despite the ubiquity of fractional reasoning in our lives, it is an area of mathematics that many people struggle with learning and applying, especially as children.

Fractions are a difficult area of mathematics for all students at all grade levels but can be a particularly sticky topic for students with a learning disability. While a large achievement gap between students with and without learning disabilities exists, simply documenting the performance differences between these groups is not enough to improve their educational outcomes. It is critical for educators to understand the complexity of knowledge students bring into instruction and how to best go about teaching to students' strengths.

When Dr Hunt began her work, hardly any research had been done to understand the complex conceptions that these students bring into their study of fractions. She wanted to describe the differences in conceptual understandings that students with learning disabilities use to solve problems with fractions, how instruction might be designed from students'



strengths, and how to facilitate connections between existing and new understandings.

An appreciation for how students with learning disabilities naturally approach a topic is critical in order to develop tasks and responsive pedagogies that enable these students to build fraction knowledge from their neuro-diversities.

Dr Hunt wants to know not only what concepts might be common across students with a learning disability but also what differences exist in their patterns of thinking, problem-solving strategies, and response to lesson

‘Rather than focusing on students’ propensity to regenerate a teacher’s thinking, research and instruction should attempt to uncover the complex understanding students DO have and can develop.’

formats when it comes to mathematics. Identifying the knowledge these students DO have is key in developing effective methods of teaching fractions that promotes learning from the understandings these students bring into instruction.

Elucidating the Divide

Dr Hunt’s work in fraction education started with describing the conceptual frameworks that students with learning differences use to solve fraction math problems and determining how it differed from other students’ approaches. She performed clinical interviews with students with a learning disability in the third, fourth, and fifth grades to assess their understanding of fractions and the approaches they took to solve fraction problems.

Dr Hunt found that students with a learning disability had a different grasp of fraction strategies as compared to their peers. Students were pulling from similar subsets of strategies as other students. When zooming in to look at two case-study students’ reasoning, Dr Hunt found distinct learning trajectories reflecting different prior knowledge that each student used to reason and make sense of fractions. One student used ratios to understand fractions while another student used measurement.

These findings are important because they suggest that this is an area where teachers can have a greater impact by figuring out *how* students understand and then using that knowledge to support students to grow their own conceptions of fractions. This attention to students’ unique ways of knowing and learning is the initial key to closing the achievement gap between groups of students.

Building from Strengths and Meeting Students Where They Are

One of Dr Hunt’s key findings for improving education for students with learning disabilities has been that these students are bringing more to the table than they are often given credit for. Many models of teaching students with a learning disability assume that there is something to be fixed in the child rather than a problem of misalignment of teaching practice and students’ unique conceptions.

Children with learning disabilities are often offered repetitive lessons on simplified concepts that do not provide great opportunities for conceptual growth and may actually contribute to the achievement gap in some cases. In a novel approach, Dr Hunt and her team tried something new with students in elementary schools who had been receiving the simplified concept approach for years without much improvement.

Rather than the typical teacher-led lesson, the teachers in the study worked to first elicit where the child was in their understanding and their thought process, then offered goal-oriented activities suited to each child. This continued as a reciprocal process where the teacher was constantly assessing each child’s performance in their tasks and problem-solving strategy when designing the next lesson. The participating children experienced great improvements in their understanding of fractions.

This work suggests that by taking a student’s perspective into consideration, the entire student-teacher dynamic can be shifted to promote a depth in students’ learning. ‘Rather than focusing on students’ propensity to regenerate a teacher’s thinking, research and instruction should attempt to uncover the complex understanding students DO have and can develop,’ says Dr Hunt.

Assessing for Success

Given the benefits of understanding the student's perspective, it is no surprise that Dr Hunt views assessment as a launch point for student success. By understanding a student's present knowledge and available problem-solving strategies, teachers can know where to start and what to leverage in lesson plans to have the greatest impact. However, many educators struggle with the best way to perform these assessments to obtain useful results.

Dr Hunt's work suggests that clinical interviews provide a flexible way to recognise both how a child understands a topic and what thinking processes underlie that understanding. Interviews provide more insight than standard assessments thanks to open-ended questions and flexibility in the way in which questions are asked.

Dr Hunt posits that by structuring interviews in ways that allow teachers to learn what knowledge students already have, discovering what thought processes they use, and building a respectful bond, the education of students with a learning disability can be transformed.

Dr Hunt's ideal interview structure starts with tasks that show a student's ways of making sense, has a flexible plan for questions to understand and interpret student logic, and provides a way to document findings that will be useful later. To begin, she suggests that educators consider what content they are trying to assess, in what ways children might conceive it, what tasks and questions would best illuminate these conceptions, and how the potential for learning expansion can be assessed.

To create a strong relationship with the student, interviews must be planned with consideration for how the interview process will be explained to the child and how trust and respect will be established. Effective documentation should record where the child is now in their understanding, what could they further accomplish with hints, which explanations and contexts did they find meaningful, and how these findings could fit into a lesson plan.

When a teacher starts with a clinical interview, lessons start where the students are. Through continued cycles of observation, interaction, and lesson tailoring, students with learning disabilities are able to make impressive gains in their understanding of complex mathematical concepts.

Changing Perspectives

Though Dr Hunt's work is focused on helping students with a learning disability close the achievement gap, some of her findings could benefit every student in the classroom. Studying how students with a learning disability conceptualise and learn fractions has helped Dr Hunt identify teaching strategies and exercises that could benefit all students.

The most common framework for teaching fractions is the part to the whole approach. Students learn that a fraction is simply one out of many parts of a whole through exercises such as folding paper or colouring a pizza. This framework often fails when students are asked to make the leap from physical representations to working with fractions as numbers and proportions. Students who have learned fractions this way often struggle with using them effectively across multiple contexts.

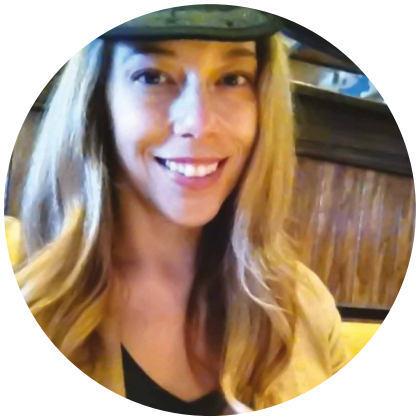
Another playful framework for teaching fractions is named the French Fry method (Tzur & Hunt, 2015). In this method, children are asked to share a very long French fry equally between a given number of people by estimating how long each piece of the fry would need to be.

They start with sharing with two, a simple half, and work up to larger numbers. During each progression of the task, the children discuss their results with each other and the teacher, analysing if their guess was too short or too long and how they should adjust their next guess. With each stage, children focus on how to get equal amounts in the least number of guesses. This is just the first learning situation in an instructional trajectory of 12 situations that Dr Hunt and her team is testing as a conceptually based mechanism to support students fractional reasoning.

Working together through this goal-oriented task encourages children to approach fractions from a perspective that is more accessible to many students and more easily translates into conceptualising fractions as quantities.

A Brighter Future

As Dr Hunt's work continues, she is devoted to developing new and improved ways to reach students with a learning disability where they are and bring out their best. She describes how she is using what she has learned, 'to develop new assessment and instructional environments for students with learning differences, including applications in immersive gaming, virtual reality, and project-based learning.'



Meet the researcher

Dr Jessica Hunt
Associate Professor
Mathematics Education and Special Education
North Carolina State University
Raleigh, NC
USA

Dr Jessica Hunt is currently an Associate Professor of Mathematics Education and Special Education in the College of Education at North Carolina State University. During her time as a middle school mathematics teacher and elementary interventionist, she came to love teaching students deemed to be at risk for mathematics difficulties or labelled as having disabilities. Dr Hunt contends that research and pedagogical practice for children with disabilities should begin from a respect for children's ways of knowing and learning. Her work examines how children with disabilities display their thinking, the factors that influence learning, and how teachers can work with students' implicit and explicit goals to facilitate meaningful learning.

CONTACT

E: jhunt5@ncsu.edu
W: https://www.researchgate.net/profile/Jessica_Hunt3
@teach_doc_jhbh

KEY COLLABORATORS

Susan Empson, Ron Tzur, Marty Simon, John Woodward, David Geary, Beth MacDonald, Juanita Silva, Jasmine Welch-Ptak, Kristi Martin, Blain Patterson, Andy Khounmeuang, Pever Baran, Payam Tabrizian, Garrett Millar

FUNDING

National Science Foundation

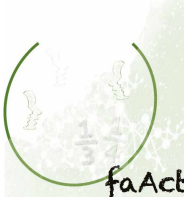
FURTHER READING

JH Hunt and SB Empson, Exploratory study of informal strategies for equal sharing problems of students with learning disabilities, Learning Disability Quarterly, 2015, 38, 208–220.

JH Hunt, R Tzur and A Westenskow, Evolution of unit fraction conceptions in two fifth-graders with a learning disability: An exploratory study, Mathematical Thinking and Learning, 2016, 18, 182–208.

J Hunt and R Tzur, Where is difference? Processes of mathematical remediation through a constructivist lens, Journal of Mathematical Behavior, 2017, 48, 62–76.

R Tzur and J Hunt, Iteration: Unit fraction knowledge and the French fry tasks, Teaching Children Mathematics, 2015, 22, 148–11.



A DIFFERENT TANGENT TO TEACHING TRIGONOMETRY

Learning trigonometry is a challenge for many high-school students, impeding their access to careers in science, technology, engineering, and mathematics. **Dr James McClelland**, a professor of cognitive science at Stanford University, California, has been working to make higher-level mathematics concepts accessible to as many people as possible by assessing the effectiveness of a different approach to learning trigonometry at high-school.

The Vital Role of Mathematics Education

A good grasp of higher-level mathematics is often key to success in most careers related to science, technology, engineering, and mathematics (STEM). Mathematics is a central part of most scientific disciplines – as it provides methods to analyse data or build computational tools, both of which are principal aspects of scientific practice.

The fields of technology and science are developing at a progressively faster pace, increasing the need for qualified and competent professionals to cover a wide range of STEM-related positions. Delivering high-quality science and mathematics education to high-school students is therefore of crucial importance, to ensure that young generations are well-equipped to pursue further studies and careers in science and engineering.

According to a 2012 study by the Program on International Student Assessment (PISA), the United States is behind other nations in mathematics and science education. The study found that only 25% of US 15-year olds had reached a point where they could understand and complete higher order mathematics tasks, compared to the average 31% of students across the 34 countries assessed.

The National Mathematics Advisory Panel has often highlighted the need for educators in the US to find new ways of enhancing mathematics and science training for high-school students, as this would increase their chances of securing STEM-related industry, government, research and education positions.

Dr James McClelland, professor and director of the Center for Mind, Brain, and Computation at Stanford University, has been developing and testing a different approach to teaching higher-level mathematics concepts. Dr McClelland hopes to identify effective ways of making complex mathematical concepts meaningful and accessible to a greater number of people.

Stanford's Trig Academy Platform

Dr McClelland's research explores the role of a visuospatial representation grounded on mathematical concepts related to pre-calculus trigonometry, a subject that is challenging for many, but sits at the gateway to entry into many STEM fields. His studies are aimed at enhancing students' understanding of trigonometry concepts and their reliance on them, with the hope that this might ultimately facilitate their success in other STEM-related disciplines.

'We are interested in opening up the world of higher-level mathematical ideas to as many people as possible,' explains Dr McClelland. 'These are the ideas that scientists use to describe the physical world, enabling the technologies that have changed our world over the last three centuries and allowing innovations in medicine, physics, and computation that have transformed our society.'

The overreaching goal of his work is to make mathematics meaningful to all students – not just the few who somehow 'get' what mathematics is about. 'Although some believe that making mathematics meaningful amounts to linking it to specific applied problems that are relevant to the daily lives of students, our construal of what it means to make math meaningful is different,' he says. 'We see mathematics as a set of constructed systems that provide powerful tools for inference and reasoning but that involve constructs and conventions that are often quite foreign to the experience of the learner.'

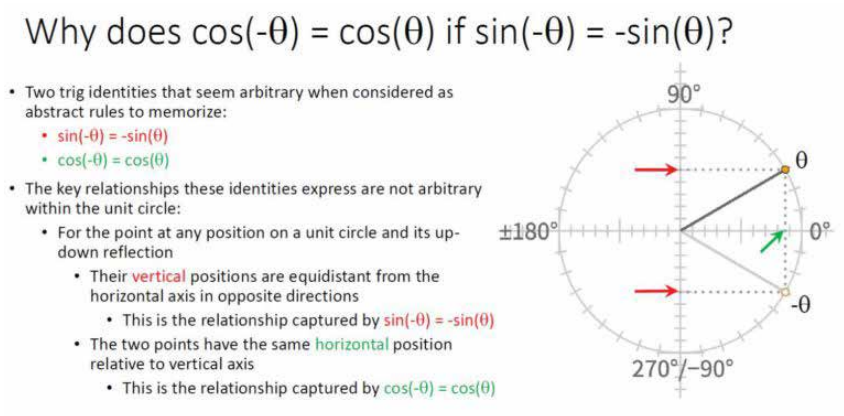


Figure 1. By identifying variables such as 0 *with positions on a circle and identifying the trig functions* **sin** *and* **cos** *with the vertical and horizontal positions of points of the circle, the meaning of an expression like* **cos**(-0)=-**cos**(0)*, and the reason why the expression is true becomes clear.*

His work also has three broader aims – adapting the course material for use with students that have never been exposed to pre-calculus trigonometry – extending the content covered by the course to include additional pre-calculus trigonometry topics – and deploying the extended version of the current training program in 11th and 12th grade classrooms (for young people aged 16-18 years old), to assess its outcomes.

Dr McClelland and some of his colleagues have established the Trig Academy platform at Stanford University – a project aimed at providing students with a good and coherent background for understanding trigonometry. Instead of asking students to merely memorise rules and formulas, Dr McClelland hopes the materials his team has created will help students to understand and reason applying trigonometric relationships. The course provides students with a series of learning materials, through which they can progress independently.

A Structured System for Learning Trigonometry

Dr McClelland's approach to teaching trigonometry is based on a spatially grounded conceptual model called the 'unit circle'. The researcher hypothesises that this model could link trigonometric expressions to measurable properties of a physically realisable visuospatial model that can be internalised and applied as a basis to understand trigonometry-related concepts.

An example showing how the unit circle model can make two very arbitrary, and perhaps even seemingly contradictory, trigonometric relationships meaningful is provided in Figure 1. 'We have found that students who ground their understanding of trigonometry in the unit circle correctly understand that the cosine of a value is equal to the cosine of the negative of the value, as captured by the formula **cos**(-0)=**cos**(0),' Dr McClelland notes.

However, those who do not ground their understanding in the unit circle assume that **cos**(-0)=-**cos**(0). 'Students who approach trigonometry as a system of arbitrary rules have no basis for understanding the correct relationship,' Dr McClelland explains. 'Unfortunately, the educational system leaves students far too susceptible to coming away from several weeks of trigonometry without appreciating the basic meaning of trigonometric expressions.'

'By immersing the learner in the structured system and making it clear to the learner that the goal should be to understand how the system works – and not to memorise lists of formulas – we hope to convey a productive understanding that allows the student to build toward more advanced mathematics ideas and concepts,' explains Dr McClelland.

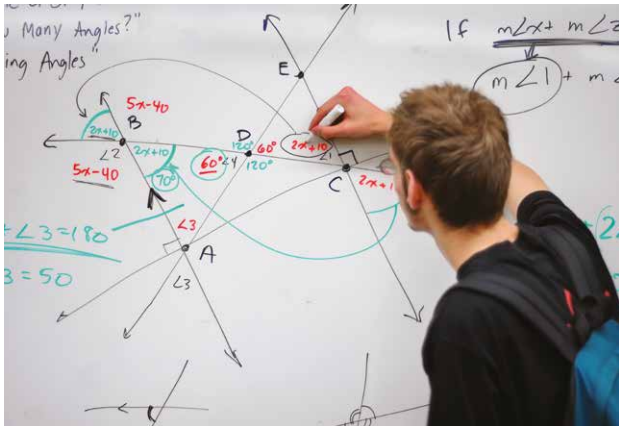
The Trig Academy Platform views trigonometry as a system to understand the quantitative properties of spatial relations. Achieving a thorough understanding of this system and its conventions should ultimately make these relationships intuitive for students.

According to Dr McClelland, it is vital that students start seeing formulas as a way of efficiently expressing relationships they can visualise and manipulate in their minds, rather than as mere arrangements of meaningless symbols to manipulate, with the only goal being that of solving mathematics exercises.

Prompting this change in perception and ensuring that students achieve a full understanding of trigonometric relationships usually takes time – requiring the core realisation that the goal is to understand the system and not to achieve the correct results by memorising formulas. For this reason, students participating in the program are asked to take their time while progressing through the material.

Dr McClelland's work is based on previous research suggesting that spatial ability and the acquisition of elaborated conceptual structures to approach mathematics and science problems are strongly associated with success in many STEM-related fields. Stanford's Trig Academy curriculum specifically asks students to think about mathematical meaning in space, in the context of an imaginary circle (the unit circle) that should help them to better understand trigonometric relationships.

Students are asked to complete a series of interactive exercises that explain the overall mathematical system, prompting them to interact with it and observe resulting relationships. Eventually, the visual representations that assisted students in understanding



the mathematical relationships are removed, asking them to internalise what they learned and reproduce the same visualisations in their mind.

Initial Results

So far, Dr McClelland has tested his approach to teaching trigonometry on undergraduate students at Stanford, after first exploring the strategies successful students used to solve trigonometry identity problems. Use of the unit circle was associated with better performance in exercises, leading McClelland and his team to build their learning platform around the unit circle. The original course material was developed with Stanford undergraduates in mind and the researchers then adapted it to make it more suitable for students with less prior knowledge of trigonometry.

In a first round with the new lesson materials, McClelland's team recruited 25 volunteers from a collaborating nearby high school called Tahoma Summit School as well as 14 students at a neighbouring community college. The students were asked to complete pre-tests before starting the course, a series of exercises during the course, and post-tests once the course was completed.

Tahoma Summit students were supported by a teacher and had previously been exposed to trigonometry, while community college students completed their study completely independently, working entirely through an internet-based learning platform. The results collected were similar for both groups of students, despite the different learning conditions.

Most students showed a significant improvement in their post-test and their performance was found to be the same three weeks after the study, suggesting that the ideas they learned were well retained.

Overall, the study findings suggested that while learning how to use the unit circle visualisation method required more time than other strategies, it was generally associated with more accurate performance. Dr McClelland says, 'our greatest measure of success comes from students, who tell us we have changed their experience of mathematics.'

After completing the trigonometry materials delivered by Dr McClelland, for instance, one student wrote, 'I would like to add that the study material is amazing and I have learned a great deal. This time around I'm actually learning something and comprehending everything so I appreciate this study very much.'

The Trig Academy, in its current form, does not work for all students. However, high-school students who had little prior knowledge of pre-requisite mathematical concepts that were built on in the course material seemed to encounter greater learning difficulties during their studies. 'Up to the present, we have been able to achieve successful learning outcomes with three-quarters of all students,' says Dr McClelland. 'However, we find that the remaining one-quarter of students still don't "get" the ideas we are trying to teach them. Our focus now is on understanding the key prior ideas and thinking skills these students may need to allow them to succeed.'

Making Mathematics Meaningful

Mathematics is often viewed by students as a subject based on numbers, symbols and rules – but it is actually the study of patterns and relationships. These relationships are at the core of most scientific disciplines and gaining a comprehensive understanding of them can be beneficial for all students who wish to pursue further studies and careers in STEM-related fields.

Academic programs such as the one developed by Dr McClelland and his colleagues could be incredibly valuable, providing students with a thorough grasp of important mathematical concepts that will help them stand out when competing for a variety of scientific positions in future.

Dr McClelland is now planning to engage in further collaboration with Summit Public Schools, introducing the materials that he developed into several other schools in this network. In future, he would also like to apply similar learning approaches to other areas of mathematics.

Additional research exploring the impact of learning through visuospatial representations on students' performance and understanding of mathematical concepts will help to inform educators and policymakers on the best strategies to teach mathematics.

'Our goal is to make the world of mathematical ideas and concepts meaningful,' says Dr McClelland. 'Math can seem to be a hopeless jumble of complex expressions and it is often taught as a system of arbitrary rules that must be memorised. Instead, mathematics is really a set of ideas, not just a language for describing them. To learn these ideas, we aim to teach students to see relationships they have not considered before, and then gradually learn to rely on these relationships.'

CREDIT: Angela Drury – Stanford University

Meet the researcher

Professor James L. McClelland
Lucie Stern Professor in the Social Sciences
Director, Center for Mind, Brain and Computation
Department of Psychology
Stanford University
Stanford, CA
USA

Dr James McClelland is a Professor of Cognitive Science in the Psychology Department and Director of the Center for Mind, Brain and Computation at Stanford University. He received a BA in Psychology from Columbia University and a PhD in Cognitive Psychology from the University of Pennsylvania. He has since held teaching and faculty positions at numerous universities, including the University of California and Carnegie-Mellon University. Professor McClelland's research addresses a broad range of topics in cognitive science and neuroscience, including perception and perceptual decision making, learning and memory, language and reading, semantic and mathematical cognition and cognitive development. Over the course of his career, he has contributed substantially to both experimental and theoretical literature in several areas. Professor McClelland has also served as Senior Editor of the journal *Cognitive Science*, as President of the Cognitive Science Society, as a member of the National Advisory Mental Health Council and as President of the Federation of Associations in the Behavioural and Brain Sciences. He has received many honours and awards, including the APS William James Fellow Award for lifetime contributions to the basic science of psychology, the David E. Rumelhart prize for contributions to the theoretical foundations of Cognitive Science, and the Heineken Prize in Cognitive Science.

Stanford University

CONTACT

E: mcclelland@stanford.edu
W: https://stanford.edu/~jlmcc/

KEY COLLABORATORS

Kevin Mickey, David Romano, Su Su, and Laura Weseman Kreisel, Stanford University.
Kyle Moyer, Summit Public Schools

FUNDING

Grant IES R305A150453 from the US Department of Education to J. McClelland and National Science Foundation Graduate Research Fellowship to K. Mickey

FURTHER READING

K Mickey and JL McClelland, The unit circle as a grounded conceptual structure in pre-calculus trigonometry. In DC Geary, DB Berch, R Ochsendorf and K Mann, Koepke (Eds.), Acquisition of Complex Arithmetic Skills and Higher-Order Mathematics Concepts, 2017, Vol. 3, Elsevier/Academic Press.

SHIFTING STUDENT OUTCOMES WITH THE INVESTIGATIVE SCIENCE LEARNING ENVIRONMENT

Devising novel ways to engage students in science courses is a long-standing goal of many educators, but even the best applications of traditional teaching methods often fall short. A team of scientists, led by **Professor Eugenia Etkina**, has developed a novel method for teaching physics – the Investigative Science Learning Environment – that is transforming how students learn physics. Their next step is to make this method available to the masses.

The Need for Improved Science Education

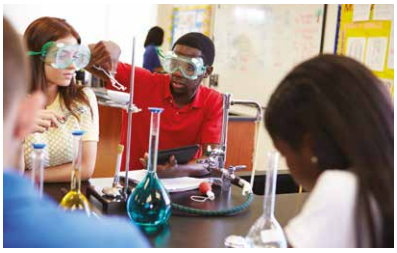
In a world that is increasingly technology driven and facing global problems that require scientific reasoning to address, science education is more important than ever. However, traditional memorisation methods of teaching science have failed many students, leading to a general population that holds many erroneous ideas about how science works and a limited understanding of how scientists come to conclusions.

Over 20 years ago, Professor Eugenia Etkina from Rutgers University developed a novel method of teaching physics that holds promise for a more scientifically literate future. Her Investigative Science Learning Environment (ISLE) teaching system engages students in learning how to think like scientists through experimental design and analysis.

Professor David Brookes from California State University has been using the method and contributing new activities for the past 15 years. Professor Matthew Vonk of the University of Wisconsin and Peter Bohacek of the Pivot Interactives have developed ways of simulating student experimental design through arrays of videos for the students who do not have access to real equipment. They formed a partnership with the ISLE development team to explore ways for students to engage in scientific investigations in non-traditional settings such as an online learning environment.

A Winding Path to a Better Way

Professor Etkina began her career as an educator in the Soviet Union, teaching physics in a high school in Moscow. As a motivated young teacher, she spent countless hours preparing for each of her classes, designing lessons that revolved around intricate physics demonstrations. Her lessons were well received, and she was regarded as one of the best physics teachers at her school. However, she would soon experience two major revelations that shifted her teaching philosophy radically.



First, Professor Etkina came to the realisation that most of her students would not go on to become physicists, but they would all become members of society. While they might not have a strong need to understand particle interactions or calculate object trajectories, they would all encounter information that they'd need to evaluate with a critical eye. She envisioned a future in which her pupils, regardless of career, would approach the world like scientists. She wanted them to ask questions such as, 'How do you know this?', 'What assumptions were made?', and 'Is there evidence for that conclusion or is it a best guess?' She wanted her students to learn the principles physics, of course, but more importantly, she wanted them to understand how these principles were discovered in the first place, in other words, how to think like a physicist.

Second, a chance encounter with a former student led her to a shocking insight. The young man had been a diligent 'A' student that enjoyed her class. However, when she ran into him years later, he admitted that the only thing he really remembered was a presentation he had given on a topic he had researched himself. Despite her meticulous physics presentations, the student only remembered material he had learned on his own. She realised that instruction that facilitated students in making their own discoveries would be more effective than any demonstration she could give.

Professor Etkina began experimenting with novel ways to engage her students in active learning, with the goals of teaching them to think like scientists and encouraging them to learn some processes on their own. She had students work in small groups to explain physics phenomena that she demonstrated during class. With Professor Etkina's guidance, they had to design and run their own experiments, collect and analyse their own data, and discuss their findings with their classmates. From these exercises, she formed the foundation of a novel physics learning system, which she would later bring to the United States and develop into the ISLE teaching system.

Learning Through Exploration

The ISLE system starts with the students performing a simple physics experiment suggested by the instructor, observing the outcomes and finding patterns. Students are asked to describe what they see without making any predictions about the outcome. They are asked to approach the phenomenon free of expectation. The students then break into groups and are encouraged to come up with as many potential explanations for the patterns they found as they can. Next, students take their list of possible explanations and, with instructor guidance, design experiments to test each one.

Before any testing experiments are performed, the students must make predictions based on their explanations, requiring them to carefully consider the assumptions they are making about the process. The students then perform the experiments they have designed and analyse the outcomes. When their predictions match the outcomes, they are encouraged to consider whether alternative explanations would produce the same result. When their predictions do not match the outcomes of the experiments, they go through a review of their additional assumptions or propose new explanations and experiments. Explanations that survived many tests are later used to solve practical problems. Critical thinking is encouraged at every step of the journey.

The ordering of activities is perhaps one of the most unique twists of the ISLE curriculum. In the conventional physics classroom, students are expected to have read the text for a topic prior to starting it in class, with the idea that they will be prepared to discuss the topic when they arrive. In the ISLE classroom, students are discouraged from reading the associated chapters of their textbook until after their experiments and discussions for a topic are complete. This encourages a genuine sense of scientific exploration as the students navigate their experiments. Instead of reading explanations in a book and picking the

'right' experiment to do, they are relying on their own ideas and curiosity to move their knowledge forward. When they read the textbook afterward, they are able to tie the text to their own concrete experiences.

Transforming Student Understanding

The ISLE system has proven effective at providing students with memorable learning experiences that help them think more like scientists. When Professor Etkina and her colleagues evaluated the system at Rutgers in a physics class for non-physics majors, their results were beyond impressive. After only eight weeks of labs in an ISLE-based course, the vast majority of students were able to independently perform feats such as designing their own experiments, collecting and analysing their data, evaluating their results, and challenging their scientific assumptions.

When solving complex physics problems, over half were drawing diagrams to conceptualise their solution, at nearly quadruple the rates seen in traditional classrooms. Almost half of these non-physics majors were able to explain how they would go about testing multiple potential explanations for a phenomenon – a genuinely startling feat when you consider that none of their non-ISLE educated peers who were actually majoring in physics could do the same. In fact, only a handful of first year physics graduate students had reached this level of mastery – the ISLE students were discussing problems in a manner comparable to many advanced graduate students.

Perhaps the most exciting result was that they could adapt the reasoning processes they had mastered in physics to approach experimental problems in biology. They were able to recognise the important parts of the problem, create visual representations to explain their reasoning, figure out how to collect data with the equipment on hand, and analyse and evaluate their results. The ISLE students had truly learned to approach the world as scientists.

Bringing ISLE to Students Everywhere

The ISLE system has been a smashing success in classrooms and has now been adapted into a college textbook. While it is a great benefit to students that are lucky enough to join these classes, Professor Etkina, Professor Brookes, Professor Vonk and Bohacek now plan to make the ISLE learning process available to students all over the world.

With funding from the National Science Foundation, they are working to develop materials for a virtual ISLE resource – a collection of interactive videos and other tools that work to replicate the full ISLE process online. The materials include interactive videos, measurement tools, embedded graphing tools and supporting questions appropriate for students in middle school through college, along with guidance for physics teachers who wish to use the video-based ISLE in their classroom.

Describing the goals of her team's newest venture, Professor Etkina says, 'How can we recreate the freedom and creativity of students designing their own experiments with real equipment in situations when only videos are available? How many variations of the same experiment do we need to video so that the students feel that they are making their own choices in what to investigate? How do students reason when they interact with the videos of experiment not the real experiments? Our project aims to answer these questions.'

These are not small challenges. Though it is easy to offer observational experiments for the ISLE system though video, it is difficult to recreate the experience of students having unlimited choices to test the explanations they come up with. Unlike a physical classroom equipped with an array of experimental equipment that offers broad options for students to come up with their own experiments for a problem, the options available in a virtual classroom are limited by what its creators choose to include.

The team's solution is to create online activities featuring matrices of videos of testing experiments. Unique digital tools invented by Bohacek and Vonk, embedded in the videos, allow students the freedom to explore and design investigations. Students must use their creativity to choose what and how to measure, similar to how they would design experiments in a fully equipped lab room. Foreseeing all possible ideas that students can come up with is not easy, but this is where the collective teaching experience of the team, knowledge of physics education research, and experience of implementing ISLE help. Feedback so far is promising, with teachers in schools with limited funds and equipment noting that the videos let them expand the experiments available to their students and the students expressing that the videos help bring concepts together.

Initial studies of student outcomes suggest that the virtual ISLE holds as much promise as hands on experiments, particularly for topics where real-life experimentation can become finicky and tedious for students. The team is currently working to understand the gaps in the virtual labs and find solutions to fill them. 'So far we see that certain physics topics are easier to investigate with real equipment and certain topics are better with videos. But we do not know the optimal level of help that we need to provide to the students who are working remotely with the videos,' Professor Etkina explains.

The Future of Science Education

The ISLE team's work is demonstrating the potential for active science learning to transform how students interact with and understand the world. By expanding this system into a virtual learning environment, they are making cutting-edge science education accessible to students around the world.

Meet the researchers

Professor Eugenia Etkina
Graduate School of Education
Rutgers University
New Brunswick, NJ
USA

Professor Eugenia Etkina began her career as a high school physics teacher in Soviet Russia. She later continued her education to earn a PhD in Physics Education from Moscow State Pedagogical University. In 1997, she joined the faculty of the Graduate School of Education at Rutgers University, where she is currently recognised as a Distinguished Professor. Her award-winning work focuses on novel methods of teaching physics to students of all levels and physics teacher preparation.

CONTACT

E: eugenia.etkina@gse.rutgers.edu
W: https://gse.rutgers.edu/eugenia_etkina

Professor David Thomas Brookes
Department of Physics
California State University
Chico, CA
USA

After obtaining a Master's degree in Theoretical Physics from the University of Cape Town and a second Master's in Physics from Brandeis University, Dr David Brookes earned his doctorate in Physics Education from Rutgers University. In 2015, he joined the Physics Department at California State University, where he continues his research in physics education.

CONTACT

E: dbrookes@csuchico.edu

Peter Bohacek
Direct Measurement Video Project
Afton, MN
USA

Prior to diving into physics education, Peter Bohacek spent over a decade in a successful career in digital electronics. He began teaching high school physics in 2002, and in 2011 he completed his Masters of Science Education with an emphasis in Physics. Bohacek is the co-founder of the Direct Measurement Video Project, a video library of physics experiments for educational purposes.

CONTACT

E: peter.bohacek2@gmail.com

Professor Matthew T. Vonk
University of Wisconsin
River Falls, WI
USA

Dr Matthew Vonk earned his PhD in Physics from the University of Minnesota before joining the faculty at the University of Wisconsin River Falls in 2004. He currently chairs the AP (Advanced Placement) Physics-C Exam Development Committee and recently served as a Fulbright Traditional Scholar in Medellín, Colombia. His current research focuses on electronics design and physics education via video-based experiments.

CONTACT

E: matthew.vonk@uwrf.edu

FUNDING

US National Science Foundation

FROM VISION TO CHANGE: TRANSFORMING HOW LIFE SCIENCE IS TAUGHT

Science education is critical to prepare students for the world and jobs of the future, yet many institutions in the United States are using outdated educational models to teach science. The PULSE working group is a team of educators and administrators working to shift the culture of biology departments for stronger student outcomes in the life sciences.

Rethinking Approaches to Educational Reform

Science and technology stand at the forefront of modern industry and many of the world's major challenges, such as climate change and feeding the global population, can only be solved through scientific innovation.

Despite the need for quality science, engineering, technology and mathematics (STEM) education, many colleges in the United States are not prepared to offer undergraduate students comprehensive and modern curriculum in the sciences. Across the US, many undergraduate institutions are utilising outdated pedagogical frameworks for teaching the life sciences, leaving students ill-prepared for high level coursework or career development related to biology. These schools are in dire need of curriculum updates to bring them up to speed with current best practices in biology instruction.

In an effort to solve this problem, the Partnership for Undergraduate Life Sciences Education (PULSE) was formed in 2012 as part of a collaboration between the National Science Foundation (NSF), the Howard Hughes Medical Institute (HHMI), and the National Institute for General Medical Sciences (NIGMS). Program officers from these prestigious institutions selected 40 PULSE Fellows, each with a history of administrative success shaping undergraduate curriculums. Working together, these Fellows have developed a framework and tools to help institutions shift their biology teaching practices.

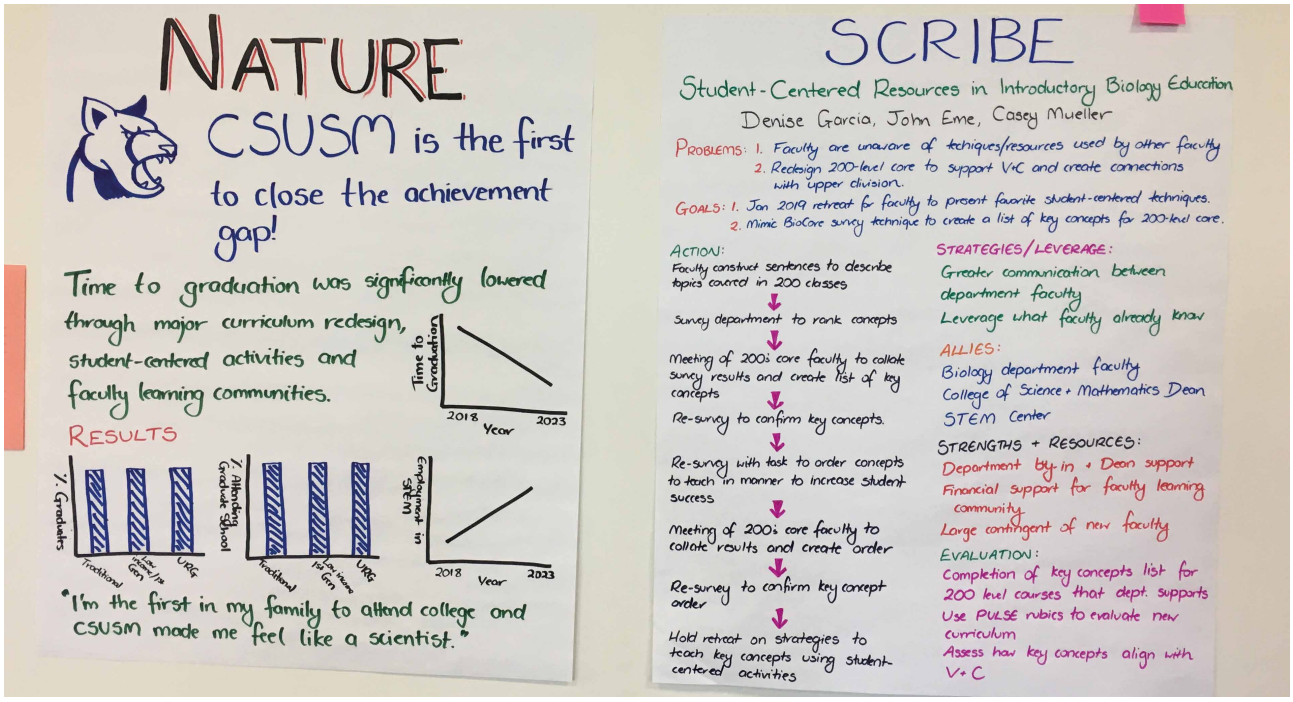
PULSE is unique because it pulls from the expertise of educators at all types of undergraduate institutions, from community colleges to universities with biology PhD programs, providing perspectives that shape a multifaceted view of how a biology curriculum can operate. Further, PULSE focuses on instituting department level changes rather than shifting the practices of any individual professor. This helps to ensure that changes will be long lasting and consistent across a program.

Getting Local

A key component of the PULSE mission is engaging educators in workshops and conferences. The PULSE Fellows team recognised that in order to do this

effectively, it was necessary to develop regional teams that could provide locally relevant content and reduce travel costs for live trainings. PULSE Regional Networks include those from the Northeast, Southeast, Midwest/ Great Plains, Northwest, and Southwest.

The Southwest PULSE Network is composed of PULSE Fellows and educators across the southwestern US who meet in regular videoconferences designed to stimulate departmental reform. Through these virtual meetings, the idea of forming sub-regional networks for live workshops was born. The Southern California PULSE Institute (SCPI), a 2½-day event first run in June



Teams work to create Action Plans

2018, brought local undergraduate biology educators together for a series of activities designed to foster leadership skills, shift departmental strategies, and develop networks of engaged biology departments across Southern California.

While SCPI was based on similar PULSE events run in other regions, it leveraged novel aspects of the region to develop a program with unique features. First, as part of an effort to increase diversity in STEM, the PULSE Fellows chose to focus on Hispanic serving institutions for seven of the eight team slots, with the ultimate goal of increasing the number of Hispanic and Latino students in biology. Second, Southern California was chosen as the inaugural sub-region in the Southwest due to its dense population and close geographic proximity of schools. This allows SCPI to aid in the formation of a network of life science faculty and administrators that can easily visit one another and exchange ideas and social support. Third, the program included an inclusivity module designed to raise awareness of challenges facing students from populations underrepresented in STEM fields.

Planning the Perfect Workshop

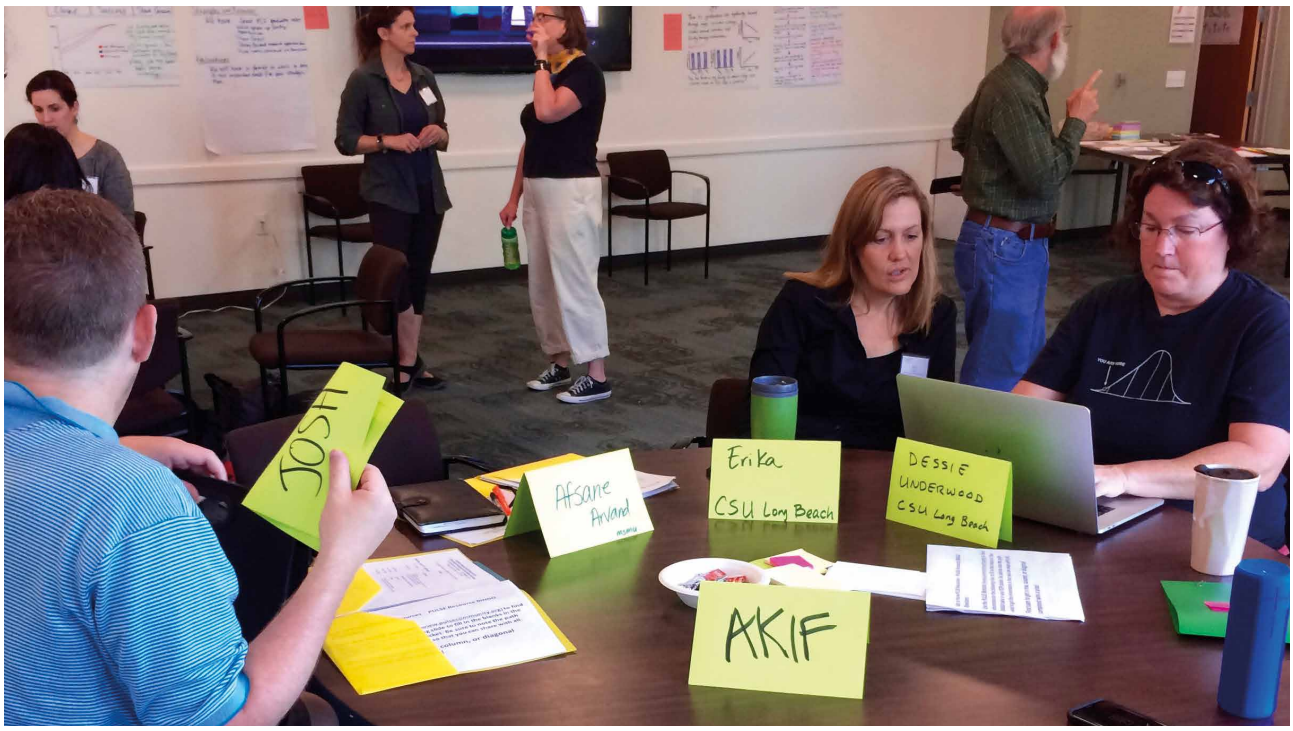
Prior to the event leaders from the Southwest PULSE Network, two PULSE Fellows from other regions that had already hosted a similar workshop, and two outside consultants met to plan the workshop. Using data collected from workshops in other regions, they were able to target key topics and areas for improvement to craft an effective 2½-day plan for SCPI. For the workshop to be successful, it was critical that the biology departments of participant institutions were assessed before and after to determine how effective the delivery was. Additionally, criteria for participant selection had to be outlined and a framework for selecting PULSE Catalysts established.

Describing the SCPI's goals PULSE member Dr David Marcey explains, 'We wished to provide opportunities for faculty and administrators to increase their awareness and understanding of the recommendations in *Vision & Change in Undergraduate Biology Education: A Call to Action*, identify specific elements to implement within their own departments, increase their understanding and awareness about systemic approaches and challenges to achieving inclusive excellence in undergraduate science education, and as a team, develop a shared vision of the outcomes they would like to see in their undergraduate curriculum, and develop an action plan to help them reach that vision.'

Bringing Diversity to the Table

Life science departments from the Southern California region were invited to apply to SCPI through an online survey, designed to determine their overall awareness of current biology teaching guidelines, their level of commitment to change, what obstacles they might be facing, the composition of their team, and unique features of their department.

To ensure that all levels of influence were represented at the workshop, teams of faculty, and in a few cases administrators, from schools that included 2-year colleges as well as universities ranging from liberal arts to research institutions, were selected. PULSE required a statement from an administrator of each institution that reform efforts would be supported and that improvement of life science departments was a priority.



Teams work to create Action Plans

Once teams were selected, they were asked to complete a number of PULSE Vision & Change Rubrics assessments to help score where their departments fell in relation to current best practices, the department's focus on student outcomes, availability of faculty support for life sciences, ability of the department to accommodate new curriculums, and how well the department as a whole was supported by their institution. These rubrics help PULSE Fellows determine what resources a participating team will need to succeed and what obstacles they might face that PULSE could help them to overcome. Further, they help identify how the workshop impacts a department by offering a prior baseline.

Three Days of Transformation

In the first day of the workshop, teams worked together to review their PULSE Vision & Change Rubrics and evaluate their departments alignment to best practices. They worked to find ways that their department functions as a cohesive system and to identify places where the system is impeded. Finally, they built out a vision for the future of their department and considered potential barriers to that vision.

The second day of the workshop began with teams learning about research demonstrating how students best engage with science to through active learning and high order thinking. They learned about PULSE resources designed to help them achieve the vision they developed on day 1 of the workshop and began formulating a strategy to get there. To conclude, a speaker with expertise in Hispanic STEM education presented issues relevant to the student demographics of the teams.

On the final day of the workshop, the teams worked to solidify their plans for success. They presented their strategies to other teams and received feedback and other ideas. They identified resources needed to achieve their goals and networked to find other PULSE participants who could serve as mentors and support across institutions. Finally, PULSE Catalysts were selected and prepped for their exciting new role in the Southern California life science education community.

Moving Forward

An assessment of the effectiveness of SCPI and PULSE initiatives will be conducted through a rigorous research follow up. Participating teams take part in quarterly video interviews and progress meetings to share how their strategy is progressing and will complete yearly rubrics to evaluate how their departments are changing. These data will not only help PULSE develop even more effective programs in the future, but will also help to keep participants on track with their visions for their departments.

Dr Marcey and his PULSE collaborators' next steps are to take the learnings from SCPI and use them to begin transforming schools in other sub-regions of the Southwest. 'We are evaluating the effectiveness of the institute and intend to incorporate participant feedback in order to deliver institutes similar to SCPI in targeted areas with high densities of undergraduate institutions,' he says. The PULSE program's dedication to biology education is set to shape life science departments across the US, creating a better future for all.

Meet the Team

David Marcey
Fletcher Jones Professor of Developmental Biology
Biology Department
California Lutheran University
E: marcey@callutheran.edu

Richard Cardullo
Howard H. Hays Jr. Professor
Biology Department
University of California, Riverside

Akif Uzman
Dean, College of Sciences & Technology
University of Houston-Downtown

Edwin Barea Rodriguez
Associate Dean for Student Success and Instructional Innovation
University of Texas, San Antonio

Alan Savitsky
Professor, Biology
Utah State University

Lisa Elfring
Assistant Vice Provost, Office of instruction & Assessment
University of Arizona

Christine Goedhart
Biology Instructor/Science Education Specialist
University of British Columbia

Betsy Desy
Professor Emerita, Biology Department
Southwest State University

Nalani Linder
Ready to Rise National Director
Degrees of Change

Steven Byers
Owner
Helping Human Systems

Kimberly Tanner
Professor, Biology Department
San Francisco State University

CONTACT

W: http://www.pulsecommunity.org/group/southwest-pulsers
E: marcey@callutheran.edu

FUNDING

US National Science Foundation

PULSE

A THREE-DIMENSIONAL APPROACH TO CONNECTING BIOLOGY & CHEMISTRY

Applying knowledge from one discipline to another is an oft-cited goal for undergraduate students. However, in many universities, science courses are taught essentially in isolation and do not provide adequate opportunities for students to connect their knowledge across disciplines. **Drs Rebecca Matz**, **Sonia Underwood**, and **Kristin Parent**, along with their collaborative research team at Michigan State University (MSU) and Florida International University (FIU), are developing activities that help address this gap.

Integrating Science Disciplines

The approach to teaching science courses in universities is often to compartmentalise disciplines from one another. If a student chooses to enrol in a chemistry degree program, they are immersed in the world of molecular structures, reactions and laboratory experiments. Likewise, a biology student will study evolution, cell structure and molecular biology. Though some broad foundational courses are required (e.g., a biology student will enrol in general chemistry), rarely will students make explicit connections to another discipline within a given course.

Therefore, when a student commits to a particular degree program, they may encounter few opportunities to connect their knowledge across disciplines before graduation. Such compartmentalisation fails to reflect the reality that addressing important scientific challenges requires drawing on knowledge from multiple areas of science (and other fields as well). This poses a dilemma to students – how do they acquire and practise using such knowledge?

As science and technology continue to advance in complexity, it is becoming recognised that a multidisciplinary approach is useful for science learning. Novel discoveries as well as a deep understanding of the fundamentals in biology increasingly require connections with other areas in science. Drs Rebecca Matz, Sonia Underwood, and Kristin Parent, along with their team at MSU and FIU, together share a wealth of expertise in chemistry, biology and science education research. Their two-year National Science Foundation-funded project, 'Creating Assessments for Student Understanding of Core Chemistry Ideas in Introductory Biology' aims to develop activities that assess undergraduate students' abilities to make such connections.

The Three Dimensions of Science Learning

The research team aims to develop these activities aligned with a 'three-dimensional' strategy. Developed by The National Research Council (NRC), the *Framework* for three-dimensional

learning rests on a view of science that 'continually extends, refines and revises knowledge'.

The three dimensions consist of: (1) scientific practices, that is, what we want students to do with their knowledge (e.g., build an argument from evidence); (2) crosscutting concepts,

‘Without assessments to measure students’ abilities to use scientific practices in the context of crosscutting concepts and core ideas, courses will continue to be driven by algorithmic assessments that leave students with inert science knowledge, unconnected between disciplines.’

that is, lenses for understanding problems that are useful across disciplines (e.g., systems thinking); and (3) core ideas, that is, ideas that are both central to a discipline and generative of new ideas (e.g., evolution in biology).

The aim of the *Framework* is to support the development of a future generation of proficient citizens and scientists who are able to draw on knowledge from multiple areas to address modern scientific challenges. ‘In the project, we are designing activities (appropriate for both group and individual work) that ask students to use their knowledge of chemistry to explain a biological phenomenon,’ says Dr Matz.

Project Design

To achieve the project objectives, the team is carrying out a research plan that consists of several tasks.

The first task entailed developing and implementing a survey for instructors

about which areas of connection between chemistry and biology they most valued in their local context. By matching the areas of interest with the instructors’ views, the team aimed to ensure that the assessments would be valid and therefore more likely to be relevant for distribution on a wider scale. The research team then used the results of the survey to prioritise the areas of connection for developing the activities.

Following a simplified method of evidence-centred assessment design, the team determined the goal of each activity as well as the responses students would provide as evidence of their connecting the core chemistry idea with the biological phenomenon. The team designed each activity to incorporate a scientific practice, crosscutting concept and core chemistry idea, and used an instrument called the Three-Dimensional Learning Assessment Protocol (3D-LAP) to verify that the activities reflected each dimension.

Each activity is situated within a biological phenomenon. For example, one activity asks students to explain the connection between the role of energy in the formation and breaking of covalent bonds and a molecular motor that effectively packages DNA into a virus particle using ATP. Students are prompted to recognise that the energy released from ATP hydrolysis must be physically proximate to the virus particle and DNA in order to power the molecular motor.

Each of the activities has been distributed in various ways to students in general chemistry and introductory biology courses at both MSU and FIU. Following pilot administrations and revisions for clarity, the team administered the activities to various populations of students at each institution, collecting approximately 800 student responses in total. Follow-up interviews helped the team to investigate the face validity of the activities, identifying what students were thinking about as they completed parts of the activity and points of confusion.

The team's preliminary analyses indicate a range of responses showing that some students are able to connect across the chemistry and biology concepts, while others continue to demonstrate compartmentalised knowledge; prior course-taking patterns are an important variable to consider in interpreting the student responses. Regardless, students often mentioned to instructors that the activities helped them make connections that were otherwise never explicitly highlighted for them. Collecting feedback from instructors, an external evaluator, and a project advisory board is also ongoing.

Propagation and Future Projects

The research team has endeavoured to share the results of their work with an array of audiences, including the Society for the Advancement of Biology Education Research (SABER), the American Chemical Society (ACS), and the National Association for Research in Science Teaching (NARST). Each audience brings a mix of practitioners and researchers who might benefit from seeing how students are making connections between chemistry and biology using the designed activities.

Upon successful completion of the project, the team aims to expand this work by developing a longer-term project in which specifically designed curricular materials and supports for three-dimensional teaching and learning are provided for larger groups of students. Over a longer time-scale, the researchers hope to build new collaborations that would support designing activities and curricular materials for different combinations of courses, such as chemistry and mathematics or biology and physics.

How pressing is it that universities undertake the large scope of work in order to transform their science curricula? Dr Matz says, 'Without assessments to measure students' abilities to use scientific practices in the context of crosscutting concepts and core ideas, courses will continue to be driven by algorithmic assessments that leave students with inert science knowledge, unconnected between disciplines.'

Meet the researchers

Dr Rebecca Matz
Hub for Innovation in Learning and Technology
Michigan State University
East Lansing, MI
USA

Dr Sonia Underwood
Department of Chemistry & Biochemistry and STEM Transformation Institute
Florida International University
Miami, FL
USA

Dr Kristin Parent
Department of Biochemistry and Molecular Biology
Michigan State University
East Lansing, MI
USA

Dr Rebecca Matz is an Academic Specialist in the Hub for Innovation in Learning and Technology at Michigan State University. Dr Matz completed her BS in Chemistry at University of Illinois before moving to University of Michigan to complete a PhD in Chemistry and MS in Educational Studies. Dr Matz's research interests lie broadly in assessment and organisational change within STEM. Her work explores the levers and barriers to institutional reform and adoption of new teaching practices, assessment of curricular changes in early mathematics courses, and challenges in making connections across subject areas. In particular, Dr Matz's current work aims to design activities that give undergraduate students the opportunity to use their knowledge of chemistry to explain biological phenomena.

CONTACT

E: matz@msu.edu
W: https://hub.msu.edu/our-team/

Dr Sonia Underwood is an Assistant Professor in the Department of Chemistry & Biochemistry and the STEM Transformation Institute at Florida International University (FIU). Dr Underwood joined FIU in 2016 after working as a Research Associate at Michigan State University in chemistry education research. Prior to that, she earned her PhD in Chemistry from Clemson University. Dr Underwood's research interests are focused on developing assessment measures to determine the impact of curriculum transformations, investigating how students use a chemical structure to predict a compound's macroscopic properties, and exploring the connections students make between their chemistry, biology, and physics courses.

CONTACT

E: sonia.underwood@fiu.edu
W: https://case.fiu.edu/about/directory/people/sunderwo.html

Dr Kristin Parent is an Assistant Professor who joined Michigan State University's Department of Biochemistry and Molecular Biology in 2013. Dr Parent's research focuses on understanding viral entry into host cells, and she uses cryo-electron microscopy to visualise the macromolecular structure of viral machines. Through this research we now better understand how viruses find, attach to, and infect specific hosts. In addition, her research has shed light on viral diversity in the environment. Dr Parent has won several awards and grants for both her research and teaching, including the MSU Outstanding Mentor and Teacher-Scholar Awards, and an NSF CAREER award for her work on virus host interaction and involving undergraduate, high-school and middle-school students in scientific research.

CONTACT

E: kparent@msu.edu
W: https://kparentlab.natsci.msu.edu/

FUNDING

US National Science Foundation

FIU FLORIDA INTERNATIONAL UNIVERSITY

MICHIGAN STATE UNIVERSITY

INFUSING CREATIVE THINKING INTO STEM EDUCATION

Creative thinking is the source of most great human inventions, works of art, and discoveries made throughout history. Professor Raphael DiLuzio, working at the University of Southern Maine (USM), is an artist who bridges traditional painting and drawing praxis with digital media. He has recently concluded work on a grant aimed at developing a pedagogy to infuse creative thinking into STEM education. This has been done through, research, workshops and the design of courses in creativity.

Theorising and Teaching about the Creative Process

Creativity is a very important skill that can sometimes be overlooked, particularly by students and professionals operating outside of creative or artistic fields. Yet creation and discovery are at the core of innovation over the many centuries of human existence. All human inventions and breakthroughs are the direct result of the creative act, the innate human ability to create something out of nothing or solve complex problems through the use of imagination and 'original' thought.

Almost all educational institutions worldwide try, among other things, to foster creative thinking in students, hoping that they will eventually develop their creative potential to the fullest, coming up with innovative ideas and approaches to solving the many problems of society. However, the creative process itself is often not actively and explicitly included as an independent discipline in most institutions' academic programmes.

Generally, the teaching and fostering of creativity is primarily limited to the Fine Arts and Design, as well as to other specific areas of the Humanities, such as creative writing. There is much ongoing debate as to whether creativity is a habit of the mind or an isolated type of intelligence. Several psychologists have proposed that human beings have a considerable number of different intelligences, with some researchers considering creativity or creative intelligence to be one of these.

Professor Raphael DiLuzio, an artist and associate professor at the University of Southern Maine, has been largely studying and theorising about the creative process and creative thinking, developing models that could foster creativity in students and individuals worldwide. In 2013, Professor DiLuzio was awarded a grant by the National Science Foundation (NSF) for a project particularly aimed at teaching creativity and fostering creative thinking in the areas of Science, Technology, Engineering and Mathematics (STEM) education.

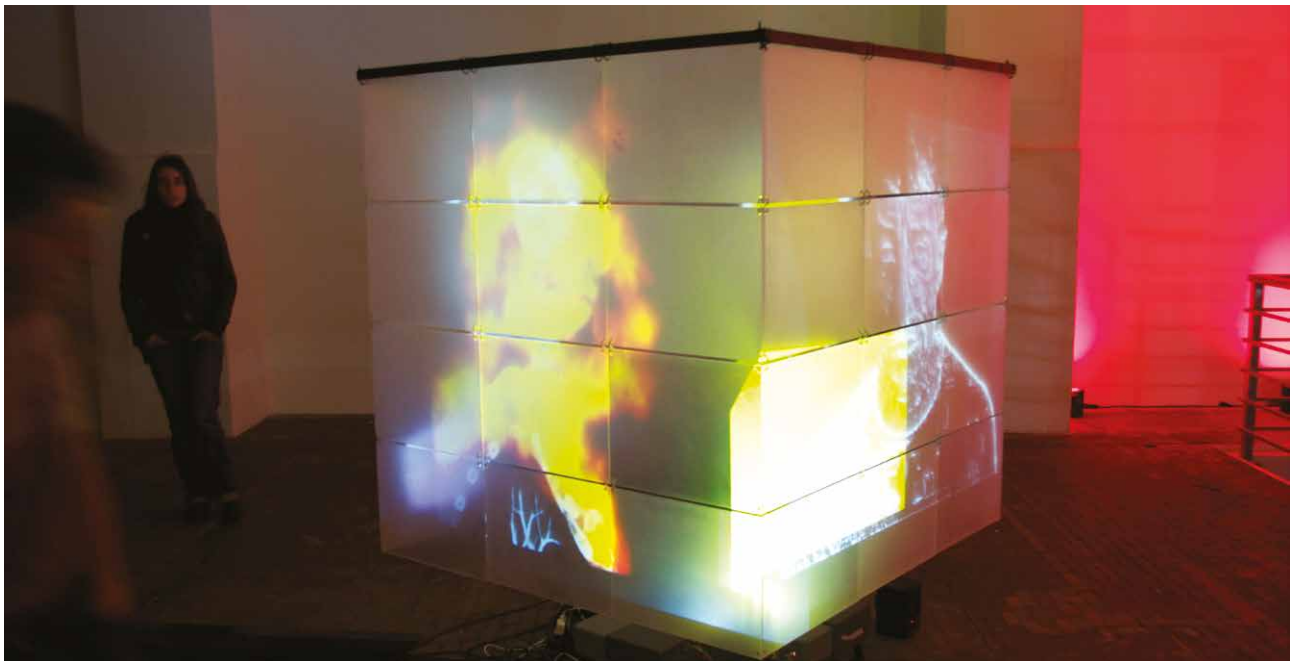
Infusing Creative Thinking in STEM Education

The 'Infusing creative thinking in STEM education' project, developed by Professor DiLuzio, includes a series of workshops, exercises, and techniques aimed at fostering creative thinking within STEM education settings. Professor DiLuzio explains that his work tries to, 'develop concepts, tools and processes to teach creative thinking strategies to STEM students and others outside Art. I like to refer to it as engineering creativity.'

'I want to engage people and help them to realise they are all creative thinkers,' he adds. The training method devised by him is based on the assumption that while creative thinking and problem-solving may be innate aspects of human nature, they can be enhanced throughout an individual's lifespan through teaching and experience.

According to Professor DiLuzio, there are two main types of creativity, one that could be described as the 'Grand Act', the process used when coming up with an innovative idea, and the other as the 'Small Act', comprised of all minor day-to-day actions, changes, decisions, or conversations that path the way towards the creation of new constructs or solutions.

‘We assert that as a species, we are inventors down to our very core. We are tool makers, problem solvers, and dreamers. Whether by accident or design, we all engage in the creative act – grand or small – on a regular basis.’



In one of his papers describing the project, Professor DiLuzio says that, ‘we assert that as a species, we are inventors down to our very core. We are tool makers, problem solvers, and dreamers. Whether by accident or design, we all engage in the creative act – grand or small – on a regular basis.’ The workshops, lectures, and training programmes developed by him try to address the complex task of defining and enhancing the process of creation in individuals from all kinds of academic and cultural backgrounds.

The principal goal of the project funded by the NSF is to expand the understanding of creative thinking as a dimension of undergraduate coursework in STEM faculties, ultimately creating opportunities in which students can train to improve their creative abilities. This is done by engaging faculty in intensive creative thinking workshops, introducing them to techniques that could stimulate creativity, which could later be included in their course material.

So far, Professor DiLuzio’s workshops have brought together faculty members from the Departments of Applied Medical Sciences; Environmental Science; Exercise, Health, and Sports Sciences; Biology; Computer Science; Mechanical Engineering; and Technology, at the University of Southern Maine.

Participants were taught techniques and strategies to create modules that combine creative thinking with material from existing STEM academic curricula that they could then incorporate into their classes. The workshops were ultimately aimed at helping the teachers to develop their students’ creative thinking and fostering mindsets that value innovation, while also teaching them new ways of integrating creativity into their daily work.

The Seven Stages of the Creative Process

The techniques used in Professor DiLuzio’s creative thinking workshops are based on prior literary discourse and on his very own theories about creativity. Taking inspiration from a range of works that includes Plato’s Theaetetus dialogue about the nature of knowledge to The Art of Thought, a seminal work, by Graham Wallas, DiLuzio combines them with his own research and experience, he concludes that the creative process could be thought of as having seven stages.

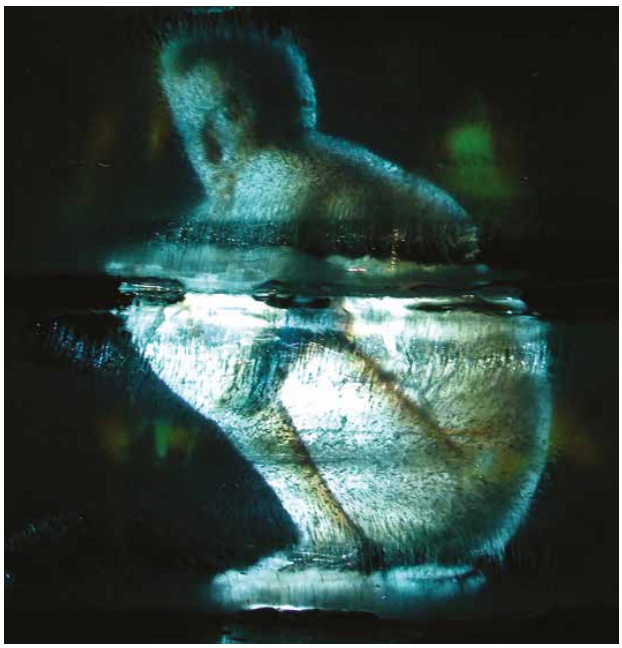
The first stage involves preparing or framing the question that the creating individual is trying to address with a solution or idea. This is the period during which the problem is identified, and it involves learning how to ask the right question, before getting started on the actual process of creation.

After that comes the stage of researching and learning more about the problem of interest. According to Professor DiLuzio, this should be done in moderation, to ensure sufficient preparation to cover all relevant aspects of the problem, without getting lost in an overwhelming amount of detail.

The third stage of the creative process is defined as ‘incubation’ or the phase in which an individual thinker lets the question and all related information he or she has acquired sink in, allowing the subconscious to work on it and make new associations.

Finally, the so-called ‘Eureka moment’ follows, the moment when the individual becomes aware of a new possible solution or interpretation to the question that he or she is trying to address. ‘Ideas and sudden inspiration do not always revolve around the question or problem we are directly working on,’ writes Professor DiLuzio. He says that, ‘in fact, we often have wild ideas that may seem to have nothing to do with anything. Sometimes they seem so, “out there”, that we instantly discard them.’

In his work, Professor DiLuzio highlights the importance of continuously capturing ideas, no matter how small or useless these might seem. He states that, ‘all too often a great idea is lost because we don’t capture it, or we consider it silly. There have been many ideas lost in this manner.’



The stage that follows the 'Eureka moment', arguably the most challenging one, is actual creation, the period in which an idea is brought into the world. This phase is particularly challenging as it often entails a significant amount of self-doubt and fear of failure, associated with the possibility that the idea might not be as successful or effective in real life.

The sixth stage of the creative process involves receiving feedback or criticism from others on the object of creation. The seventh stage involves the iterative process by either re-working the creation or re-evaluating it in terms of its relevance and effectiveness. After which, the creator releases or applies their creation to real life, whether that means releasing a product to the public or publishing or exhibiting a work of art. It is important to note that these stages are not necessarily linear as one can start at the Eureka moment and work backwards and so forth.

These seven stages are re-affirmed throughout many of Professor DiLuzio's current class in creativity, lectures and workshops, to help individuals enhance their understanding and application of their creative process.

Professor DiLuzio's Unique Artistic Vision

The 'Infusing creative thinking in STEM education' project merely represents a small part of Professor DiLuzio's wide array of artistic creations and academic experiences. Throughout his life, he has sought diverse ways of applying his creativity, publishing several theories on time-based painting and creative thinking, while also producing art, and experimenting in the entrepreneurial world.

Despite his academic background in traditional drawing and painting, for more than a decade Professor DiLuzio has been making use of emerging technology in his art, seeking ways to transition from fixed images to paintings that change over time. In a paper that describes his views on time-based art, he writes, 'digital time-based visual art is the form that has resulted from the advancements in the technology and its accessibility as a creative medium for the artist. Used as a time-based tool it enables the artist to create visual work that embodies time as a formal element and engages it as an aspect of expression and narrative structure.'

Professor DiLuzio has produced numerous time-based projected paintings, reconnecting his traditional painting skills with contemporary digital media. Meanwhile, he has placed extensive efforts in trying to enhance creative thinking in individuals from all kinds of backgrounds, through a series of talks, workshops, and courses worldwide.

Bringing Creativity into Educational Settings

An in-depth evaluation of the, 'Infusing creative thinking in STEM education' project, has been completed. Pre- and post-workshop surveys answered by participating faculty members revealed an overall increase in their perceived importance of creativity (both generally and specific to STEM subjects), as well as greater comfort and perceived preparation in teaching creative thinking as part of their courses.

Overall, participants were very enthusiastic during the workshops and went on to introduce a creative thinking module within the curriculum taught to their classes following participation in the workshop. The project's results are now being observed on a larger scale through DiLuzio's live and online version of the course in creativity at the University of Southern Maine and workshops conducted at the *Ci2 Concept Research Lab*, that Professor DiLuzio founded and established to foster further creative work by STEM students at USM.

Professor DiLuzio's research serves as a unique and inspirational example of how creative thinking could be brought into a greater number of classrooms and learning environments worldwide. Professor DiLuzio is now working on a book about his ideas and beginning this summer he will be giving a series of lectures at a number of universities.

Initiatives like the one devised by Professor DiLuzio could help to ensure that future generations are not only academically and professionally trained but are also filled with the timeless wonder and vision that has allowed our species to create, innovate, and transform society throughout our existence.

Meet the researcher

Professor Raphael DiLuzio
Associate Professor of Digital Art and Design
University of Southern Maine
Portland, ME
USA

Raphael DiLuzio is an artist, writer, entrepreneur, and professor of Digital Art and Design, as well as the developer and Director of the *Ci2 SRS Learning Lab* at the University of Southern Maine. His work explores ways of reconnecting traditional studio art with digital media produced using contemporary technology. As an artist, he considers himself to be a visualiser, merging traditional painting and drawing with digital and interactive media, to create impactful artwork that is exhibited internationally. In 2013, Professor DiLuzio was awarded a grant by the National Science Foundation (NSF) to develop his method of teaching Creative Process Thinking to Science, Technology, Engineering, and Mathematics (STEM) professors, students, and other individuals with no prior engagement in art. He has published several papers and theories on Creative Process, Creative Intelligence, Design Science, and working with time-based media, as well as critical examinations of how current and emerging technology affects arts and culture. Professor DiLuzio has founded three start-ups and has participated in a series of international conferences, lectures, and events. He has also given a TED Talk about some of his ideas and conducted workshops to encourage the creative processes of higher education students and individuals worldwide.

CONTACT

E: diluzio@maine.edu
W: http://www.raphaeldiluzio.com/raphaeldiluzio/who.html

FURTHER READING

R DiLuzio and C Bates Congdon, Infusing the Creative-Thinking Process Into Undergraduate STEM Education: An Overview, 2015, 5th IEEE Integrated STEM Conference, Princeton University, Princeton, New Jersey, USA.

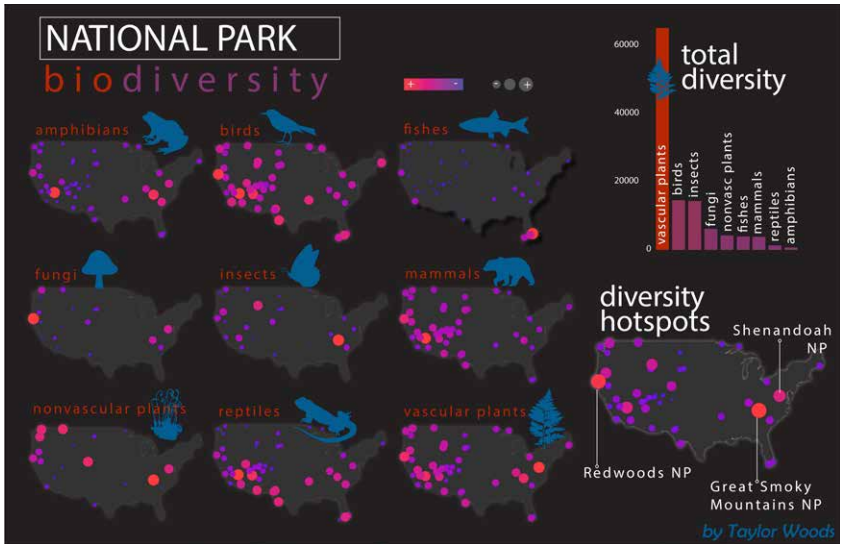
R DiLuzio, Chapter IX: Broken Cinema: The Eye and Hand in a Time-Based Art, in The Handbook of Research on Computational Arts and Creative Informatics, Edited by: J Braman, G Traikovski, and G Vincenti, 2009–2010, Towend University, 2IGS International.

R DiLuzio, Vjing, Edited by: M Shmalstieg, 2011, Grayscale Press, Geneva, Switzerland.

UNIVERSITY OF SOUTHERN MAINE

AN ARTS-BASED APPROACH TO SCIENCE COMMUNICATION TRAINING

Rapid growth in the number and diversity of digital media outlets is creating novel opportunities to increase public engagement with science. **Dr Daniel J. McGarvey** and **Sarah E. Faris**, working at Virginia Commonwealth University, have developed an interdisciplinary training program that teaches STEM graduate students to use digital media to effectively communicate scientific topics to general audiences.



Poster by Taylor Woods, summarising and mapping the diversity of animals and plants within US National Parks

A Need for More Engaging Science Communication Skills

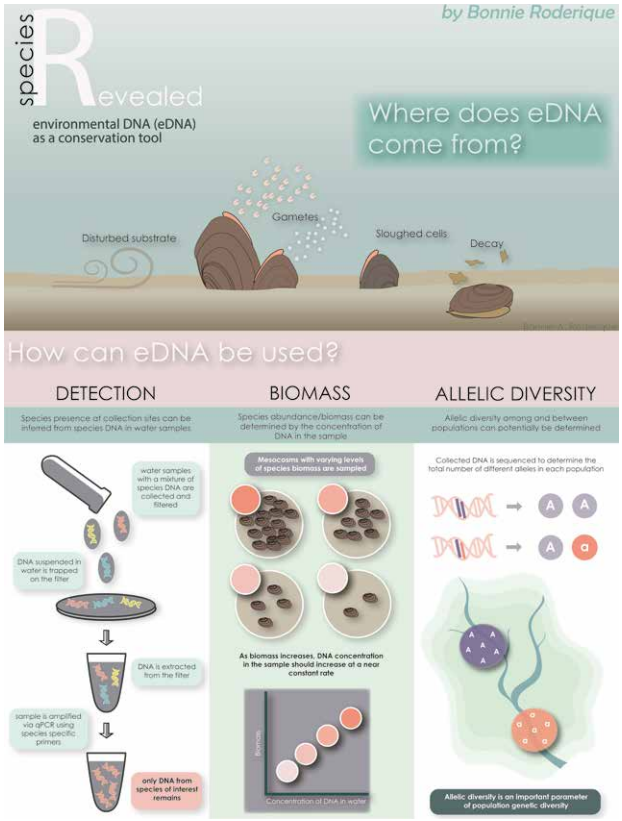
Communicating science in a way that is both informative and engaging is a significant challenge. Scientists are trained to write for technical journals but rarely have specialised skills in graphic design or the creation and use of digital media. This has allowed an information gap to develop in the public's understanding of science. In some cases, members of the public may simply remain unaware of scientific advances. But in others, audiences may turn to unvetted or erroneous sources of information on science, which are now abundant on the internet.

'Public interest and trust in science have eroded in the past decade, allowing misinformation to proliferate on topics such as climate change, vaccinations and genetically modified foods,' says Dr Daniel McGarvey, associate professor and graduate program director in the Center for Environmental Studies at Virginia Commonwealth University (VCU). 'Many within the scientific community are now mobilising to address this issue, but formal training mechanisms for young scientists to improve their broad communication skills are limited.'

In response to the lack of opportunities that STEM graduate students currently have to develop a diverse set of communication skills, Dr McGarvey has been collaborating with Sarah Faris, an assistant professor in VCU's Department of Communication Arts. The pair is developing a training project that teaches graduate students to apply digital media and design tools when conveying the details and importance of their research to non-specialist audiences. The result is an interdisciplinary training program, called 'Ecological and Environmental Perception version 2.0' ($eESP_{2.0}$), which uses an arts-based approach to enhance the visual communication skills of STEM graduate students at VCU.

Ecological and Environmental Perception, Version 2.0

At face value, an arts-based component to STEM graduate training may seem radical. Science is, after all, an exercise in objectivity and standardised methodology. Yet the underlying methods and motivation of $eESP_{2.0}$ are simple. Dr McGarvey and Faris are teaching students to leverage industry-standard tools in digital media and graphic design, with the hope that aesthetic visual content will spark greater public interest in science. The communicative power of strong visuals is something that all artists and designers are intimately familiar with. Well-designed visuals are generally more effective communication devices than the primarily text-based documents that scientists are trained to prepare. Indeed, empirical research has shown that messages accompanied by liberal graphical content are often retained more clearly and for longer periods of time than messages presented in primarily auditory or textual formats.



Poster by Bonnie Roderique, illustrating the production, analysis, and application of environmental DNA (eDNA)

Funded by a VCU Quest Innovation Grant, the eESP$_{2.0}$ program launched in the autumn of 2014. It has since offered formal courses that prepare students to work in several media formats. 'So far, eESP$_{2.0}$ course offerings have included a digital illustration and infographic design class, a second course in digital documentary filmmaking, and a third in website design,' says Dr McGarvey. 'However, the infographic design course has clearly emerged as the most germane to our STEM graduate students.' In this course, students learn to create digital, vector-based images that can be used in any type of media, ranging from slides and posters to websites, animations, and print articles.

Dr McGarvey explains that 'in a world that is saturated by digital media, where effective communication must often begin with an image that is sufficiently aesthetic to out-compete other stimuli for an audience's attention, we are teaching our STEM students to leverage the knowledge base and many of the technical skills that artists and graphic designers use on a daily basis.' By training graduate students to use modern tools in digital media and design, Dr McGarvey and Faris hope that their students will one day share their work with general audiences in more captivating and interesting ways than many of their scientific peers.

Structure of eESP$_{2.0}$ Courses

Dr McGarvey and Faris want their students to understand that audiences respond to visual cues in predictable ways and that careful preparation of visual content can dramatically improve communication effectiveness. Accordingly, the fundamental objectives for all eESP$_{2.0}$ courses are to teach students core principles of design, train them to anticipate the perceptions of target audiences, and provide them with enhanced technical skill in the creation of visual content.

Lesson plans include the basics of typography and legibility, colour theory, and effective use of space in page layouts. Sketchbooks and in-class critique sessions are used to experiment with and evaluate students' ideas. And with each consecutive assignment, students are challenged to further develop their technical skill with media-specific software, such as Adobe Illustrator and Photoshop. Students also learn to work across software platforms, often creating base charts and maps with R statistical software or ArcGIS, then importing their work to Illustrator for further editing and integration with other graphical and text elements.

Reflecting on the effort, Faris explains: 'The feeling of simplicity in science visual communications is a challenge, because research by its nature is often highly technical and far from simple. All information in science is connected, and the context in which it lives can be quite expansive, so prioritising and distilling information is a large part of the effort. Pathways through these tasks using an artistic approach are at the heart of what we try to impart to our students. Topics of discussion often include assessing what the intended audience already knows, the intended impact on the audience, and cultural considerations that can encourage or hinder understanding. Watching how one's own mind works when viewing a peer's infographic has shown to be a great learning tool in critique.'

'Of course, this has been a trial-and-error process,' notes Dr McGarvey. 'Not everything that we have tried has worked equally well and we are continually reassessing what we do in the eESP$_{2.0}$ courses.' For instance, students often want to develop thematic visuals that can immediately be used in their own individual research. But students enter the eESP$_{2.0}$ classes at different stages of their training and the instructors have found it is often best to use common themes and datasets for teaching purposes. One assignment that does require students to think hard about their individual work is the personal logo. Each student must create an image that is simple yet visually compelling, while thinking in an abstract way about their professional interests and identity.

Dr McGarvey and Faris are also happy to report that class sessions are a lot of fun. Students have ample time to share ideas and their work with classmates and to receive individual help from the instructors. A past student shared her experience: 'The infographics class had a tremendous impact on my career trajectory, in terms of getting recognised and standing out from the crowd. Having a skill that sets you apart from other applicants is a tremendous confidence booster from a personal perspective and for overall happiness as a grad student. This is a really fun, creative skill to have and good to be able to work on in a somewhat therapeutic way if other work is frustrating.'

Logos designed by students

Student Accomplishments so Far

All of the eESP$_{2.0}$ students acquire visual skills that are conspicuous, relative to other STEM graduate students. A few have gone further and genuinely surprised their teachers by demonstrating an obvious latent talent for visual communication. Dr McGarvey and Faris are now assembling indicators of student success that are anecdotal, but nonetheless compelling. A high-resolution version of each of the graphics included here can be downloaded at https://doi.org/10.6084/m9.figshare.7667735.v1.

Several of the past infographics students have received best presentation awards at regional and national research conferences. One was invited to speak about her infographics training and the opportunities it has created in a special science communication symposium at the 2018 Annual Meeting of the Society for Freshwater Science. Another was asked to create a modern redesign of an iconic ecological image (Raymond Lindeman's food web diagram from Cedar Bog, Minnesota), then co-authored an article in the Bulletin of the Association for the Sciences of Limnology and Oceanography in which the new image was published. And most recently, a student from the documentary film course won the grand prize at the 2018 Richmond Environmental Film Festival.

Though pleased, Dr McGarvey has not been surprised by these accomplishments. 'I expected that our students' unique visual skills would quickly be recognised by their peers,' he says. He did not anticipate, however, that eESP$_{2.0}$ training might lead some students to career tracks that focus primarily on science communication, rather than on scientific research per se. Yet in several cases, this is precisely what has happened. For example, one student who developed particularly strong design and visualisation skills was hired as an intern by the conservation organisation NatureServe. Four years later, he has been promoted to a lead design and science communication position at NatureServe.

A Glance to the Future

Reflecting on the eESP$_{2.0}$ experience to date, Dr McGarvey and Faris are proud of what they have built and of the progress their students have made. But they are also pondering the program's future and how it might be implemented at larger scales. 'We're thrilled to see that eESP$_{2.0}$ has immediately helped many of our students as they build their careers,' Dr McGarvey explains. 'But we believe the eESP$_{2.0}$ model can and should be implemented beyond VCU.'

Moving forward, Dr McGarvey and Faris see a need to shift their focus from individual student accomplishments to a systematic study of communication effectiveness that directly incorporates audience reactions to their students' work. 'The next step in this effort will be to directly measure how effective our students are in communicating with general audiences,' says Dr McGarvey. 'Currently, we have a proposal in review at the US National Science Foundation that, if successful, will allow us to assess how well our students communicate with general audiences, using live public forums to collect audience feedback.'

The plan is to pair eESP$_{2.0}$ students with representatives from local regulatory agencies and nongovernmental organisations. These representatives will provide students with thematic narratives and supporting data on topics of local and regional interest. Students will then develop multimedia presentations from these materials and present their work to public audiences.

To assist in collecting and analysing audience feedback, Dr McGarvey and Faris have recruited new help through the VCU School of Education. Dr Christine Bae, an assistant professor and specialist in STEM teaching and learning, is the newest eESP$_{2.0}$ collaborator. This partnership will provide a sound pedagogical foundation as Dr McGarvey and Faris work to place eESP$_{2.0}$ within a broader scientific context.

'If we can show a measurable, systematic benefit of our training program, we will move quickly to roll-out a larger precedent and accompanying curriculum that can be transferred to other institutions,' says Dr McGarvey. 'Our ultimate goal is to facilitate a strategic shift whereby a functional comprehension of design principles and a moderate-to-advanced level of skill in digital illustration and data visualisation are seen as fundamental to STEM graduate training.'

Meet the researchers

Dr Daniel J. McGarvey
Center for Environmental Studies
Virginia Commonwealth University
Richmond, VA
USA

Dr Daniel McGarvey is an associate professor and the graduate program director at the Center for Environmental Studies, Virginia Commonwealth University (VCU). He holds a BA in Biology and Geology from Wittenberg University, an MS in Fisheries Science from Pennsylvania State University, and a PhD in Biology from the University of Alabama. He joined the Center for Environmental Studies in 2011, after several years working as an environmental modeler at the US Environmental Protection Agency and a course instructor at the University of Georgia and Oregon State University. In the past, he also worked as a stream ecologist for the National Council for Air and Stream Improvement and as a fisheries consultant for the US Fish and Wildlife Service. Dr McGarvey's research focuses on a broad range of topics, including stream ecology, fisheries science, community and ecosystem ecology, biogeography, macroecology and ecological modelling.

CONTACT

E: djmcgarvey@vcu.edu
W: http://www.mcgarveyecology.com/

Sarah E. Faris
Department of Communication Arts
Virginia Commonwealth University
Richmond, VA
USA

Sarah Faris is an assistant professor in the Department of Communication Arts at VCU and the principal illustrator at SciMed Studios. She holds a BFA in Communication Arts from VCU and an MA in Medical and Biological Illustration from John Hopkins University. She has worked at VCU for 10 years, where she has transitioned from an adjunct to assistant professor. In the past, she was a medical illustrator for Amicus Visual Solutions and Seif and Associates. Faris has created medical and scientific illustrations for several textbooks and publications. Her work has received multiple honours and awards, including the 2011 Award of Excellence for Professional Medical Legal Illustration by the Association of Medical Illustrators.

CONTACT

E: s2sefari@vcu.edu
W: https://www.behance.net/scimedstudios

KEY COLLABORATORS

Dr Christine L. Bae
School of Education
Virginia Commonwealth University
Richmond, VA
USA

FUNDING

VCU Quest Innovation Grant

VIRGINIA COMMONWEALTH UNIVERSITY

DREAM STEM: DRIVING ENTREPRENEURSHIP & ACADEMIC SUCCESS

Identity as a scientist and entrepreneurial thinking are critical for students of STEM to succeed, both in their college-based education and their careers. In recognition of this, a team of researchers from North Carolina Central University has developed DREAM STEM – a program that aims to develop scientific identity and a mindset for entrepreneurial thinking. This, in turn, improves enrollment, retention, persistence and graduation rates.

The Importance of Identity and Entrepreneurial Thinking

Identity is what makes us, us. Of course, identity is a dynamic notion – something that changes throughout our lives. Our background and experiences will shape it greatly. Nevertheless, many would agree that a sense of identity and where one 'fits' is a fundamental aspect of what motivates them from day to day. The same is true of STEM students. Identity influences not only their choice to enter related fields, but also their determination to continue down that path.

Another important tool for success in the world of STEM is entrepreneurial thinking. This type of thinking enables students to solve challenging problems – perhaps thinking outside the box to do so. It also helps students to tailor their career goals and aspirations to market needs, and to make strategic business decisions. Often these skills are lacking in STEM graduates. It is important, therefore, that college STEM programs are equipping students with these attributes.

To that end, a team of researchers from North Carolina Central University (NCCU) – consisting of Dr Caesar Jackson, Dr Alade Tokuta, Dr Tanina Bradley and Clarrisa Grady – developed a program known as 'DREAM STEM', or 'Driving Research, Entrepreneurship, and Academics through Mastering STEM'. DREAM STEM aims to develop a student's identity as a scientist and expand their mindset for entrepreneurial thinking. This, in turn, has improved enrollment, retention, persistence and graduation in physical and mathematical sciences undergraduate degree programs at NCCU.

DREAM STEM – An Overview

The DREAM STEM project was established at NCCU in 2012 with a grant from the Historically Black Colleges and Universities Undergraduate Program (HBCU-UP) of the National Science Foundation (NSF). The major goals of the program are to increase enrollment and retention in STEM degree programs at NCCU, to increase persistence and graduation rates in STEM and to produce highly-skilled STEM graduates who can create and innovate.

There are three central components of DREAM STEM, along with related initiatives and strategies, to ensure that these goals are attained. The first component focuses on what the team refers to as 'Teaching-as-Research'. The second one focuses on entrepreneurship in science education. Finally, the third component aims to develop a student's identity as a scientist.

Component 1 – 'Teaching-as-Research'

The Teaching-as-Research component promotes innovation in the teaching practices of STEM faculty at NCCU. To do this, DREAM STEM provides financial assistance through mini-grant awards to incorporate, study and test evidence-based approaches in their classrooms.

One mini-grant awarded by DREAM STEM focused on increasing participation rates of African American students in STEM classes by offering engaging learning activities based on real-world scenarios. During this initiative, a new science course known as 'STEM 1200 – Scientific Decisions in Everyday Life' was created. The associated learning experiences centered on the mathematics of stock markets, the science of musical sounds, and the kinetics of human movement, to name a few. All units used student-centered demonstrations and active engagement activities in the instructional approach.

In another project, teachers designed and implemented two analytical chemistry courses – 'Quantitative Chemical Analysis' and 'Instrumental Analysis'. Each project involved identifying a problem, locating an appropriate method by searching the literature, designing a study, collecting samples, measuring variables, analyzing data and presenting the results in a formal report and an oral presentation. Students engaged with many interesting projects – analyzing latent fingerprints, gun powder, over the counter cough syrups and water samples in the process.

Component 2 – Entrepreneurship

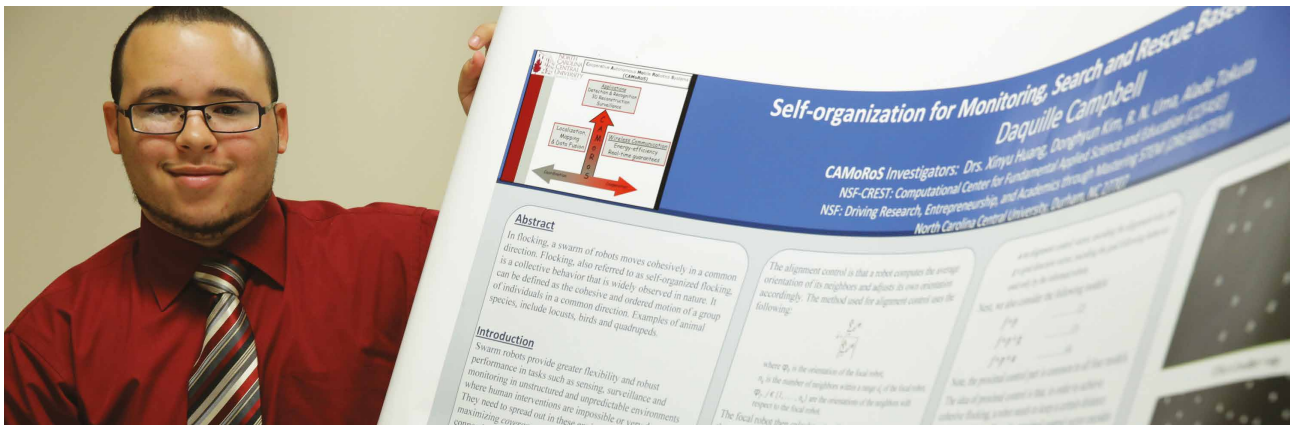
The 'Entrepreneurship in STEM Education' component is delivered through the Research, Discovery and Innovation (RDI) Summer Institute. To support the delivery of this program, the DREAM STEM team created a new course known as 'STEM 1000 – Rediscovering STEM through Entrepreneurial Thinking.' In conjunction with RDI Summer Institute, this course is an experiential opportunity that engages students in the research and development (R & D) aspect on entrepreneurship by encouraging them to propose creative solutions to real-world problems and prototype their innovative products. In addition to hands-on design skills development, students were trained on how to carry out market analysis and identify financial sources to fund a business behind their products and solutions.

At the end of the RDI Summer Institute, students pitched and demonstrated their creations to an audience of peers, faculty, staff, and guests in a closing program. Examples of student-designed products include: a phone case with integrated solar charging capabilities, a voice-activated taser and flashlight bracelet for personal safety, a door-bell security system with fingerprint recognition, and automated claws for drones that can identify objects and pick them up.

Component 3 – Developing Identity

As is highlighted by the DREAM STEM team, a student's scientific identity is thought to consist of three overlapping facets; namely, performance, competence, and recognition. In addressing these facets, DREAM STEM offers students scholarships to demonstrate performance, undergraduate research experiences to demonstrate competence, and opportunities to attend and present at national STEM meetings to gain recognition.

To support this process, students are awarded academic scholarships for tuition and fees, book awards, work stipends, paid undergraduate research experiences, and conference travel to attend professional meetings. Furthermore, to make students feel like they are part of the scientific community, DREAM STEM undergraduate researchers submit



abstracts and give oral and poster presentations at the Annual Emerging Researchers National (ERN) Conference in Washington, DC. In addition, DREAM STEM also supports students attending and presenting at the Annual Biomedical Research Conference for Minority Students (ABRCMS) and the National Society of Black Physicists Conference.

DREAM STEM – Impact on Students

The first project component of DREAM STEM, that is, Teaching-as-Learning, resulted in two mini-grant activities, both of which had a positive effect on student learning. For example, STEM 1200 – Scientific Decisions in Everyday Life achieved statistically significant gains in student's confidence in areas such as writing, scientific thinking and problem solving. The analytical chemistry course resulted in higher course retention and increased student confidence in terms of laboratory, analytical and communication skills.

The second component, Entrepreneurship in Science Education, likewise imparted many benefits to students. Surveys conducted by the DREAM STEM team found that students' felt more confident in their ability to turn ideas into feasible business opportunities, develop a product plan, conduct market analysis and make strong presentations. Students also reported higher self-belief. In terms of technical skills, students felt that they could better select a promising concept and implement the design. Many even reported a stronger desire to be a business owner or inventor in a STEM-related field.

Finally, the DREAM STEM team found that the third component helped students to develop their identity as a scientist. Surveys indicated that students were more confident in their ability to apply science knowledge, work independently in a lab, communicate science and technology to professionals both orally and in the written form, prepare technical or science research talks and critique their work and that of others. In summary, they felt part of the scientific community.

Retention and Graduation

Due to the support offered by the DREAM STEM team, many students were able to persist in their studies and graduate with STEM degrees. Retention rates for freshmen who were DREAM STEM participants averaged 97% compared to 28% for non-DREAM STEM students in the general population of STEM majors. Likewise, persistence in STEM to 3rd year for DREAM STEM participants was 92% compared to 23% respectively. In addition, four-year graduation rates for freshmen who were DREAM STEM participants was 43% compared to 10% for non-DREAM STEM students.

The Chemistry, Mathematics and Physics degree programs at NCCU were specifically targeted by DREAM STEM, and during post-HBCU-UP award period, average degree production increased in Chemistry by 69%, in Mathematics by 50% and in Physics by 88%.

Challenges and Moving Forward

The DREAM STEM team did acknowledge some barriers to meeting the objectives of the project. For example, there was a low number of submissions for mini-grant proposals and some of the STEM faculty felt that the effort required to prepare a mini-grant proposal was a limiting factor to their participation. Another challenge was that some of the STEM faculty did not have the full complement of skills needed to define and conduct education research projects. Unfortunately, after a few rounds, no new calls were made for faculty mini-grant proposals and this component was suspended. Given the benefits imparted to students while implementing and testing evidenced-based pedagogies, future opportunities will be explored that provide professional development of STEM faculty in the education research area.

All things considered, DREAM STEM has had a hugely positive impact on student learning in STEM. It has achieved this through three components – improving the delivery of STEM education through 'teaching-as-research' initiatives, stimulating and enhancing entrepreneurial thinking, and strengthening a student's identity as a scientist. All of this has positively impacted retention, persistence and graduation in STEM at NCCU, as has been evidenced thus far. This will only continue as DREAM STEM is enhanced and expanded in the years to come.

Meet the researchers

Dr Caesar R. Jackson
Department of Mathematics
& Physics
North Carolina Central University
Durham, NC
USA

Dr Caesar R. Jackson received his PhD in Physics from North Carolina State University in 1992. He joined North Carolina Central University as Professor of Physics, where he led the development and implementation of DREAM STEM with aims to increase enrollment, retention, persistence, and graduation in physical and mathematical sciences undergraduate degree programs at NCCU, focusing on students' science identity development and entrepreneurial thinking mindset.

CONTACT

E: crjackson@nccu.edu
W: http://www.nccu.edu/directory/details.cfm?id=crjackson

Dr Alade O. Tokuta
Department of Mathematics
& Physics
North Carolina Central University
Durham, NC
USA

Dr Alade Tokuta received his PhD in Electrical Engineering/ Computer Science from the University of Florida. He currently serves as Professor and Graduate Coordinator at NCCU. His research interests include computer graphics, image processing, robotics, computer networking, computer-aided design, geometric modelling and bioinformatics. He leads the undergraduate research experiences activities that provide intensive scientific training of students and prepares them to communicate science to professional and general public audiences.

CONTACT

E: atokuta@nccu.edu
W: http://www.nccu.edu/directory/details.cfm?id=atokuta

Dr Tanina Bradley
Department of Mathematics
& Physics
North Carolina Central University
Durham, NC
USA

Dr Tanina Bradley received her PhD in Electrical Engineering from North Carolina Agricultural and Technical State University in 2012. She has been with NCCU since 2013, where she now serves as 3+2 Dual Degree Program Advisor and Adjunct Assistant Professor. Through the DREAM STEM program, she assists with the delivery of a holistic academic support, and provides enrichment, research, and work opportunities for mathematics, physics and engineering students.

CONTACT

E: tbradle9@nccu.edu
W: http://www.nccu.edu/directory/details.cfm?id=tbradle9

Clarrisa L. Grady
Department of Mathematics
& Physics
North Carolina Central University
Durham, NC
USA

Clarrisa Grady received her Master's degree in Public Administration from NCCU in 1995. Since then, she has worked with several federal, state and non-profit organizations as a public servant administrative manager. Since 2013, she has been serving as the Program Coordinator for the DREAM STEM Project.

CONTACT

E: cgrady@nccu.edu
W: http://www.nccu.edu/directory/details.cfm?id=cgrady

FUNDING

National Science Foundation (NSF)

NCCentral UNIVERSITY

INTEGRATING TEAM SCIENCE INTO THE STEM GRADUATE TRAINING EXPERIENCE

Over the past few decades, research in science, technology, engineering, and mathematics (STEM) has experienced a major shift towards collaboration. On a quest to prepare graduate students for today's team-based research environments, **Dr Susan Cozzens** at Georgia Institute of Technology is leading an interdisciplinary team in the development and implementation of evidence-based 'team science' professional development materials for STEM graduate students.

The Rise of Team Contributions in Science

Over the second half of the twentieth century, STEM research started to become increasingly team-based, with a growing number of multi-authored publications and studies carried out by groups of scientists. Despite this notable shift, there has been little or no change in the preparation of students entering STEM careers that involve greater collaboration.

Science of Team Science (SciTS) is a new discipline that aims to understand and enhance the success of collaborative research. Developed in response to the observed trend towards larger research teams, SciTS engages scholars from a variety of fields, including organisational science, social psychology and health promotion, in addition to groups outside of academia, such as private companies.

The findings obtained from SciTS studies are already helping researchers to develop evidence-based tools and programs to improve the effectiveness of team science initiatives. These tools can be used to prepare students for collaborative and interdisciplinary work, ultimately assisting them in tackling their future professional endeavours.

Several universities worldwide have started to recognise the increasing shift towards team-based research and are implementing strategies that promote a cultural shift towards team science. These strategies include establishing on-campus interdisciplinary research centres and seed grants for team-based proposals, as well as building strong ties with local laboratories and companies. Such university-driven initiatives that foster collaboration can provide students with a better understanding of how to best operate in teams. Unfortunately, however, graduate programs almost never pay explicit attention to the skills students need to survive and thrive in these settings.

To equip graduate students for success in today's team-based research world and foster more effective science collaborations, an interdisciplinary team of STEM researchers at Georgia Tech, led by Dr Susan Cozzens, has

been developing, implementing and assessing evidence-based team science training experiences for STEM graduate students. Joining Dr Cozzens in this work are Dr Mary Lynn Realff from Materials Science and Engineering, Dr Kata Dosá of the Center for Teaching and Learning, and Dr Angus Wilkinson of Chemistry and Biochemistry. Dr Meltem Alemdar and Christopher Cappelli from Georgia Tech's Center for Education

Integrating Science, Mathematics, and Computing, are assessing the curriculum materials.

A Team Science Program for Graduate Students

Integrating Team Science into the STEM Graduate Training Experience, a project initially devised by Dr Nancy Devino, now of the University of Texas at ClearLake, builds on prior evidence of the efficacy of team training to promote teamwork skills and enhance team effectiveness. It draws on some of the best practices for team training in a variety of sectors, including education, industry, healthcare and the military, as well as undergraduate team training at Georgia Tech, while also taking inspiration from previous NSF-funded team science initiatives.

The project design is based on a three-dimensional C.A.S. approach, which stands for competencies, audience and settings. It aims to introduce team science competencies to a diverse student audience, in a variety of settings. These competencies include knowledge about the nature and value of teamwork, skills in communication and conflict management, and attitudes about diversity – both cultural and disciplinary.

In order to maximise the flexibility of the program and its transferability to other institutions, the curricular material is created in small units that can be delivered within different settings. For instance, the same curriculum can be integrated into semester-long academic courses or combined into half-day or full-day workshops.

Integrating Team Science into the STEM Graduate Training Experience is designed to be innovative and transformative. In contrast with other team science endeavours, it does not limit the training to students in one discipline, but is instead offering it to all STEM graduate students at Georgia Tech.

Dr Cozzens and her colleagues believe that team science training will eventually become a standard part of graduate education and reach nationwide institutionalisation. Their work could offer an important example of how to equip STEM graduate students for collaborative and team-based work environments.

Project Implementation

The new professional development team science materials available at Georgia Tech follow a multi-dimensional approach. They are based on an innovative design that allows Dr Cozzens and her colleagues to study the development of transportable team science competencies for a graduate student audience and in a variety of settings.

The project's implementation plan follows a series of key steps. Firstly, it involves the adaptation and design of instructional materials that could help to achieve the desired objectives. Secondly, these instructional materials will be tailored to fit a variety of institutional settings.

As part of the project, the team is assessing the effectiveness of the learning materials, then revising in response to student feedback. This cycle is set to be repeated several times,

with the researchers learning from previous implementations and using their observations to perfect and improve the program.

Once these materials have been developed, refined and tested, the researchers will make them available at Georgia Tech, initially for students completing MS and PhD degrees in computing, engineering and science. In Years 2 and 3 of the project, the researchers aim to engage with other institutions, to test their curricular materials in other educational settings.

Program Structure and Content

The team science curriculum is designed to teach graduate students to appreciate the importance of collaboration, cultivating the interpersonal skills required for effective team performance. During each of the modules, students will participate in team-building exercises, discussions, and interactive activities, designed to strengthen their collaboration skills. As many STEM research teams now collaborate remotely, the course content also highlights some of the challenges and opportunities associated with virtual work spaces.

The six modules under development address the following core competencies: the value of teams; team composition, roles, and leadership; communication in teams; conflict management in teams; diversity in collaboration and team science; and technical tools for distributed teams. Each module has multiple components, which are designed to be delivered in time segments of 15–45 minutes each.

Each of the modules features complementary instructional resources, including interactive and web-based exercises, case studies, facilitated discussions, team building exercises adapted from other sources and assigned readings. Participating students will also be asked to complete self-assessment questionnaires to better understand their strengths, weaknesses, conflict resolution styles, and social sensitivity, as well as those of their team-mates.

After completing the modules, the students should have a better understanding of the differences between working alone and in teams. They should also be more aware of communication challenges associated with team-work, roles and conflict management styles, the implications of diversity, and effective tools to collaborate remotely. The training should enhance their collaboration skills, teaching them strategies to tackle communication challenges, diversity and conflicts.

Evaluating the Project's Outcomes

Georgia Tech's Competencies, Audience, and Settings (C.A.S.) approach includes a robust and comprehensive assessment plan that will allow the project team to answer research questions such as: 'Which instructional materials and approaches are more effective for students' development of team science competencies?' and 'What setting is most suitable for learning and retaining specific transportable skills?'.

Assessment results will provide Dr Cozzens and her colleagues with crucial guidance on how to improve the training, while also measuring its impact on participating students' team science knowledge and skills.

The project's assessment leader, Dr Meltem Alemdar, and her colleague Christopher Cappelli, are also contributing to the curriculum design process, so as to maximise the potential for measuring the impact of the program on participating students' knowledge and skills. Dr Alemdar will work with peers at other institutions that are testing the materials, to collect and analyse data measuring the effectiveness of the team science materials.

The assessment data will be collected using both quantitative and qualitative methods, such as student and faculty surveys, institutional records, observations collected during student focus groups, and document analysis. As well as determining whether the program's objectives have been met, this assessment might also provide key insight about the effectiveness of specific SciTS modules, strategies and techniques, which could inform further work and initiatives.

A Transformative Team Science Project

Integrating Team Science into the STEM Graduate Training Experience is an innovative project aimed at preparing STEM graduate students to enter careers that involve team-based research and collaboration, whether in academia, industry, the government, or the non-profit sector. While the project at Georgia Tech primarily targets MS and PhD students graduating in STEM disciplines, the same course content could be transferred and adapted to serve different student populations in a variety of educational settings.

The SciTS modules developed by Dr Cozzens and her colleagues offer a flexible and complementary team science curriculum that can be delivered to diverse audiences in a variety of settings. As the researchers hope to develop a curriculum that can be adopted nationally, they plan to test its effectiveness in different content delivery settings and schedules and train graduate program staff to use the modules on their own.

In future, the training could be implemented at other universities, promoting effective team science preparation on a far larger scale. By developing, implementing and assessing the impact of these comprehensive team science processional development materials, Georgia Tech could become a key contributor to the evolution of STEM graduate education.

Meet the researchers

Dr Susan E. Cozzens
School of Public Policy
Georgia Institute of Technology
Atlanta, GA
USA

Dr Susan E. Cozzens is Professor Emerita and former Vice Provost for Graduate Education & Faculty Development at Georgia Institute of Technology. She holds a BA in Sociology from Michigan State University, as well as an MA and a PhD in Sociology from Columbia University. She has previously been Associate Dean for Research in Georgia Tech's liberal arts college, Chair of the School of Public Policy as well as director of doctoral programs there, and Director of the US National Science Foundation's Office of Policy Support. Dr Cozzens has served as a consultant for a wide array of national and international bodies, including the United Nations Commission on Science and Technology for Development, the White House's Office of Science and Technology Policy, the Department of Homeland Security, the UK Department of Health and the Canadian Council of Science and Technology. She has been part of several advisory and evaluation panels, including the Environmental Protection Agency's Board of Scientific Counselors, and many expert panels under the National Research Council. Over the course of her career, she has published over 40 scientific papers and books exploring a variety of topics.

CONTACT

E: scozzens@gatech.edu
W: https://www.iac.gatech.edu/people/faculty/cozzens

Dr Angus P. Wilkinson
Dr Angus P. Wilkinson is an Associate Chair in the School of Chemistry and Biochemistry at the Georgia Institute of Technology, and he leads a research team that uses synchrotron X-ray and neutron scattering methods to probe structure-property relationships in inorganic materials. This work involves collaboration with scientists at several US Government funded National Laboratories.

Dr Kata Dosa
Dr Kata Dosa is a faculty developer and discipline-based education researcher. She earned her PhD in Environment and Resources from the University of Wisconsin-Madison, where her research looked into environmental decision-making and reasoning processes. Dr Dosa's current research interests are teaching-as-research, incorporating sustainability across the curriculum, team science, and competency development in higher education.

Dr Meltem Alemdar
Dr Meltem Alemdar is Associate Director and Senior Research Scientist at Georgia Institute of Technology's Center for Education Integrating Science, Mathematics and Computing (CEISMC). Her research focuses on improving STEM education through research into curriculum development, teacher professional development, and student learning in integrated STEM environments. She is currently co-PI on the project *Integrating Team Science into the STEM Graduate Training Experience* and leads the assessment efforts.

Dr Mary Lynn Realff
Dr Mary Lynn Realff is an Associate Professor of Materials Science and Engineering at Georgia Tech. She received her PhD in Mechanical Engineering and Polymer Science & Engineering from the Massachusetts Institute of Technology. At Georgia Tech, she teaches graduate and undergraduate courses in the mechanics of textile structures and polymer science. In addition to her contributions to this project, she leads a campus initiative on Integrating Effective Team Dynamics in the Curriculum.

Christopher Cappelli, MPH
Christopher Cappelli is a Research Associate at CEISMC, Georgia Tech. His research focuses on using novel methods to explore issues in graduate education, state education agencies, teacher retention and teacher development. He is specifically interested in the use of social network analysis and quantitative methods to explore research questions in education and public health. His role in *Integrating Team Science into the STEM Graduate Training Experience* is in research and assessment, where he collects and analyses data to improve the workshop materials.

FUNDING

The work is supported by NSF Grant 1735017 under the Innovations in Graduate Education program.

CONNECTING DIVERSE LEARNING EXPERIENCES

Students often have experiences outside of school with real academic value. It can be difficult, however, to demonstrate this value and have it recognised by educational institutions and employers. The digital badge platform developed by **Dr Katie Davis** and colleagues at the University of Washington aims to provide high school students with a way to connect their out-of-school achievements to their academic and career interests in science, technology, engineering and mathematics (STEM).

Bridging Institutions with Practice

Dr Katie Davis and her team at the University of Washington Information School have been engaging with an afterschool science program at Seattle's Pacific Science Center that offers high school students learning experiences that are informal but rich with educational value.

Dr Davis argues for a need to recognise value like this in activities that take place outside of formal school contexts. 'There is growing recognition that a lot of rich learning experiences happen in out-of-school contexts. However, these learning experiences aren't always recognised by or connected to more formal education contexts,' says Dr Davis.

In order to bring recognition and credibility to experiences like these, Dr Davis and her colleagues have been developing and investigating a digital badge system that represents students' informal learning achievements and allows them to share those achievements with relevant parties, such as college admissions officers and prospective employers. In this way, badges are intended to help connect students to future educational and career opportunities.

Digital badges are web-based digital icons containing rich metadata that represent learning achievements. In the context of this project, they are being used to recognise relevant science, technology, engineering and mathematics (STEM) accomplishments outside of the school system.

The project, called Digital Badges for STEM Education, has received attention from scholars, practitioners and policymakers. Early in the project, Dr Davis and her team investigated students' perceptions of badges and what opportunities and challenges they saw in a prototype system. They used a process of *Participatory Design* from the start that involved input from coordinators and students of the afterschool program.

An important goal of the project is to use digital badges to establish the credibility of skills students have learned in their afterschool science program. The platform features a representation of visible learning pathways to help students appreciate what they have accomplished and clearly see the future learning opportunities that correspond with their new skills. Dr Davis and her team hope to use the badge system to bridge contexts between informal learning activities and formal education and employment opportunities by verifying and clearly displaying students' achievements.

'The goal is for students to use digital badges to make their learning visible to themselves and to people outside the program, thereby supporting their science identities and connecting them to future education and career opportunities,' Dr Davis explains.

A Narrow Pipeline

The project responds to the United States' shortage of STEM professionals as well as a disconnect that students often feel between their learning experiences in and outside of school. Taking issue with the tendency of policy initiatives to focus exclusively on the one-dimensional 'school to workforce' pipeline in STEM fields, Dr Davis wanted to put in place a system that recognised the nonlinear paths it is possible to take to a STEM career. By facilitating these paths, she believes it is possible to achieve increased diversity in the STEM workforce.

‘The goal is for students to use digital badges to make their learning visible to themselves and to people outside the program, thereby supporting their science identities and connecting them to future education and career opportunities.’

Discovery Corps

Cultivating a Scientific Identity

The team’s work is informed by the idea that students’ learning and career trajectories can have limits imposed by social and institutional barriers associated with their socioeconomic background. By recognising science learnt in informal settings, the badge platform empowers students whose talents and curiosity may not always be recognised through traditional institutional structures such as schools and universities. Alternate avenues to STEM careers are in this way opened up to a wider, more diverse group of students.

Dr Davis believes that the flexibility associated with informal settings can give students greater control over their STEM learning. However, students also need ways to display their accomplishments in informal learning settings for the value of their experience to be recognised. It is important for students to have a means of seeing both the relevance of their scientific pursuits and their aptitude for them. The badge platform allows more students to recognise their own achievements and also provides a way to communicate these accomplishments to others.

Surveying the Users

Early in the project, Dr Davis and her team carried out interviews with 36 of the roughly 70 14-19-year-old students participating in the afterschool science program to evaluate and assess the potential success of the badge system. Students were shown the prototype on a laptop so that they could comment on its potential effectiveness. The students expressed an overwhelmingly positive reaction to using the badges.

During the discussion, students raised opportunities more often than challenges. The most frequently mentioned opportunities were that the badge platform would make learning pathways visible (83% of students), connect contexts of learning (78%) and readily show the credibility of the learner (78%). Dr Davis found that the badge platform was flexible enough to resonate with students’ individual interests and goals.

One 16-year-old female participant commented on the efficiency of proving the value of her experiences, saying that, ‘I think it’s a good idea because it would be really hard to explain everything I did in the program in my college application and just a link would direct college admissions to my achievements and what I did.’

Students also said the pathways would help them visualise their careers. One student commented that it would help students to prioritise which skills to focus on learning. Others valued that the badges provided motivation and helped keep track of achievements. ‘I think they’d definitely be more useful than just a poster in a room,’ one student said. Students also commented that the platform helps to quantify the value of the afterschool program and that it streamlines the verification of each student’s experience, replacing the previous analogue system.

Design from Multiple Angles

A *Participatory Design* project involves users directly in the development of a technological tool. In this case, several stakeholders were involved in the design of the badge system, which required balancing their diverse values and goals. Dr Davis has found that when new design methods are adopted by a community, they can stimulate

The Pacific Science Center

the imagination of those implementing the project in practice.

The research team wanted to further investigate the perceptions of students' own roles in the complex design project of the badge platform. In a recent case study, members of the *Participatory Design* group reflected on the first year of the project to gain more insight into how both adult participants and young people perceived their roles.

They found that each group of people viewed the process differently based on their expertise and experience, and that some young people still did not consider themselves as full-fledged co-designers. *Participatory Design* has only recently come into play in the study of adolescents and the dynamics involved in the collaboration between adults and teens, so the work of Dr Davis' research team is moving into an exciting new area to further understand these interactions.

Expanding Legitimacy

Dr Davis and her team have concluded, based on results collected so far, that the badge system shows great potential. The team has developed several additional features based on students' feedback on the initial deployment of the badge platform. These include a portfolio feature that allows students to categorise their badges in order to present them to different audiences and for different purposes.

Dr Davis describes how, 'included in the second round of development is a new portfolio feature that allows students to organise their badges into portfolios that they can tailor for specific audiences, such as college admissions officers or potential employers.' Further, a direct messaging system has been integrated that allows students to message program coordinators within the badge platform to quickly address issues such as missing badges.

Due to the sheer scope of the project, there are challenges to overcome in terms of introducing a completely new system of credentialing. These include challenges establishing the credibility and perceived value of badges, concerns about protecting students' privacy, and the logistics associated with introducing a new sociotechnical system into an existing program that is primarily analogue.

Some students expressed concern that the significance of the badges may not be immediately clear to those outside the afterschool program with whom they share their badges and portfolios. Dr Davis has established that it is important to make it clear to the world at large that digital badges represent real achievements with transferable value.

The team has begun dialogues with higher education stakeholders to explore mechanisms for recognising badges in higher education. Furthermore, they will be working on expanding the badge ecosystem and tracking its usage as students enter college over a three-year period.

The badge platform was launched in August 2016 and the new features were introduced in 2018 at the afterschool program at Seattle's Pacific Science Center. Dr Davis and the team are currently addressing the challenge of fully integrating the platform into the regular lives of students.

Data is currently being collected and analysed from interviews, surveys and web analytics for the purpose of monitoring the effectiveness of the platform and the improvements that could be made. Dr Davis says, 'we are currently investigating how students' experiences in the science program and their use of digital badges connects to other aspects of their lives.'

The ways in which the platform fits into the daily lives of students across time and across contexts is of key interest to the team. The more Dr Davis and her team discover about how students use the badge system, the more it can be improved in future work. The potential of such a system is limited only by the extent of the participation in its design and use.

Meet the Team

Dr Katie Davis

University of Washington Information School

Seattle, WA

USA

Dr Katie Davis is an Assistant Professor at the University of Washington (UW) Information School, Adjunct Assistant Professor in the UW College of Education, and a founding member of the UW Digital Youth Lab. Her research explores the role of new media technologies in young people's personal, social, and academic lives, with a particular focus on the intersection between technology and identity development during adolescence and emerging adulthood. Dr Davis holds two master's degrees and a doctorate in Human Development and Education from Harvard Graduate School of Education. In 2015, she was the recipient of a National Science Foundation Early Career Development Award. Along with Howard Gardner, Dr Davis co-authored the 2013 book, *The App Generation: How Today's Youth Navigate Identity, Intimacy, and Imagination in a Digital World*, which explores how today's 'digital youth' grow up.

CONTACT

E: kdavis78@uw.edu

W: http://katiedavisresearch.com/

@katiebda

KEY COLLABORATORS

Research Team

Katie Davis (Principal Investigator), Adam Bell and Caroline Pitt

Pacific Science Center Staff

Bianca Barnes, Danielle Lang, Josh Kemper and Portia Riedel

Advisory Board

Allison Druin, Angela Calabrese Barton, Carrie Tzou, Erin Knight, Leslie Herrenkohl, Philip Bell and William Penuel

Badge Developers

Adam Barton, Joey Bruckner, Nate Otto and Trevor Orestes

FUNDING

National Science Foundation

FURTHER READING

A Bell and K Davis, Learning through participatory design: designing digital badges for and with teens, In Proceedings of the 15th International Conference on Interaction Design and Children (IDC '16), Manchester: ACM New York, 2016, 218–229.

C Pitt and K Davis, Designing together? Group dynamics in participatory digital badge design with teens, In Proceedings of the 2017 Conference on Interaction Design and Children (IDC '17), New York: ACM New York, 2017, 322–327.

K Davis, C Pitt, A Bell, and A Kim, Using digital badges to promote student agency and identity in science learning, Proceedings of the Connected Learning Summit (CLS '18), To appear: Pittsburgh, PA: Carnegie Mellon ETC Press, 2018.

K Davis and E Klein, Investigating high school students' perceptions of digital badges in afterschool learning, Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI '15), New York: ACM Press, 2015, 4043–4046.

E Klein and K Davis, Designing digital badges for an informal STEM learning environment, In L.Y. Muilenburg and Z.L. Berge (Eds.), Digital badges in education: Trends, issues, and cases, New York: Routledge, 2016, 145–155.

C Pitt, A Bell, R Strickman and K Davis, Supporting learners' STEM-oriented learning pathways with digital badges, Journal of Information and Learning Science, (forthcoming).

Information School | UNIVERSITY of WASHINGTON

NSF

BRIDGING SKILLS GAPS

CLOSING SKILLS GAPS IN STEM THROUGH TARGETED TRAINING

In the final section of this edition, we showcase several innovative educational programs, each designed to address a shortage of highly skilled professionals in a specific area of the STEM workforce.

In the first article of this section, we meet Dr Alexis Vogt of Monroe Community College, Rochester, who is addressing the global shortage of optics technicians. Funded by a grant from the National Science Foundation, the 'Optics & Photonics Technology Innovation' program provides students with professional development opportunities and industry work placements, in order to support their transition to rewarding careers in the fascinating field of optics.

Another area in dire need of skilled workers is genomics – a rapidly-growing field that holds the potential to transform modern medicine. The flurry of progress in this field has created challenges for teachers who are trying to keeping up with the latest developments. Here, we meet Dr Charles Wray of The Jackson Laboratory who works to overcome these challenges through his educational program called 'Teaching the Genome Generation'. His innovative approach informs and trains high school teachers, with the widespread impact of increasing student literacy in genomics, in the hope that they might consider a career in this booming field.
From here, we move on to generating much-needed professionals in the diverse fields of nutrition and dietetics. Worldwide, obesity has almost tripled over the past 50 years, leading to greater incidences of heart disease, cancer, diabetes and other associated diseases. Therefore, experts in diet management and nutrition are now required more than ever before, in order to prevent and treat obesity. In the next article of this section, we meet Dr Michelle Schelske Santos at the University of Puerto Rico, who has created an academic initiative designed to enhance nutrition and dietetics education in Puerto Rico, with the aim of forming professionals who are better equipped to deal with the current obesity epidemic.

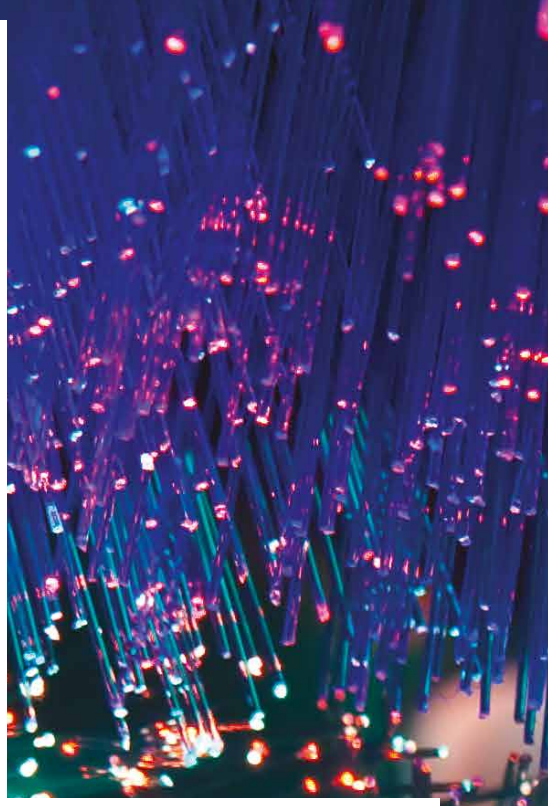
Next, we introduce Dr Edward Urban at the University of Delaware and the Scientific Committee on Oceanic Research (SCOR), who take an interdisciplinary approach towards upskilling the marine science workforce. Better understanding the interactions between biological, physical, chemical, and geological processes affecting ocean dynamics is essential in the fight against climate change. Therefore, through a series of novel initiatives, SCOR aims to motivate and train our next generation of scientists in ocean science, particularly those from developing countries.

On the topic of climate change, the development of renewable energy technologies and sustainable food production is particularly important, and highly competent researchers are urgently required in these fields. In the next three articles of this section, we introduce different aspects of the 'Duke Energy Academy at Purdue', an informal summer program that aims to inspire undergraduates and graduate students to pursue careers in the integrated sustainable development of food, energy and water under changing climatic conditions. The program incorporates a range of different activities and shared experiences, with teachers learning side-by-side with students.

We conclude this section by showcasing the University of Sydney's novel course, which has been designed to create professionals who can work with massive datasets to predict the behaviour of complex systems, such as Earth's changing climate. Course Director Dr Mikhail Prokopenko explains the importance of this new course in our increasingly complex and interconnected world. Developed in consultation with several international and Australian industrial research organisations, this is another example of how higher education is adapting to demands for a highly qualified contemporary STEM workforce.

OPT IN! – GENERATING EXPERTS IN THE FIELD OF OPTICS

Optics is an intrinsic part of many powerful and developing technologies in areas such as biotechnology, national security and manufacturing. However, there is a global shortage of optics technicians, which is hindering progress. To address this, **Dr Alexis Vogt** of Monroe Community College, Rochester, New York has created the *OPT IN!* program – a pipeline between high school, college and employment in the field of optics.



Progress Stifled by a Shortage of Optics Technicians

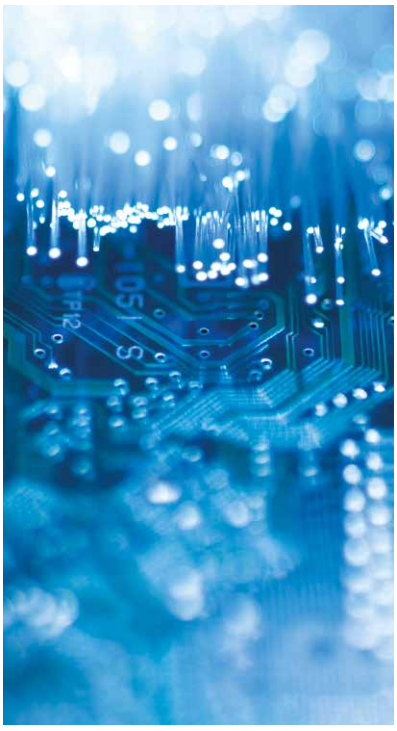
According to the *Encyclopaedia Britannica*, optics is the field of science 'concerned with the genesis and propagation of light, the changes that it undergoes and produces, and other phenomena closely associated with it.' The terms 'optics' and 'photonics' in many cases are interchangeable, but photonics generally refers to applications in electronics and telecommunications.

Optics is an intrinsic and indispensable part of innovation and design in several fields. For example, research in optics has contributed to developing improved imaging techniques for biomedical applications, micro-fabrication and cutting techniques, national security-related devices and systems, credit card and banking systems and sustainable energy technologies, to name a few. Optics is a field of science that touches on many aspects of life and offers many benefits.

However, the optics industry is facing a challenge. Despite significant growth – more than 3% per year – there is a shortage of skilled-up STEM graduates in the field. It is estimated that 20% of experienced technicians and engineers are approaching retirement and there are simply no students to take their place. To add some numbers to this situation, 75% of Upstate New York optics technician job openings go unfilled annually. Meanwhile, 75% of small and medium-sized German companies report their shortage of skilled optics workers inhibits their innovation.

Monroe Community College: Leaders in Optics Education

Dr Alexis Vogt of Monroe Community College in Rochester, New York sees education and training as integral to addressing the shortage of optics technicians. Monroe Community College has always focused on education and practical training. In 1971, the college created a two-year degree course for training technicians to work in the optics industry. And nearly 50 years later, the school's optics program is still the nation's only community college that awards associate degrees in precision optics.



The optics program at Monroe Community College focuses on three main areas of training: fabrication, assembly and metrology (the study of measurement). Over the course of their studies, students will have produced, tested and handled an array of optical components and systems – many of which are used in lasers and sophisticated photonic systems for homeland security,

aerospace, biomedical equipment, digital displays, telecommunications and nanotechnology. To support their learning, the college features well-equipped, state-of-the-art optical manufacturing labs where students are trained hands-on, in real-world settings.

Optics students have three educational tracks at Monroe Community College: Optical Systems Technology Associate of Applied Science Degree, Optical Systems Technology Certificate and 2+2 Dual Admission at select four-year institutions. The two-year Associate of Applied Science (AAS) Degree provides a direct path to careers in optics and electro-optics/photonics. The one-year Certificate Program provides a background in optics to those currently working in a related field who wish to add optics to their competencies. Students intending to earn their Bachelor of Science Degree in Optics or Imaging Science can complete the first two years at Monroe Community College and transfer to complete their final two years the University of Rochester, Rochester Institute of Technology, or the University of Arizona.

What *OPT IN!* Brings to the Table

Dr Vogt wanted to build on Monroe Community College's success and boost the intake of students into the program. To achieve this, she saw the need to develop an updated curriculum and implement a variety of course delivery models to promote learning and student retention. She also wanted to provide professional development opportunities and strengthen industry partnerships, to support each student's transition into industry. With a grant from the National Science Foundation (NSF), she developed a targeted program – the 'Optics & Photonics Technology INnovation' or *OPT IN!* program.

The vision of *OPT IN!* is to strengthen the regional optics and photonics workforce and provide students with employment opportunities in regional industries to fill high-skill, high-demand positions. It achieves this by educating and upskilling STEM students through professional development, strengthening industry partnerships and broadening community awareness of educational and employment opportunities.

The program has several unique features that it brings to the table. For example, *OPT IN!* creates partnerships with high schools and assists them to integrate optics-related content into secondary STEM education. *OPT IN!* facilitates a unique dual enrolment initiative where optics courses are taught in high schools by qualified high school teachers, and students who successfully complete the course receive Monroe Community College credit. Moreover, to support transition to further studies, *OPT IN!* features summer internships and transfer opportunities between Monroe Community College and four-year institutions. Students may avail themselves of this provision if they wish to pursue a bachelor's degree.

Another noteworthy feature is that *OPT IN!* offers internship opportunities and expands outreach efforts to populations underrepresented in the optics and photonics industry, such as women, veterans and individuals from minority groups. To that end, *OPT IN!* has several recruitment, retention and outreach initiatives, including the development of a portable 'Optics Road Show' and other public presentations. Many of these initiatives have been tailored for women, African Americans, Latinos and those from low income backgrounds.

Initial Insights Highlight *OPT IN!*'s Success

OPT IN! began in April 2017 and is now well into its second year. Initial data and feedback has indicated that *OPT IN!* is already having a significant positive impact and achieving many of the goals that Dr Vogt set out to achieve. Broadly speaking, *OPT IN!* has assisted over 850 school and college students. In May of 2018, 17 college-level students successfully graduated from Monroe Community College's two-year degree course in optics. This is a significant increase from May 2016, before the *OPT IN!* program had been implemented. On the high school level, 12 high schools are currently participating in the program and over 200 high school students are enrolled.

In addition, several Monroe Community College graduates have already benefited from the program by receiving placements within industry. Here are some of their comments and experiences:

'Hello Professor Vogt. I am happy to say I got the job with OptiPro. I will be an Advanced Process Development Lab Technician. I start on July 9th. I really appreciate everything you taught me and the position you put me in to succeed was great. Hope to see you around in the future in the well-knit optics community!' – Justin Arrajj, working at OptiPro.

'Professor Vogt, the end of the semester came fast, and I did not get a chance to properly thank you for all your help, support, guidance and knowledge shared throughout my time in the optics program. I truly believe the time spent in the program was well worth it and that it was the push I needed in the right direction for my future. As a job update, I did accept a full-time position at RPO as an Optical Technician.' – Salaahuddin Karim, working at RPO.

The Current Lay of the Land

Dr Vogt hopes to improve the program, with an emphasis on increasing enrolment and graduates. But the question remains, even with a two or three-fold increase in graduates, would it be enough to fill the void of technicians? The answer is likely no. Dr Vogt feels that other institutions and industry partners need to get involved and create further opportunities, as Monroe Community College programs alone cannot provide the needed number of highly-skilled precision optics technicians. Dr Vogt does acknowledge, however, that *OPT IN!* would be challenging to replicate elsewhere, especially because Monroe Community College has built a reputation of excellence and has thoroughly refined optics education.

Industry partners, who already have the knowledge and resources needed to train students, are seen as an integral part of moving forward. Thankfully, companies share this vision and are implementing training programs in optics. Optimax Systems Inc in Ontario, New York, offers three-year accredited apprenticeship programs in optics where apprentices spend a month working in different manufacturing areas across the company, whilst taking optical systems technology courses at Monroe Community College. Corning Incorporated created a Technician Pipeline Program which includes a two-year scholarship to earn an AAS Degree in optics from Monroe Community College, a $25,000 annual salary while in the program and a full-time technician role with Corning Incorporate upon completion of the degree. Optimax and Corning are not alone. Other optics companies, including JML Optical, OptiPro Systems and SCHOTT AG, are working on implementing their own apprenticeship programs.

What the Future Holds

A serious shortfall of optics and photonics technicians exists. To address this, passionate students of STEM are needed, and they need to be encouraged to take up careers in these fields. Education and training, with appropriate support and incentives, are key. Building on an established reputation for excellent optics education, that's exactly what Dr Vogt, Monroe Community College and *OPT IN!* have set out to provide.

So far, the program has been exceptionally successful. This is evidenced by increased participation and graduation rates, growth of industry partnerships, and most importantly, feedback received from students themselves. Many have already secured positions in the optics industry and with more apprenticeship programs in the pipeline, this will surely continue. Monroe Community College continues to work with optics companies to achieve the best possible outcomes for students. These measures will undoubtedly increase the intake of suitable STEM students into optics-related fields of employments and research. Given the vast array of applications, these students are sure to make a difference.

Meet the researcher

Dr Alexis Vogt
Monroe Community College
State University of New York
Rochester, NY
USA

Dr Alexis Vogt received her PhD in Optics from the Institute of Optics at the University of Rochester. She currently serves as Endowed Chair and Associate Professor of Optics at Monroe Community College (MCC), State University of New York. Prior to joining MCC, Dr Vogt was the Applications and Business Development Manager at Melles Griot, and prior to that, designed contact lenses and intraocular lenses for Bausch + Lomb. In addition to her industry experience, Dr Vogt holds three patents and has authored numerous research papers and other publications. She has even authored the definitions of 'light' and 'polarisation' for *The World Book Encyclopaedia*. In recent times, she has been working on a program known as '*OPT IN!*'. This educational program provides professional development and training in the field of optics, strengthens industry partnerships and broadens community awareness of educational and employment opportunities.

CONTACT

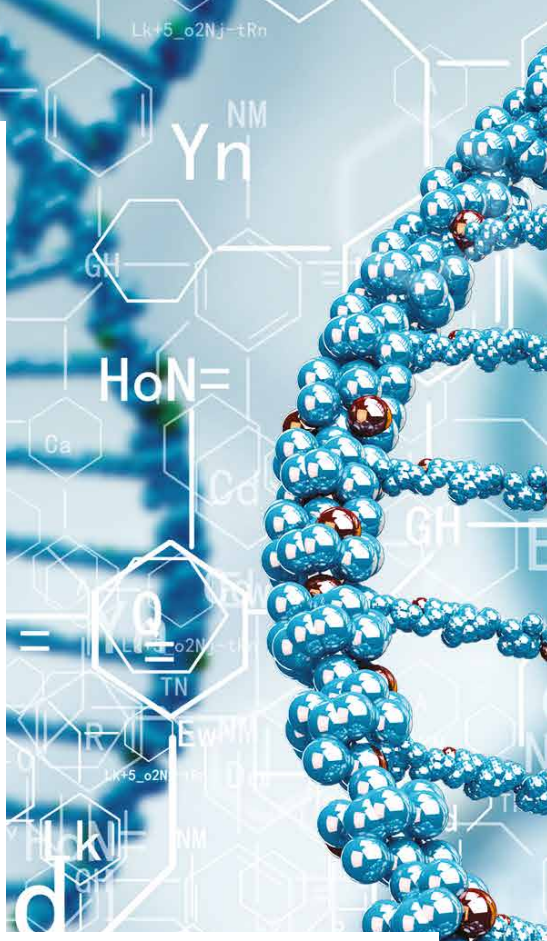
E: avogt4@monroecc.edu
W: http://www.monroecc.edu/depts/eomctech/faculty-staff/single/?Alexis_Vogt
@alexisvogt
@MonroeCC

FUNDING

This material is based upon work supported by the National Science Foundation under Grant No. 1700617

Monroe Community College
STATE UNIVERSITY OF NEW YORK

TEACHING THE GENOME GENERATION



Since the release of the first human genome, our understanding of genetics has grown significantly. However, keeping up with developments in the field can be overwhelming for students, and even teachers. **Dr Charles Wray** of The Jackson Laboratory has created a unique program, 'Teaching the Genome Generation' or 'TtGG', to address this issue. TtGG aims to inform and train high school teachers, and in turn, increase student literacy in genomics and interest in STEM careers.

Society Needs Robust Genomics Education

Genetics is the study of heredity, or how the characteristics of living organisms are transmitted from one generation to the next through DNA. Genetics research typically involves the study of a specific gene, limited numbers of genes, or parts of genes. Genomics, on the other hand, investigates the entirety of an organism's DNA – both genes and non-coding DNA – called the genome.

The field of genomics has exploded in recent times. In 2003, after 13 years of hard work on the part of scientists across the globe, the Human Genome Project was completed. This project was a joint venture to determine the exact order of all the DNA that makes up the human genome. Now, 16 years after the release of the first human genome, and driven by significant technology developments in high throughput DNA sequencing, one genome became dozens, hundreds, thousands and now hundreds of thousands of genome sequences. Not a month goes by without the publication of new human genome sequences.

Indeed, as technology and computing techniques improve, the study of genetics and genomics has advanced by leaps and bounds. With such advancement in genomics, comes incredible levels of complexity. While both general and scientific media try to cover and explain the developments, confusion can arise. Genomic complexity can confound learners at any level, including high school students. Nevertheless, many of the foundational concepts are understandable, if they are explained and taught correctly. Unfortunately, many educators are not trained or equipped to teach basic genomics.

To address this, Dr Charles Wray of The Jackson Laboratory and his colleagues have created a special professional development program called 'Teaching the Genome Generation', or 'TtGG'. TtGG provides training to teachers so they can improve how they teach genomics at the high school level. The program helps educators to stay abreast of genomics research and integrate up-to-date content into their lessons. In commenting on TtGG, Dr Wray explains, 'we are working hard to modernise genetics and genomics education at

the high school level, and we're doing this by providing lessons, teaching materials and resources for teachers. We seek to make genetics, genomics, bioinformatics and bioethics exciting for students and teachers, and in so doing, foster STEM careers.'

TtGG – An Overview

In a paper of 2018, Dr Wray and his co-authors describe TtGG as 'a high school teacher professional development program that provides educators in the New England region with the tools they

2015 Connecticut TtGG Professional Development Course participants

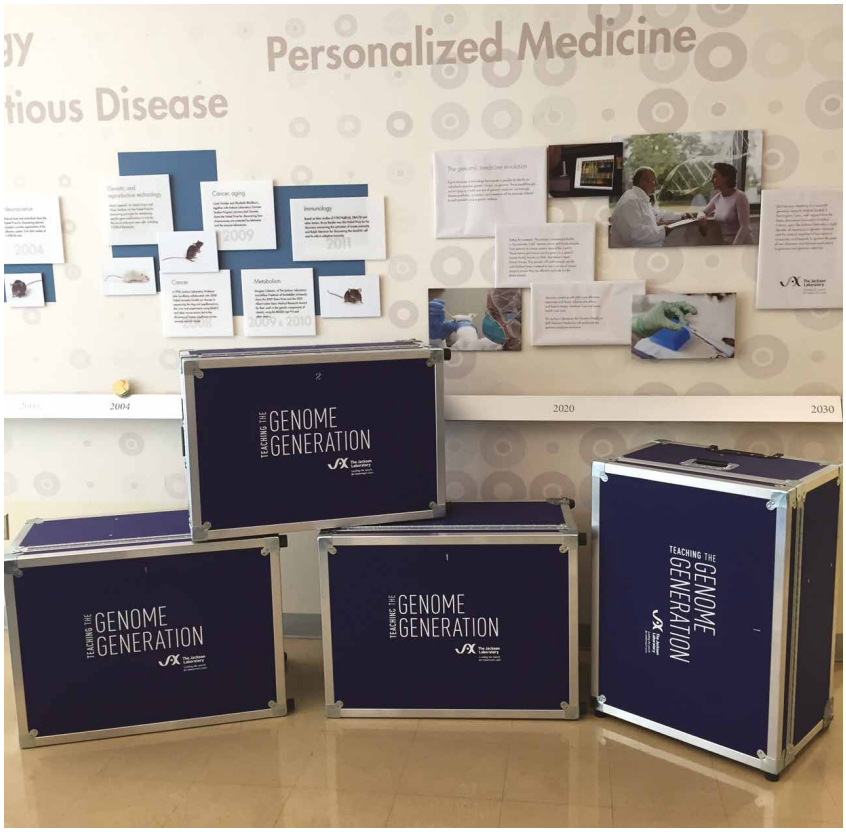
need to prepare their students for life in the genomics era.' The program is directed by The Jackson Laboratory, with financial assistance from a National Institutes of Health, Science Education Partnership Award.

The program consists of summer professional development courses that integrate instruction in molecular genetics laboratory techniques, bioinformatics and bioethics. The program empowers teachers, and encourages them to pass on their knowledge, skills and practical techniques to their students. The professional development course sets aside a substantial amount of time for discussion and lesson plan development. Teachers are also supported throughout the subsequent implementation phase. Finally, to assist with roll-out, teachers are provided with customised mobile laboratory kits, supplies and reagents and extensive curriculum resources.

As was mentioned at the outset, our understanding of genomics is forever changing, especially as new developments come to light. In recognition of this, TtGG provides continual access to updated genomics education resources through an online TtGG repository. This includes laboratory protocols, bioethics and bioinformatics exercises, instructional videos and external content such as news articles, abstracts of scientific papers and suggested books. This helps teachers to keep abreast of the latest developments and to ensure they are passing on the valuable knowledge to their students.

Molecular Genetics, Bioinformatics and Bioethics

Practical skills and hands-on learning is very much the focus of the **molecular genetics** component of TtGG. Through a series of six activities, teachers gain relevant practical skills and techniques. In fact, they perform the very experiments they will later implement in the classroom setting, so they can be confident when guiding their students. These experiments involve many of the techniques that genetics researchers routinely use, such as micro-pipetting, DNA extraction, PCR (Polymerase Chain Reactions), restriction enzyme digestion, gel electrophoresis DNA sequencing and sequence analysis. **Bioinformatics**, on the other hand, is the science of collecting, analysing and storing biological information. Bioinformatics is an essential and rapidly expanding area of science with wide-reaching implications, particularly in genomics. However, at the high school level, it is a very challenging topic to teach. As a result, many secondary school teachers avoid including it in their learning activities. Through a series of case studies and exercises, the bioinformatics component of TtGG provides teachers with hands-on experience using genomics databases and the needed know-how to effectively engage their students in bioinformatics. For example, one exercise encourages participants to use relevant databases to research the genes associated with familiar diseases.



And finally, TtGG aims to assist teachers with their **bioethics**-related learning activities. Bioethics is an interdisciplinary field of study that explores the moral and ethical issues surrounding biological research and its implementation in the real world. Teachers are given specific training on how to cover related issues in their teaching, with foci including reproductive genetics, personalised medicine and public policy. There are six ethics lessons during the course that utilise active learning strategies to explore these topics.

How TtGG Translates in the Classroom

After having received this training, as one may expect, teachers are itching to apply their new skills and knowledge to enhance learning in their respective classrooms. This is very much reflected in the feedback received thus far. As highlighted in Dr Wray's 2018 paper, over the past three academic years (2014/15, 2015/16 and 2016/17), 75% of teacher-participants have implemented the TtGG lessons in their classrooms. These are encouraging signs, and it demonstrates the real-world value of the instruction received.

Of particular note are the sessions in which students complete authentic laboratory exercises, using the equipment supplied by The Jackson Laboratory. Using real-world resources and conducting authentic experiments very much enriches student learning. Given that teachers have actually performed the experiments themselves and know what to expect, they bring these sessions to life. Referring again to the feedback received thus far, the data has indicated that students are deeply engaged and learning new skills in TtGG laboratory sessions.

TtGG's Widespread Impact

In 2018, Dr Wray and his team reported the highest number of school implementations – some 144 schools, of which 129 were public. 149 teachers have been involved in the program across the New England region. These teachers, equipped with new-found knowledge and teaching strategies, have made an impact on over 7000 students over the course of 202 implementations. Many of these implementations have occurred in schools where more than 20% of the students are members of groups underrepresented in science. This growth is set to continue.

The TtGG team attributes the program's success to several factors: (1) they hired TtGG-dedicated staff members to support and manage classroom implementation; (2) they have incentivised implementing of the curriculum with a one-time $500 stipend; and (3) they have increased teacher communication and interaction throughout the academic year, including regional teacher-participant meetups, participation in other regional high school teacher events and publication of a monthly bulletin that highlights genomics and bioethics news. These features will continue to be a regular feature of TtGG.

The Future of TtGG

Of course, Dr Wray and his colleagues will continue to make improvements to the program. For example, they want to find a way to make bioinformatics more accessible and improve implementation rates for that component of the program. They also want to understand the impact of TtGG on individual teaching practices and on participants' self-efficacy in teaching genomics, and they have suggested further strategies to that end.

Nevertheless, TtGG continues to enthuse and equip teachers to include or improve genetics and genomics education. This will have an impact on student learning in STEM, the genomics industry, and the future advancement of genetics and genomic research. This is exciting news because these fields of study are poised to revolutionise healthcare, have high career development potential, and ultimately, are very intriguing fields of study. Without a doubt, students will carry this enthusiasm into their further studies and employment in related fields.

Meet the researcher

Dr Charles Wray
The Jackson Laboratory
Bar Harbour, ME
USA

Dr Charles Wray received his PhD from Yale University in 1994. After postdoctoral work across several institutions, he joined The Jackson Laboratory first in 1999 and then again in 2014. He currently serves there as Director of Courses and Conferences, and teaches courses covering genetics, genomics and bioinformatics. Within the field of evolutionary biology, his research has centred on using molecular biology to investigate evolutionary and ecological issues. He focuses the majority of his time, effort and resources on science outreach and education. In fact, he has been a science educator and outreach director since 1986, teaching across all levels of education. Most recently, he created 'Teaching the Genome Generation' (described herein) and launched 'Big Genomic Data Skills Training for Professors' – an effort to train professors from small colleges and regional universities in curricular integration of genomic data analysis into undergraduate courses. TtGG aims to increase students' genomic and genetic literacy by training and equipping high school teachers.

CONTACT

E: charles.wray@jax.org
W: https://www.jax.org/education-and-learning/high-school-students-and-undergraduates/teaching-the-genome-generation

KEY COLLABORATORS

Dana Waring, MS, personal genetics education project (pgEd, Harvard University)
Michael McKernan, The Jackson Laboratory
Sarah Wojiski, PhD, The Jackson Laboratory
Kelly Brackett, PhD, The Jackson Laboratory
Alison Kieffer, MBA, The Jackson Laboratory
Kristin Bass, PhD, Rockman et al., Education Evaluators

FUNDING

National Institutes of Health (NIH) SEPA program

FURTHER READING

KM LaRue, MP McKernan, KM Bass, CG Wray, Teaching the Genome Generation: Bringing Modern Human Genetics into the Classroom Through Teacher Professional Development, Journal of STEM Outreach, 2018, 1, 2.

The Jackson Laboratory

TEACHING THE GENOME GENERATION

NUTRI-VÍAS: CREATING PATHWAYS FOR DIVERSIFIED NUTRITION EDUCATION

Worldwide obesity has almost tripled over the past 50 years. This alarming statistic calls for new initiatives aimed at promoting better weight management, in order to prevent and treat obesity and associated diseases. **Dr Michelle Schelske Santos**, professor and former director of the Nutrition and Dietetics Program at the University of Puerto Rico, has been working on an academic initiative designed to enhance nutrition and dietetics education in Puerto Rico, forming professionals who are better equipped to deal with the obesity epidemic.

Need for Nutritionists & Dieticians

According to the World Health Organization, in 2016 over 1.9 billion adults were overweight and 650 million suffered from obesity. This means that around 40% of the total adult population on our planet was above their ideal weight, and was either at risk of or affected by a number of chronic health conditions, such as diabetes and cardiovascular disease.

The US is among the 20 countries with the highest obesity rates. In Puerto Rico, a Caribbean island that is part of US territory, over 65% of the adult population is either obese or overweight, putting them at risk of many diseases. A 2015 Report on Health revealed that cancer, cardiovascular disease, diabetes and Alzheimer's disease, four health conditions associated with a poor diet and altered metabolism, are the primary causes of death in Puerto Rico.

The high prevalence of excessive weight among the Puerto Rican population is the consequence of numerous underlying factors, which may include a scarcity in affordable good quality foods, inadequate health insurance, a need for more effective nutrition education and poorly understood genetic differences.

In Puerto Rico and other areas with high obesity rates, the work of nutritionists and dieticians is thus of crucial importance, as it can help to educate the population about the importance of healthy eating, encourage better body weight management and prevent the onset of chronic illnesses. As obesity is largely a preventable condition, there has been an increase in initiatives and programs designed to improve nutrition and foster better health in recent years. Many of these initiatives are aimed at improving nutrition and dietetics education, to train qualified professionals that can assist people in either preventing obesity and related health problems or reducing their weight and acquiring healthier eating habits designed to effectively manage their conditions.

Tower at the Río Piedras Campus of University of Puerto Rico, close to the Nutrition and Dietetics Program.

A comprehensive nutrition and dietetics study program should cover topics rooted in a variety of disciplines, including genetics, genomics, microbiology, psychology, chemistry, and much more. The University of Puerto Rico covers these well; however, an inter-disciplinary or trans-disciplinary focus with nutrition

‘Our goal is to prepare highly-qualified nutrition and dietetics professionals who can enter the workforce with confidence to address complex nutrition-related health issues and health disparities.’

is lacking, as well as funds to send students to mainland US universities for further training or specialised courses. To address these limitations, Dr Michelle Schelske Santos at the University of Puerto Rico is creating a new academic consortium called Nutri-Vías, which is designed to train students to become highly qualified nutritionists and dieticians.

Improving Nutrition & Dietetics Education

Nutri-Vías, the academic initiative devised by Dr Schelske Santos, will incorporate graduate curricula and over 1,200 hours of supervised practice experience, which should allow students in Puerto Rico to meet the criteria of nutrition and dietetics accreditation agencies for graduate degrees. The ultimate goal of this program, which should be ready in May 2020, is to strengthen the nation’s professional workforce, preparing future generations of nutritionists and dieticians to serve a culturally diverse and more globalised society.

Nutri-Vías is supported by a Higher Education Challenge Grant from the National Institute of Food and Agriculture (NIFA). In addition to producing effective graduate curricula, the project will entail the creation of innovative and collaborative educational experiences that focus on enhancing students’ cultural sensitivity and encouraging a future reduction in health disparities, as well as targeted and more successful nutrition interventions. The committee that will develop the Nutri-Vías curriculum and practical experiences includes faculty members from different universities, nutrition scientists or renowned health professionals.

When she was first getting started on the project, Dr Schelske Santos travelled to the Academy of Nutrition and Dietetics’ annual Food & Nutrition Conference in Chicago. Here, she connected with leading educators who developed or teach programs that are endorsed by the Accreditation Council for Education in Nutrition and Dietetics (ACEND). This allowed her to start recruiting members of the Nutri-Vías curriculum and supervised practice committee.

Diversified Learning Experiences

Up until May 2020, the Nutri-Vías committee will develop new multi-disciplinary curricula and academic practices aimed at increasing the preparation of students on a variety of topics related to nutrition and dietetics. This academic content will cover areas such as genetics and genomics, psychology and behaviour modification, economics and food security, early-life and later-life nutrition, sports nutrition, and much more.

‘We are aiming to harness the expertise of faculty and researchers from each collaborative institution to broaden student exposure to unique and diversified learning experiences that will enrich their professional preparation,’ says Dr Schelske Santos. ‘This will be done by integrating multiple disciplines as well as providing multi-cultural opportunities for research and skills development in communication and problem solving.’

A further highlight of the Nutri-Vías project will be creating more opportunities for students to acquire multi-cultural sensitivity while learning about nutrition-related topics. To achieve this, the University of Puerto Rico will partner with two mentoring institutions in the US that offer successful ACEND-accredited graduate programs and have renowned resident scientists, healthcare professionals or nutrition programs. The university is also studying the feasibility of partnering with an institution or agency in the Dominican Republic, where students would be able to participate in humanitarian aid projects focusing on community nutrition.

Once completed, the curriculum developed by the Nutri-Vías committee will be implemented as part of the Nutrition and Dietetics Program at the University of Puerto Rico. The updated program should teach students to apply knowledge related to environmental and molecular factors (such as genes and proteins), as well as anatomy, physiology, biochemistry, microbiology, food science, social and psychological nutrition-related constructs, and much more. Throughout the program, the students will learn to consider culturally-specific aspects of nutrition in their professional practice.

Three Curricular Components

One of the focuses of the Nutri-Vías committee will be the development of three key curricular components or graduate education pathways for future dieticians, called Nutri-Banco, Nutri-Módulos, and Nutri Práctica.

Nutri-Banco will be an open source bank of multi-disciplinary, culturally-sensitive nutrition case studies for graduate-level education. These case studies will focus on a variety of Hispanic and Latino groups, but they will also be adapted to fit other populations and cultural backgrounds.

Nutri-Módulos, on the other hand, will be a set of nutrition and dietetics curricular modules that cover a wide range of topics from different disciplines, in a culturally-sensitive way. Finally, the Nutri-Práctica component involves interdisciplinary and culturally-relevant graduate-level supervised practical experiences and research rotations that will be based in Puerto Rico, the US and the Dominican Republic.

These three components will be aligned with the general vision of the Nutri-Vías project and will thus be aimed at teaching graduate students to apply different disciplines, critical thinking, and culturally-specific insight in their future nutrition and dietetics practice. By collaborating with a university in the Dominican Republic, a sister island with a predominantly Hispanic population, Dr Schelske Santos hopes that the program will also provide students with the opportunity to work on community service projects, which will strengthen their professional preparation and work ethics further.

Paving the Way Towards Better Nutrition

The first Nutri-Vías curricular planning meetings will be held at the University of Puerto Rico's Río Piedras Campus, at the beginning of 2020. During these meetings, members of the Nutri-Vías curriculum and supervised practice committee will give presentations about their areas of expertise and start collaborating on the development of new curricular material and effective teaching practices.

Dr Schelske Santos hopes that the Nutri-Vías initiative will encourage greater collaboration in nutrition and dietetics education, paving the way for more comprehensive graduate courses and helping to form highly qualified professionals. She feels that forming highly-prepared nutritionists and dieticians could ultimately help to improve the wellbeing and health of Puerto Rican society as a whole.

'We expect to share our best with others in collaboration to maximise resources, outcomes and impacts,' Dr Schelske Santos says. 'Our goal is to prepare highly-qualified nutrition and dietetics professionals who can enter the workforce with confidence to address complex nutrition-related health issues and health disparities.'

The next step for the Nutri-Vías project will be to design a consortium leadership infrastructure based on best practices highlighted by other nutrition and dietetics institutions, collaborations, and academic networks. Subsequently, Dr Schelske Santos will initiate communication with experts at other universities and draft formal agreements that seal their collaboration on the project.

The unique characteristic of Nutri-Vías that she feels could also impact the training of new generations of dieticians and nutritionists in Puerto Rico is its focus on cultural sensitivity and culturally-specific aspects of nutrition. By teaching graduate students to be aware of health disparities and facets of nutrition that are specific to Hispanic populations, she hopes that they will be better equipped to deal with the severe health problems associated with excess weight that currently plague Puerto Rico, as well other parts of the US with predominantly Hispanic populations.

'Understanding ethnic and cultural influences on gene-diet interactions, and the psychosocial, economic and cultural impacts on eating behaviours to prevent and treat chronic disease are important topics to which this educational consortium hopes to contribute,' Schelske Santos adds.

Meet the researcher

Dr Michelle Schelske Santos
Nutrition and Dietetics Program
College of Natural Sciences
University of Puerto Rico
Río Piedras Campus
San Juan, Puerto Rico
USA

Dr Michelle Schelske Santos is Professor and Researcher for the Nutrition and Dietetics Program at the University of Puerto Rico. She holds a BS in Biology from Gordon College, as well as a Master's degree and PhD in Human Nutrition Sciences from Tufts University. Her primary research interests include nutrition, biochemistry, physiology, immunology and epidemiology. Dr Schelske Santos has carried out a vast number of studies and her work has been published in many renowned scientific journals, as well as in academic books. Over the course of her career, she has received numerous honours and awards, including the Excellence in Teaching Award from the University of Puerto Rico and the National Research Service Award from the National Institutes of Health.

CONTACT

E: michelle.schelske@upr.edu
W: http://natsci.uprrp.edu/nutricion/projects-and-research-groups/

KEY COLLABORATORS

Lizette Vicéns Meliá, EdD, RD, LND
Professor, Nutrition and Dietetics Program
College of Natural Sciences
University of Puerto Rico – Río Piedras Campus

Amanda S. Holliday MS, RD, LDN
Clinical Assistant Professor
Program Director, MPH/RD Program
The University of North Carolina at Chapel Hill
Gillings School of Global Public Health and UNC School of Medicine

Beth Ferrell Jenks, MS, RD, LDN
Assistant Program Director, MPH/RD Program
The University of North Carolina at Chapel Hill
Gillings School of Global Public Health

Deborah A. Hutcheson, DCN, RDN, LDN
Vice Chair and Assistant Professor, Department of Sports Medicine and Nutrition
Program Director, Coordinated BS/MS Program in Nutrition & Dietetics
University of Pittsburgh

Trisha A. Cousins, MS, RDN, LDN
Clinical Coordinator and Instructor
Nutrition and Dietetics Program
Department of Sports Medicine and Nutrition
University of Pittsburgh

FUNDING

This material is based upon work that is supported by the National Institute of Food and Agriculture, US Department of Agriculture, under award number 2017-70003-26415.

FURTHER READING

Academy of Nutrition and Dietetics Future Education Model Competencies and Performance Indicators for Graduate Studies, https://www.eatrightpro.org/-/media/eatrightpro-files/acend/futureeducationmodel/competenciesperformanceindicatorsgraduatedegree.

FROM COAST TO COAST: BUILDING CAPACITY IN OCEAN SCIENCE

The ocean plays a central role in regulating the Earth's climate and is at the front line in the battle against climate change. However, there are still many unknowns in ocean science. In recognition of this, the University of Delaware's Dr Edward Urban and the Scientific Committee on Oceanic Research (SCOR) are working hard to improve interdisciplinary marine education worldwide. SCOR aims to increase fundamental knowledge of the ocean, and to motivate and train the next generation of young scientists in modern ocean science, particularly those from developing countries.

Why is the Ocean Important?

Occupying 70% of the planet's surface and containing more than 97% of its water, the ocean forms the largest and most critical component of Earth's environment. Receiving the water that flows from the world's major rivers, the ocean is often described as the largest mixing vessel on Earth, facilitating a massive movement of materials and energy around the globe.

The Sun continually irradiates the ocean, making it the main energy store in the Earth's climate system. By transporting heat from the equator to the poles, the seas regulate our climate and weather patterns, and are therefore pivotal in mitigating the impacts of climate change. Marine plants, including phytoplankton, consume atmospheric carbon dioxide during photosynthesis – reducing its warming effect on the planet. In fact, the seas are responsible for more than half of the world's photosynthesis.

In addition to these important roles, the ocean supports a vast proportion of Earth's biodiversity, as countless creatures depend upon and live in the sea. Indeed, the seas are home to millions of species, ranging from blue whales and turtles, to giant kelp and anglerfish that occupy the ocean depths. Unfortunately, many marine species are currently facing extinction, with countless others experiencing rapid population declines, as a direct result of human activity. In addition to climate change, this ecological collapse represents an equally serious threat to humanity. Therefore, a better understanding of marine ecology is urgently needed if we are to effectively preserve the ocean ecosystems that we depend upon for survival.

The Need for Interdisciplinary Ocean Research

Over the last 60 years, researchers have significantly expanded our knowledge of the marine environment. However, many unknowns still exist, especially for parts of the ocean that are far from the coast. Furthermore, most marine research has focused on single disciplinary studies, for example in biology, chemistry, geology and physics.

Interdisciplinary research investigating the interactions between biological, physical, chemical and geological processes is urgently required for obtaining an improved understanding of ocean dynamics, so that we can lessen our impact on the marine environment. For example, predicting the impacts of human-induced ocean warming, and identifying ways to mitigate these effects, are central in combatting both climate change and ecological damage.

Educating the Next Generation

Fully addressing this vast range of complex issues requires researchers from numerous different backgrounds, from physics and chemistry, to

‘We’re trying to encourage institutions in the Indian Ocean region to band together and share resources in a way that will make more research possible.’

ecology and geology. There is also a complementary need for skilled and experienced technical staff to support global marine research activities.

However, there is a severe shortage of researchers and technicians within these fields, especially in developing countries. Thus, there is a great need for capacity building to support ocean research worldwide. At a minimum, all countries with an ocean coastline will need to develop and maintain a pool of marine scientists large enough to protect and manage their local marine environments, from the coastline to its outer limit.

The Scientific Committee on Oceanic Research

The Scientific Committee on Oceanic Research (SCOR) is an international non-governmental organisation, based at the University of Delaware. SCOR works to further international scientific activity and collaboration in all branches of marine research. SCOR’s activities focus on expanding fundamental knowledge of the ocean and its processes, which is needed now and in the future, to address ocean-related societal issues. By bringing together and upskilling the global marine science community, SCOR facilitates large-scale research projects and forms working groups focused on specific topics.

SCOR also supports international activities that promote research, observation and modelling, as it is often difficult to achieve funding for these activities from national funding sources. Furthermore, SCOR is currently funding infrastructural activities related to ocean carbon, Southern Ocean observations, and harmful algal blooms. Approximately 250 scientists from 38 countries currently participate in SCOR activities.

Executive Director of SCOR, Dr Edward Urban, and his colleagues seek to advance ocean science by promoting international cooperation to achieve goals shared by scientists in the global community. ‘It is to the advantage of everyone if people in developing regions are able to participate,’ explains Dr Urban. Although developing countries experience major coastal issues and are often hit hardest by the effects of climate change, they are often not a political priority, causing ocean research to be underfunded and underdeveloped.

Capacity Building

SCOR strives to build capacity for ocean science, under the direction of the SCOR Committee on Capacity Building which consists of scientists from across the globe. ‘The SCOR Committee on Capacity Building is the primary driver of SCOR’s capacity building activities,’ explains Dr Urban. Their capacity building efforts have primarily focused on helping individual scientists to strengthen the core skills and competencies they need for participating in interdisciplinary oceanic research.

In each of its regular activities, SCOR involves early-career scientists and researchers from developing countries. One of these activities is the SCOR Visiting Scholars program, which sends scientists to teach and mentor in developing countries for a minimum of two weeks. The host institution provides local accommodation, while SCOR

covers the cost of air travel and other local expenses. Funding for the program is derived from the US National Science Foundation, national SCOR committees, and crowdfunding. Host institutions can greatly benefit from the visiting scientists, who aim to inspire, motivate and inform both students and faculty members.

Over the past six years, SCOR has also been organising Research Discovery Camps for early career researchers at the University of Namibia. These camps provide scientists with opportunities to collaborate in an interdisciplinary research project with guidance from local and international scientists, with the primary goals of facilitating learning and project development.

SCOR research projects also host summer schools, bringing together graduate students and early-career scientists for up to two weeks to focus on specific topics of study. Summer schools have the benefit of focusing student attention on a specific topic in an intensive setting. The summer schools train scientists by combining classroom lectures, hands-on laboratory sessions, shipboard time and modelling experience.

In addition to the extensive capacity building activities outlined above, SCOR and its projects also convene large international ocean science meetings. In particular, the organisation supports the attendance of scientists from developing countries at these events, so they can present their research and form collaborations with scientists from other countries.

Evaluating SCOR's Capacity Building Activities

'The most important results of SCOR's capacity building activities have been the training of young scientists in modern ocean science and networking them with colleagues from other parts of the world,' states Dr Urban. For example, the networking achieved through summer schools has been invaluable for the career development of participating young scientists and has allowed them to foster new collaborations and networks.

Feedback from the SCOR Visiting Scholars program indicated that 95% of the SCOR Visiting Scholars kept in touch with one or more of the trainees they had worked with at their host institution. Scholars and trainees kept contact for a variety of reasons, including research collaborations, continued mentoring and to plan future research visits.

SCOR continually strives to develop oceanic research in developing countries, as the need for scientific expertise in many of these countries outpaces the availability of training and research resources. The Research Discovery Camps have attracted students and faculty from Namibia and other countries in Africa, as well as other parts of the world.

Dr Urban explains that the motivation behind the international partnerships is to encourage institutions to work together and share resources to make more research and training possible. Indeed, the visiting scholars' host institutions have greatly benefitted from broadening the scope of their oceanic research and marine science curricula, with some hosts implementing and teaching new modules. The visits have also allowed new collaborations to form, enabling the host institution to participate in international projects.

A Sea Change in Ocean Research

SCOR's activities complement the UN's Agenda 2030, which aims to advance the sustainable use and conservation of the ocean, through intensifying research capacity and increasing marine science funding, as well as the UN Decade of Ocean Science for Sustainable Development. Moving forward, SCOR seeks to increase the number of SCOR Visiting Scholars, as well as increasing funding to allow for other short visits such as internships. Another goal is to integrate the Visiting Scholars program with other SCOR capacity building activities.

In the future, SCOR aims to identify other countries and institutions that may benefit from the program. For example, SCOR and its partners are trying to build up oceanic research in the Indian Ocean region to contribute to the second International Indian Ocean Expedition. As Dr Urban explains: 'We're trying to encourage institutions in the Indian Ocean region to band together and share resources in a way that will make more research possible.'

Meet the researcher

Dr Edward R. Urban
Scientific Committee on Oceanic Research
College of Earth, Ocean, and Environment
University of Delaware
Newark, DE
USA

Dr Edward Urban achieved his PhD in Marine Studies at the University of Delaware in 1989. After graduating, he worked at the US National Research Council's Ocean Studies Board for over a decade, first as a Sea Grant Fellow, then as a Staff Officer, and finally as a Senior Staff Officer. In 2000, he became the Executive Director of the Scientific Committee on Oceanic Research (SCOR), first at Johns Hopkins University, and in 2007 moving back to the University of Delaware. Throughout his career, Dr Urban has worked in many diverse areas, including fisheries science and policy, coastal science and policy, the infrastructure of ocean science in the US, and means to improve cooperation of US and foreign ocean scientists.

CONTACT

E: ed.Urban@scor-int.org
W: https://scor-int.org/scor/about/secretariat/

SCOR COMMITTEE ON CAPACITY BUILDING

Chair: Claudia Benitez-Nelson (USA)
Members: Mary (Missy) Feeley (UK), Vanessa Hatje (Brazil), Venu Ittekkot (Germany), Prasanna Kumar (India), Margareth Kyewalyanga (Tanzania), Sun Song (China-Beijing), Jennifer Verduin (Australia)
Liaisons: Hal Batchelder (PICES), Jim Costopulos (Global Oceans), Julius Francis (WIOMSA), Peter Pissierssens/Claudia Delgado (IODE/IOC), Eric Raes (IIOE-2 Early Career Scientists Network), Sophie Seeyave (POGO)

FUNDING

The Agouron Institute
The Simons Foundation
National SCOR committees
US National Science Foundation

WEBSITE

https://scor-int.org/

A SHORT INTERDISCIPLINARY SUMMER COURSE IN SUSTAINABLE DEVELOPMENT

The survival of humanity relies upon the sustainable use of natural systems that provide food, energy, and water. However, the growth in the world's population and human activities that generate pollution are posing serious sustainability challenges to these systems. Courtesy **Professor Pankaj Sharma**, at Purdue University's Polytechnic Institute, has developed a short summer course to inspire undergraduates and graduate students focusing on the integrated sustainable development of food, energy and water under environmental and climate changes.

Present Sustainability Challenges

Currently, planet Earth is populated by 7.6 billion people and this figure is expected to rise up to nine billion by 2050. Such a rapid growth in population will accelerate the consumption of natural resources, and potentially causing irreversible environmental change.

To sustain all human life inhabiting the planet, energy and food production would need to double, despite the detrimental effects of global warming, pollution and degrading environmental conditions. In fact, humanity heavily relies on food, energy, and water: resources that are put at risk by the rapid growth in world population and human anthropogenic activities that create pollution.

This gives rise to issues such as food insecurity, depletion and degradation of natural resources, and poverty. Meanwhile, more and more people are migrating to megacities and urban areas, resulting in further lifestyle changes that could affect global health.

Developing countries, countries undergoing economic transitions, and developed countries must all confront a harsh reality to adequately face these increasingly pressing sustainability challenges. As stakeholders operating in different sectors or regions might be impacted differently by sustainability challenges, their interests often vary.

Thus, educating young generations on these challenges, their complexities and interdependencies, and the perspectives of those involved is of key importance, as it ensures that they are well-equipped to deal with these issues in the years to come.

Engineering education has undergone radical transformations in the 21st century, with more courses focusing on new areas of development, such as collaboration, teamwork, creativity, critical thinking, communication, and problem-solving. Active learning activities that require students to interact with their peers have been found to be particularly beneficial to foster problem solving and critical-thinking about complex topics, such as energy sustainability.

Dr Pankaj Sharma, courtesy professor of Engineering Technology at Purdue University's Polytechnic Institute, working in collaboration with the National Cheng Kung University, and National Chung Hsing University, Taiwan, has recently devised an interactive and interdisciplinary course that focuses on sustainable development, considering its connection to food, energy, water, policy, and environmental issues.

‘The goal of this course is to give students an opportunity to learn about the key principles of environmental sustainability and the nexus of food, water, and energy, in a unique and interactive way.’

A New Sustainable Development Course

The short course developed and taught by Dr Sharma, ‘Energy sustainability at the nexus of climate/environment and food/water’, offers undergraduate and graduate students’ opportunities for interdisciplinary and collaborative learning. ‘The goal of this course is to give students an opportunity to learn about the key principles of environmental sustainability and the nexus of food, water, and energy, in a unique and interactive way,’ says Dr Sharma.

The course places students at the centre of their learning, providing valuable opportunities for them to share their knowledge with their peers while being guided by an instructor. The course features both interdisciplinary and group learning, through group discussions and projects, and collaborative tasks. This allows students to discuss core sustainability challenges connected with energy, food, and water.

Other learning objectives include improving students’ understanding of energy technology and the role of entrepreneurship and innovation in technology development, increasing their awareness of the impacts of energy technology on society and the role of policies and regulations and increasing their global perspectives while learning to consider multiple viewpoints. Recently, Dr Sharma added two additional topics: circular economy and global health.

‘The course material is delivered through engaging lectures, case studies, games, and the students learning is substantiated through interdisciplinary team working exercises and projects,’ says Dr Sharma. ‘Students will learn about societal grand challenges in environmental sustainability, the role of energy technology, policy, and their impacts on society.’

An Interdisciplinary and Interactive Effort

Interdisciplinary learning is a key aspect of the course developed by Dr Sharma, which encourages students to consider a multitude of viewpoints and to bridge ideas from different disciplines.

The course has been taken by students specialising in a variety of fields including science, engineering, technology, social sciences, environmental planning, management, agriculture, economics, and business management. Students are asked to engage in discussions that focus on complex topics at the intersection of energy strategy, society, and policy. During these discussions, the role of the instructor is to facilitate their collective learning.

During interactive sessions, the students learn about the role of energy technology and its impact on society, as well as the significance of policy and regulations. They also examine energy in its relation to food and water.

Some examples of questions guiding student discussions are:

- How does energy play a role in our lives?
- What is currently the state-of-the-art solution for different technologies?
- What is the role of entrepreneurship and innovation in taking technology to market?
- What is the role of policy, politics, regulation, and strategy in energy sustainability?

By diving deep into these questions, students can better understand the complexity of challenges related to sustainable energy development. Students who participate more actively in interactive sessions will most likely benefit the most from them, maturing critical perspectives on the significance of energy technology and policy in today's world.

Course Components

The course is broken down into various components These include lectures, in-class activities, case studies, group discussions, field trip, quizzes, exams, games, presentations, and team projects. The students are given daily reading assignments and recurring quizzes, yet they are also asked to actively participate in discussions with their peers. The core content of the course is delivered via interactive lectures, in the morning and in the afternoon sessions.

Dr Sharma's lectures are designed to expand the students' knowledge of energy and sustainability-related topics, which they can explore further during interactive sessions. As there is no fixed textbook for the course, classroom discussions are driven by reading and learning from a wide range of sources, including journals, magazines, online videos, documentaries, non-fiction texts, and websites.

In some sessions, students are given case studies and asked to discuss them with their peers. This fosters their critical-thinking skills and helps them to develop holistic viewpoints on sustainability-related topics. The students are asked to complete assessment forms before they start the course, after each interacting activity, and at the end of the course. The feedback collected helps Dr Sharma to gauge student perceptions and identify aspects of the course which may be improved.

Course Assessment and Student Feedback

Typically, a total of 20 to 50 undergraduate and graduate students are enrolled in the course. These students come from a variety of disciplines and different nationalities. The students' knowledge of sustainability, food, energy water, and environmental issues, energy economics, policy and regulation improved significantly after the course, with some students feeling encouraged to continue learning about these topics.

One participant said: 'This is the course that I really want to take in university. I really enjoyed it and learned a lot of energy-related common sense.'

Overall, the feedback collected was very positive, with many students particularly highlighting the benefits of teamwork, interactive sessions, and interdisciplinary work compared to traditional learning.

'The course was well planned and paced,' another student said. 'I loved the fact that the whole class participated in the discussions. Hearing different points of views and opinions made the class more intriguing and educational because you learn or hear something that you probably did not think or had not taken into consideration.'

The Next Steps for this Educational Endeavour

So far, the course developed by Dr Sharma and his team has gathered very promising results, improving participating students' knowledge of energy sustainability, while also fostering their creative-thinking, problem-solving, teamwork and communication skills.

The collaborative, interdisciplinary, and interactive aspect of the course was particularly effective in broadening students' perspectives and helping them to comprehend complex sustainability issues. 'There are several improvements to this course that we would like to implement in the future,' Dr Sharma says. 'At the heart of all of these is industry involvement and engagement. We would like to develop industrial connections in Taiwan so that students can work on industry-relevant real projects and develop real solutions.'

At the moment, the projects that participating students work on are mostly classical. Industry partnerships would enable new possibilities for students, allowing them to solve real-life problems and to get a sense of how the skills they learned in the classroom could be applied in the real world to develop real solutions.

'This would help students develop the skills they need to secure jobs in industry after they graduate,' says Dr Sharma. 'We would like to organise industrial days, in which students get a chance to tour industrial facilities and see how they operate. Another activity planned for the future is to take students from Purdue University to Taiwan to learn about environmental sustainability issues and challenges in a different learning environment. Lastly, we would like to initiate a discussion about starting a degree program or a certificate in sustainability in international settings.'

In the future, sustainability could become a mandatory summer course. Dr Sharma's efforts could also inspire others to develop similar courses, better preparing younger generations to face present and future sustainability challenges.

Meet the researcher

Pankaj Sharma, PhD, MBA
School of Engineering Technology Polytechnic Institute
Energy Center, Discovery Park
Purdue University
West Lafayette, Indiana, USA

Dr Pankaj Sharma is a courtesy professor of Engineering Technology at Purdue Polytechnic Institute, as well as the managing director of Purdue University's Discovery Park Energy Center and managing director of the Integrative Data Science Initiative at Purdue. In 2002, he joined Discovery Park (DP), Purdue's hub for interdisciplinary research efforts. Previously, he was a researcher at the University of South Carolina, the University of Pennsylvania, and the University of Rochester where his work focused on the application of radioactivity for dating and tracing in geological and biomedical systems. Dr Sharma has been a visiting professor at the National Chung Hsing University and the National Cheng Kung University in Taiwan. Over the course of his career, he has received a number of awards, including the 'A Seed for Success Award', from Purdue University. He was also among the 35 recipients of the Fulbright New Century Scholars award: Universities as Knowledge Centres and Innovation Drivers.

CONTACT

E: sharma@purdue.edu
W: https://polytechnic.purdue.edu/profile/sharma
https://www.facebook.com/profile.php?id=699618182
https://www.linkedin.com/in/pankaj-sharma-052a5614/

ACKNOWLEDGMENTS

Jane Lu Hsu, Professor and Head, Department of Marketing, National Chung Hsing University, Taichung, Taiwan
Tai Hui Lin, Director, Research Center for Energy Technology and Strategy, and Distinguished Professor, Department of Mechanical Engineering, National Cheng Kung University, Tainan, Taiwan
Rodney Matsuoka, Research Associate, Research Center for Energy Technology and Strategy, National Cheng Kung University, Tainan, Taiwan

FUNDING

Aim for the Top University Project, Ministry of Education and National Cheng Kung University, Tainan, Taiwan
Higher Education Sprout Project, Ministry of Education and College of Management, National Chung Hsing University, Taichung, Taiwan.
Energy Center, Discovery Park, Purdue University, West Lafayette, USA

PURDUE UNIVERSITY | 150 1869 2019 YEARS OF GIANT LEAPS

INSPIRING STUDENTS AT THE DUKE ENERGY ACADEMY AT PURDUE

A secure and sustainable energy supply for the future depends upon communities and industries working together. To facilitate this, a skilled STEM workforce is needed. To that end, **Dr Pankaj Sharma** a courtesy professor at Purdue University and his colleagues have piloted the 'Duke Energy Academy at Purdue', or 'DEAP' – an immersive one-week program which aims to promote student interest in the energy sciences and engineering.

Meeting Our Growing Energy Needs

By 2050, the global demand for energy will have increased by 50% based on the predicted human population increase. Climate predictions for the same period are bleak. These facts highlight the need to manage our natural resources wisely and meet our growing energy needs in a sustainable manner. Researchers are working hard to develop solutions to this challenge, and much of it centres on renewable options for energy production.

Supporting associated research and development is not just about securing funding from business and industry. A new wave of STEM students is needed to bring fresh ideas, talent, enthusiasm and knowledge to the table. But unfortunately, there is a shortfall in the number and quality of students entering the STEM disciplines. This, in turn, will have an impact on society's ability to manage their environment and resources in a sustainable way in the future.

To meet this challenge, Dr Pankaj Sharma and colleagues from Purdue University, Indiana, USA, have developed and implemented a program known as the 'Duke Energy Academy at Purdue', or 'DEAP'. In a nutshell, DEAP is an intensive one-week residential program which aims to engage high school student's interest in the energy sciences and engineering by way of hands-on, interactive and real-world learning experiences. Participation is provided free of charge to over fifty participating students. These students are selected through competitive online applications.

In discussing the broader impacts of DEAP, Dr Sharma explains, 'participants in the Duke Energy Academy are provided with engaging resources and experiences which will not only positively impact upon their own careers, but the future of the energy sciences as well. Purdue is excited to partner with Duke Energy for over seven years, and we hope the academy sparks a passion for STEM in students for many years to come.'

DEAP certainly is a positive step forward in encouraging students to take up further studies and careers in STEM. This, in turn, will help provide in the future the talent needed to solve society's greatest sustainable energy challenges.

DEAP is Hands-On and Real-World

One of DEAP's primary objectives is to inspire students to enter the STEM disciplines and to consider energy-related fields when setting their educational and professional career goals. While each student's learning preferences are unique, hands-on and real-world activities are a sure-fire way to engage students in their studies and stimulate interest in STEM subjects. For this reason, these types of learning experiences are the cornerstone of DEAP.

‘Participants in the Duke Energy Academy are provided with engaging resources and experiences which will not only positively impact upon their own careers, but the future of the energy sciences as well.’

DEAP is comprised of the following learning experiences, covering STEM-related energy topics such as power generation, transportation, power transmission, energy efficiency and new research frontiers:

Lectures: Guest speakers from Purdue University, industry, and the government actively engage participants in open discussions.

Tours: Examples include visits to a fossil plant, wind and solar farms, a nuclear reactor, a waste digester, and a propulsion laboratory.

Projects: Students work on energy-related research projects and participate in team-based energy policy debates.

Experimental exercises and demonstrations: These exercises cover areas such as the role of catalysts, wind turbine and solar technology, energy storage, electricity distribution and transmission.

Implementing a Whole Variety of Activities

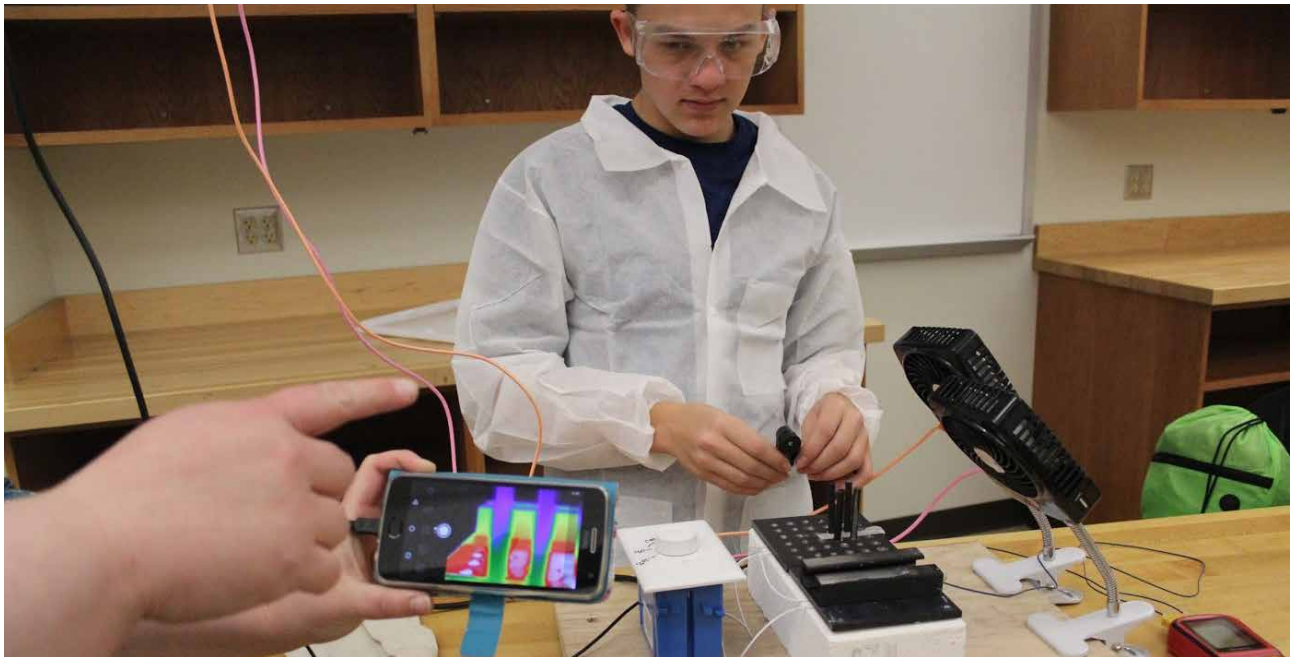
Dr Sharma and his colleagues want students to have an authentic and worthwhile experience when attending DEAP. Hands-on activities include, ‘The Wind Turbine Challenge’, ‘The Solar and Wind Farm Challenges’, ‘The Drone Challenge’, ‘LEGO Mindstorms’ and ‘Principles of Grid Operation’.

A key focus of the academy is student research projects led by faculty and their graduate students in their fields: (1) The Science of Photovoltaic Solar Cells: Fabrication and Characterisation of Dye Sensitized Solar Cells from Berries; (2) Rechargeable Batteries with Advanced Electrode Materials; (3) Fuel Cell and Transmission Electron Microscope: Catalysts for Energy Innovation; (4) Nuclear Batteries: Theory of Operation, Characterisation Methods, and Uses in Navy & Defense; (5) Understanding Nuclear Fuel and Radiation Decay Chains; (6) Plant Biomass to Biofuel, by Nate Mosier: Energy Efficient Cooling Solutions; and (7) Synthesis of ZnO Nanofibers for Thermoelectric and Piezoelectric Applications.

Carrying out the program requires the help and support of many, and it certainly highlights the importance of collaborating with STEM professionals, educators, and industry leaders to create and support a project of this kind. For the last seven years, the Energy DEAP has been made possible by the generosity of the Duke Energy Foundation, Indiana, USA, and several other co-sponsors and supporters.

DEAP is Already Having a Positive Impact on Students

Even in its relatively short history, DEAP is having a significant, positive impact on student learning and aspirations. This has been confirmed by assessment data and surveys of participants. Dr Sharma and his team report a statistically significant increase in interest in energy-related and STEM disciplines among students. Recent statistics showed a staggering 93% of participants indicated that they would enter a STEM-related field in college. Furthermore, data from the Purdue admissions office indicates that about 80% of DEAP participants do actually apply to Purdue under a STEM major.



The students comment that: 'I have had an amazing time at this Academy! I have learned so much and I have really enjoyed the research… this academy has been an amazing experience that had a huge impact on my life.' – STUDENT A

'I learned from the academy that the energy field is rapidly changing and that we need people to figure out innovative ways to change it. That makes me want to be one of many that brings energy into the future.' – STUDENT B

'I loved having the opportunity to hear from all the professors and industry leaders. I learned a lot about many fields of energy. Thank you for making this experience possible for me!' – STUDENT C

Challenges and Limitations

As with any program or course, improvements are continuing to be made over time. One of the main challenges, which in some ways is a positive, is that there is a high demand for spots on the program and so sadly, many applicants have missed out. Dr Sharma also believes that a second challenge is to maintain a high-quality program over subsequent years. As personnel and the institutional leadership involved change, this could indeed be a challenge. Not to mention the difficulties incorporating new and emerging technological developments and scaling into the program.

In terms of logistics, Dr Sharma and his team will work to relax the schedule, reduce lecture times, incorporate more open-ended hands-on activities with minimal instruction and include more evening activities. The suggested changes will hopefully maximise engagement and ensure that participants are having fun as well. Indeed, despite having run the program over several years, they are continuing to refine their understanding of the practicalities of administering and implementing such a program.

In addition to the program components mentioned above, such as hands-on activities, tours, lectures, projects and practical lessons, Dr Sharma and his team have determined that facilitating student/mentor interactions, providing career-related resources, and including societal-related elements are important aspects too.

In terms of administration, they also recognised the need for adequate counsellors and mentor teachers for students, targeting minority schools and making sure that presenters are from diverse backgrounds. They also highlight the need for conducting regular and varied assessment, engaging alumni to advocate for the program, developing long-term growth options with associated business plans, and implementing relevant marketing strategies. All these different aspects are needed for an effective and high-impact STEM education program.

DEAP – A Focus on Student Learning

Of course, Dr Sharma has many goals and targets for further improvement. Nevertheless, it is clear that, with its variety of activities and authentic learning experiences, DEAP is focused on effective student learning. This is clearly evidenced by the feedback received thus far.

Ultimately, DEAP is stimulating an interest in STEM-related careers, especially those in the field of energy production and sustainability. This is indeed good news as society places more demands upon the Earth's resources and managing them becomes a greater challenge. The continued success of DEAP and similar programs in the years to come is key to inspiring the vital next generation of future energy leaders.

Meet the researcher

Pankaj Sharma, PhD, MBA
Energy Center, Discovery Park
Purdue University
West Lafayette, Indiana, USA

Dr Pankaj Sharma is a courtesy professor of Engineering Technology at Purdue Polytechnic Institute, as well as the managing director of Purdue University's Discovery Park Energy Center and managing director of the Integrative Data Science Initiative at Purdue. In 2002, he joined Discovery Park (DP), Purdue's hub for interdisciplinary research efforts. Previously, he was a researcher at the University of South Carolina, the University of Pennsylvania, and the University of Rochester where his work focused on the application of radioactivity for dating and tracing in geological and biomedical systems. With assistance from Duke Energy Foundation, he and his colleagues have developed (since 2012) and implemented 'The Duke Energy Academy at Purdue' program, or DEAP – an immersive one-week summer program which aims to inspire high school students and teachers in the energy sciences and engineering.

CONTACT

E: sharma@purdue.edu
W: https://polytechnic.purdue.edu/profile/sharma
https://www.facebook.com/profile.php?id=699618182
https://www.linkedin.com/in/pankaj-sharma-052a5614/

KEY COLLABORATORS

Gerald H. Krockover, Professor Emeritus of Earth, Atmospheric, and Planetary Science Education, Purdue University, West Lafayette, Indiana, USA
Maureen McCann, Professor of Biological Sciences and Energy Center, Discovery Park, Purdue University, West Lafayette, Indiana, USA

ACKNOWLEDGEMENTS

Tolulope Omotoso, Graduate Student Coordinator, Energy Center, Discovery Park, Purdue University, West Lafayette, Indiana, USA
Vivien Lai, Student Coordinator, Energy Center, Discovery Park, Purdue University, West Lafayette, Indiana, USA

FUNDING

ArcelorMittal, Bowen Energy, Consumers Energy, Duke Energy Foundation, General Electric, Tipmont REMC, Siemens Technologies, and United States Office of Naval Research Grant N00014-18-1-2397

PURDUE UNIVERSITY | 150 1869 2019 YEARS OF GIANT LEAPS

TEACHERS INSPIRED BY THE DUKE ENERGY ACADEMY AT PURDUE

Much of the responsibility of improving science, technology, engineering and mathematics (STEM) education has fallen upon teachers. However, it is often just assumed that they have the tools and skills needed to fulfil that responsibility. **Dr Pankaj Sharma** a courtesy professor at Purdue University and his colleagues are hoping to address this through their informal summer program the 'Duke Energy Academy at Purdue', or 'DEAP', that is equipping teachers to deliver engaging and authentic STEM learning experiences.

Supporting Teachers to Improve STEM Education

Despite significant financial investment, there is still a need to improve STEM education across the globe. Issues such as the 'leaks' in the STEM student 'pipeline' across different disciplines have been raised as well as the shortage of skilled and talented STEM college graduates to fill the void of STEM-related employment positions.

There is also growing concern over the underrepresentation of women and minority groups in STEM-related fields of study. As a result, governments are looking to improve the situation with relevant policy changes, initiatives and incentives.

The education systems of the world, both school-based and beyond, have been a target of many of these reforms. In many cases, however, the buck stops with classroom teachers. They are, after all, the people devoting the most time to delivering STEM education to young people. The problem is, although being appreciative of the initiatives and incentives put forward by the community and government, teachers find it is often taken for granted that they have all the time, tools and skills they need to deliver engaging and real-world STEM lessons.

To meet this challenge, Dr Pankaj Sharma and colleagues from Purdue University, Indiana, USA, have developed and implemented a program known as the 'Duke Energy Academy at Purdue', or 'DEAP'. The program is both for students and teachers. To learn more from the perspective of students see the *Scientia* companion article: 'Inspiring Students at The Duke Energy Academy at Purdue'.

As far as teachers are concerned, DEAP aims to inspire teachers to communicate the importance of Science, Technology, Engineering and Mathematics (STEM) and energy scholarship in their classrooms, and to provide them with the resources and incentives to do so.

Real-World Experiences Inform Teaching Practice

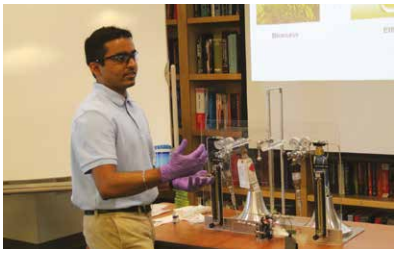
Teachers are involved in a range of different activities during the program and they also learn side-by-side with the students. DEAP comprises a number of learning experience types, covering STEM-related energy topics such as power generation, transportation, power transmission, energy efficiency and new research frontiers.

The program includes lectures from guest speakers from Purdue University, industry, and the government that are aimed at actively engaging participants in an open discussion. Tours are arranged such as visits to a fossil fuel plant, wind and solar farms, a nuclear reactor, a waste digester, and a propulsion laboratory. The participants also engage in projects working on energy-related research projects and participate in energy policy debates. There are also hands-on exercises and demonstrations that cover the role of catalysts, wind turbine and solar technology, energy storage, electricity distribution and transmission.
From the beginning, it was evident how teachers felt about these different aspects of the program. For example, in relation to one of the tours, a teacher commented, 'Today's highlight was the solar farm! I've always been curious about how a regular person like me could tap into solar energy like that.' Indeed, many were inspired by what they were learning. Ultimately, this created in them a desire to pass their experiences on to their students in classrooms.

Confirming that this was very much the case, another teacher comments: 'I learned about new technologies (because things have changed in the energy field quite a bit from when I got my degree) and I am so happy to be able to speak with more confidence with my students about new developments in this field. Also, I am planning on incorporating Purdue professors (via Skype) and sharing Purdue's cutting-edge energy research in the integrated units in my classes.'

Developing Teaching Skills

In addition to shared experiences, teachers receive specific guidance and training on how to develop engaging STEM and energy-related lessons. In one exercise, for example, teachers prepare a full energy-related lesson, with



associated planning documents, to be implemented in a classroom setting.

They then share their lesson plan drafts with mentor teachers. Subsequently, they inform DEAP staff when the lesson is to be delivered in their classrooms and the DEAP staff observe, record and assess their lessons. The lessons that have been developed are also posted on the academy website for wide dissemination.

The teachers were supported in this by being given a lesson plan template, other helpful resources, and six main criteria to serve as guidelines for the process. The guidelines for aspects to incorporate into the plan included problem statements and relevant teaching standards and technology. Such as asking questions and defining problems and incorporating the Next Generation Science Standards. Other aspects address obtaining and

evaluating information, analysing and interpreting data and using technology and software.

Opportunities for collaboration, critical thinking and communication are also encouraged and the inclusion of references – those used to develop and implement the lesson plan or that will be needed to complete the lesson. An assessment plan is also included detailing assessment methods, resources and costs and finally, an implementation plan with a timeline and estimate of completion time.

Feedback from Teachers

Assessments included pre, post and daily feedback on various activities. Feedback from teachers indicated that everyone enjoyed the program and benefited immensely from it with 85% saying they enjoyed their interaction with colleagues and scientists, with all planning to discuss the energy topics covered at the workshop with friends or family. Of the participants, 94% agreed that the academy influenced their teaching techniques. Dr Sharma and his team also reported a statistically significant increase in their confidence in integrating energy-related concepts into class activities.

Some of the participant teachers commented that: 'From beginning to end, I learned. I loved seeing the most updated statistics for our country's types of energy usage. I teach from books that are 11 years old and I feel like everything I learned in these lectures were updated and reliable.' – TEACHER A

'This was an excellent learning opportunity and an enjoyable week for me. I truly appreciate the chance I had to come to this academy and learn the many things that I did. I certainly feel more knowledgeable about the energy industry and will definitely feel more comfortable discussing it with my students.' – TEACHER B
'I find that I am using information that I learned at the Academy the very first full week of school.' – TEACHER C.

Challenges and Goals

The participants also made comments on how they think the program could be improved. Their suggestions include relaxing the schedule and avoiding back-to-back or long lectures, increasing the time allocated for teacher-teacher collaboration for networking and sharing their teaching experiences.

They also suggested increasing the time for teachers to work on lesson plans during the day, providing a clearer idea of what teachers are expected to present on the last day and allowing more time for questions at the end of lectures. As well as suggestions for incorporating more biology and environmental science-related topics, having a more even mix of lectures and hands-on activities and allowing teachers to do hands-on activities separate from students.

Dr Sharma and his team intend to take these suggestions on board moving forward, and the program will continue to improve. The program was started in 2012 and as 2018 marked the last year that Duke Energy would be sponsoring the DEAP program it is hoped that Dr Sharma and his team can acquire new sponsorship for the program given the beneficial impact that DEAP has had on both teachers and students.

DEAP – A Focus on Equipping Teachers of STEM

Teachers have a large role to play in improving STEM education globally. This is no easy task. It is important to find ways to support them as much as possible and provide them with the necessary tools to succeed. By way of lectures, tours, demonstrations, hands-on activities, and lesson planning exercises, that's exactly what DEAP has achieved and the program has impacted over 150 teachers.

Specifically, it has provided teachers with the resources and skills they need to deliver engaging and real-world STEM lessons that go beyond the typical learning context. Teachers are already implementing what they have learned in their respective teaching environments.

Beyond their knowledge gained and intention to use the knowledge in the STEM intensive program, teacher participants were also able to consistently identify the barriers that are part of educational support system such as curriculum fit, funding and materials, time availability, and state laws. Teachers described that incorporating energy-related topics as they learned during the program will be a challenge, not only because current standardised and established curricula in various different subjects are intensive, but because there is a difficulty in integrating and differentiating instruction on energy problems within these curricula.

So far, even though further improvements can be made to the program, the feedback from teachers has been overwhelmingly positive. DEAP has helped teachers to improve their practice, especially in terms of delivering STEM lessons focused on the energy industry and real-world challenges. The work of Dr Sharma and his colleagues is sure to have an impact on students who are, ultimately, the beneficiaries of enhanced teacher training. This will inevitably inspire and train students to take up future careers in STEM, particularly in the energy sciences.

Meet the researcher

Pankaj Sharma, PhD, MBA
School of Engineering Technology Polytechnic Institute
Energy Center, Discovery Park
Purdue University
West Lafayette, Indiana, USA

Dr Pankaj Sharma is a courtesy professor of Engineering Technology at Purdue Polytechnic Institute, as well as the managing director of Purdue University's Discovery Park Energy Center and managing director of the Integrative Data Science Initiative at Purdue. In 2002, he joined Discovery Park (DP), Purdue's hub for interdisciplinary research efforts. Previously, he was a researcher at the University of South Carolina, the University of Pennsylvania, and the University of Rochester where his work focused on the application of radioactivity for dating and tracing in geological and biomedical systems. With assistance from Duke Energy Foundation, he and his colleagues have developed (since 2012) and implemented 'The Duke Energy Academy at Purdue' program, or DEAP – an immersive one-week summer program which aims to inspire high school students and teachers in the energy sciences and engineering.

CONTACT

E: sharma@purdue.edu
W: https://polytechnic.purdue.edu/profile/sharma
https://www.facebook.com/profile.php?id=699618182
https://www.linkedin.com/in/pankaj-sharma-052a5614/

KEY COLLABORATORS

Gerald H. Krockover, Professor Emeritus of Earth, Atmospheric, and Planetary Science Education, Purdue University, West Lafayette, Indiana, USA
Maureen McCann, Professor of Biological Sciences and Energy Center, Discovery Park, Purdue University, West Lafayette, Indiana, USA

ACKNOWLEDGEMENTS

Tolulope Omotoso, Graduate Student Coordinator, Energy Center, Discovery Park, Purdue University, West Lafayette, Indiana, USA
Vivien Lai, Student Coordinator, Energy Center, Discovery Park, Purdue University, West Lafayette, Indiana, USA

FUNDING

ArcelorMittal, Bowen Energy, Consumers Energy, Duke Energy Foundation, General Electric, Tipmont REMC, Siemens Technologies, and United States Office of Naval Research Grant N00014-18-1-2397

PURDUE UNIVERSITY | 150 1869 2019 YEARS OF GIANT LEAPS

MASTERING COMPLEX SYSTEMS: PREDICTING THE UNPREDICTABLE

Many of the greatest challenges currently facing humanity, such as climate change and effective urbanisation, are multifaceted and intricate, with multiple moving parts. Complex systems analysts pull data and insights from diverse components to generate dynamic models that can predict the unpredictable. The Master of Complex Systems program at the University of Sydney prepares students to solve the world's biggest problems.

The Butterfly Effect

We've all heard of the butterfly effect – the idea that a butterfly flapping its wings in China leads to a hurricane in Florida – a commonly used metaphor for the behaviour of complex and nuanced systems, such as the weather, urban infrastructure, or an ecosystem.

The idea that something so small and unpredictable can be the root cause of a major event may seem laughable at the surface, but when dealing with a dynamic system that is composed of many distinct, interacting pieces, small changes can indeed lead to large outcomes. Imagine events like the failure of power grids distributed across major urban areas initiated by a single outage in a small substation or the spread of a new strain of influenza from a flock of birds to a global pandemic.

Complex systems abound in our world but are often difficult to model and predict. Big data is often used to describe the progression of an event after the fact, but does not always do a great job of predicting a problem before it arises. This is because complex systems are seldom formed from fixed data points; instead, they are collections of fluctuating variables which often influence one another in surprising ways. Understanding these systems requires the ability to connect the dots between these variables and create dynamic models that account for many ways that they interact.

Master of Complex Systems

A new program at the University of Sydney, the Master of Complex Systems, prepares students to take on the challenges of modelling and predicting the behaviour of complex systems. 'The two-year Master of Complex Systems degree has been designed by the University of Sydney, in consultation with several international and Australian industrial research organisations, to meet the demand for professionals who are capable of dealing with the complex challenges posed by our interconnected world,' explains Program Director, Professor Mikhail Prokopenko.

Launched in 2017 by the Faculty of Engineering and IT and the Centre for Complex Systems, the program is ideally suited for students with a bachelor's degree in a quantitative discipline such as engineering, science or mathematics. However, the course has also attracted students from other backgrounds, including finance.

'The degree offers several specialisations, including engineering, biosecurity, transport and research methods,' says Professor Prokopenko. 'Capstone projects are also an integral part of the degree, often resulting in internships in industry, and eventually easing a transition to a first job, or securing a career-step for graduates with a prior industrial experience. Our very first graduates have already found their jobs as artificial intelligence and computational neuroscience developers, and data and systems analysts.'

‘The two-year Master of Complex Systems degree has been designed by the University of Sydney, in consultation with several international and Australian industrial research organisations, to meet the demand for professionals who are capable of dealing with the complex challenges posed by our interconnected world’

Not Just Data Science

One of the most common questions students of complex systems seek to clarify is the difference between complex systems and big data. The field of computational data sciences has exploded over the past decade as computers have become more powerful. Data collection occurs at an ever-accelerating rate and managing the analysis of such large datasets has spawned new fields of inquiry. However, analysing data that has already been collected differs from using that data to design robust and resilient systems. Data analysis can often reveal unexpected causes of events in hindsight and can be used to inform predictive models of events, but often does a poor job of identifying the potential butterflies – the small causative elements of a situation – before the storm is underway.

On the other hand, complex systems scientists and engineers use their expertise to develop advanced quantitative models and computational simulations that account for the randomness of small influences, helping humanity predict and prevent catastrophes. For example, a complex systems expert might use knowledge of industry, crowd dynamics and logistics to help engineers design city infrastructure that is resilient to population growth, human error and attack, while also illuminating potential weak points. Or, they might leverage an understanding of ecology, climate, and geography to design sustainable agriculture, inform habitat and species conservation efforts, or develop greenhouse gas management programs.

Preventing the Next Pandemic

The faculty of the Centre for Complex Systems are active researchers themselves. Their own work effectively illustrates the power of complex systems modelling and the potential the field holds for major growth in the coming years.

In a recent study performed in collaboration with the University of Sydney’s Marie Bashir Institute of Infectious Diseases and Biosecurity, researchers at the Centre for Complex Systems examined changes in influenza pandemic dynamics across Australia as a result of urbanisation. The team leveraged census data from the previous decade and incorporated air traffic data, disease transmission dynamics and commuter trends.
The models they generated were able to accurately simulate the behaviour of influenza pandemics and predict how future outbreaks may progress under increased urbanisation. Understanding these factors can help governments to prepare for spikes in flu patients and prevent healthcare providers from becoming overwhelmed. The team’s models could also help cities to provide commuting guidelines that prevent further spread of the virus.

Students who choose to specialise in biosecurity will learn how to develop and expand upon similar models that predict the dynamics of infectious diseases and identify effective ways to prevent and manage potential crises due to epidemics or bioterrorism. As biosecurity analysts, these students will go on to aid in the improvement of prevention and containment tactics, advise public health policy, and engage in novel research in systems biology and biotechnology.

Using the Past to Understand the Future

In another recent study, researchers at the Centre for Complex Systems modelled the factors that led to the demise of the medieval city of Angkor, whose impressive ruins can be found in modern day Cambodia. In the 13th century it was the largest city in the world, but was mysteriously abandoned by the 15th century, leading historians to generate numerous theories on why, ranging from warring neighbours to religious conversions.

However, the research team identified a more likely cause. Angkor was built on an innovative irrigation system that supported the ancient city's agriculture, provided its drinking water, and provided flood control and waste management. Built during the period with relatively balanced climate, the system was put into a state of shock during several rapid climatic shifts between droughts and heavy monsoon seasons. The team's models identified that disruptions to the water management network led to uneven water flow, flooding some channels while others slowed to a trickle. Residential areas would have flooded while agricultural activity was disrupted.

While these models offer a novel insight into factors that led to the abandonment of Angkor, they also illustrate the power of complex systems modelling in identifying components of an infrastructure that are vulnerable to shock. While the research team could not accurately make direct observations of sediment in 600-year-old canals, they could identify where sediment was most likely to occur and how that would impact the city as a whole under a changing climate. The resilience of modern infrastructures in the face of climate change is an imminent issue worldwide.

Students specialising in complex systems engineering will be uniquely poised to predict how cities will respond to changes in weather patterns and water levels, and identify which components of infrastructure are most vulnerable to change. Those specialising in biosecurity will have the ability to analyse how these changes may impact agriculture and ecosystems.

Shaping City Planning

Another recent study by the Centre for Complex Systems sought to evaluate the effectiveness of a planned transition from a central business district to three spatially distinct urban districts in Sydney. The city's plan is focused on the redistribution of the population with the goal of reducing congestion and travel time for people commuting to a single city centre from the suburbs.

Utilising data on commuting behaviour, income, rent and the attractiveness of suburban versus urban dwellings, the team developed models of likely population movement. Their findings suggest that the proposed city structure is likely to fall short of expectations, as people attracted to urban residences tend to aggregate around existing urban hubs, while people choose suburbs for their availability of services and rent prices. Interestingly, the team found that commute times were less important than other factors.

Although the team's models suggest that the proposed transformation has its challenges, it also helps to illuminate potential steps that may facilitate a transition to multiple districts. A successful transition could be achieved by addressing the factors that the team identified as critical, such as access to services and appropriately priced housing.

Complex systems students who choose to focus on transport will learn how to factor human behaviour into urban planning to reduce congestion, while supporting industry and quality of life for residents.

Shaping the Future

Regardless of specialisation, the solutions generated by complex systems analysis and modelling share a common thread. They take a problem with overwhelmingly intricate and interconnected components and find the small things that matter the most. They identify where systems are vulnerable to shock, where they can be strengthened, and how they can be reimagined. The present challenges facing humanity, such as climate change, population growth, and security in an era of rapidly changing technology, will all require contributions from complex systems experts to solve. With a Master of Complex Systems degree, graduates are fully prepared to address these challenges.

Meet the researcher

Professor Mikhail Prokopenko
Centre for Complex Systems
University of Sydney
Sydney
Australia

Professor Mikhail Prokopenko began his career studying applied mathematics at the Azerbaijan Institute of Petroleum and Chemistry, USSR, and then economics at the University of Missouri, USA. He then earned his PhD in Computer Science from Macquarie University in Australia. After dedicating two decades of service to the Commonwealth Scientific and Industrial Research Organisation, Professor Prokopenko joined the University of Sydney as a professor in the Faculty of Engineering and IT, where he currently serves as Director of the Centre for Complex Systems, which has recently founded the Master of Complex Systems postgraduate program. His research involves developing computational methods for understanding the behaviour of complex and dynamic systems. His current projects focus on guiding self-organisation in complex systems, processes that can be applied across numerous interdisciplinary fields.

CONTACT

E: mikhail.prokopenko@sydney.edu.au
W: https://sydney.edu.au/engineering/people/mikhail.prokopenko.php

THE UNIVERSITY OF SYDNEY

FUNDING

Australian Research Council Discovery Projects DP160102742 and DP170102927
The University of Sydney's DVCR Strategic Research Excellence Initiative (SREI-2020)

KEY COLLABORATORS

Professor Roland Fletcher, University of Sydney
Associate Professor Joseph T. Lizier, University of Sydney
Dr Cameron Zachreson, University of Sydney

FURTHER READING

C Zachreson, KM Fair, OM Cliff, N Harding, M Piraveenan, M Prokopenko, Urbanization affects peak timing, prevalence, and bimodality of influenza pandemics in Australia: Results of a census-calibrated model, Science Advances, 2018, 4, 12, eaau5294.

D Penny, C Zachreson, R Fletcher, D Lau, JT Lizier, N Fischer, D Evans, C Pottier, M Prokopenko, The demise of Angkor: Systemic vulnerability of urban infrastructure to climatic variations, Science Advances, 2018, 4, 10, eaau4029.

E Crosato, R Nigmatullin, M Prokopenko, On critical dynamics and thermodynamic efficiency of urban transformations, Royal Society Open Science, 2018, 5, 180863.

LISTEN TO THE STORY BEHIND THE **SCIENCE**

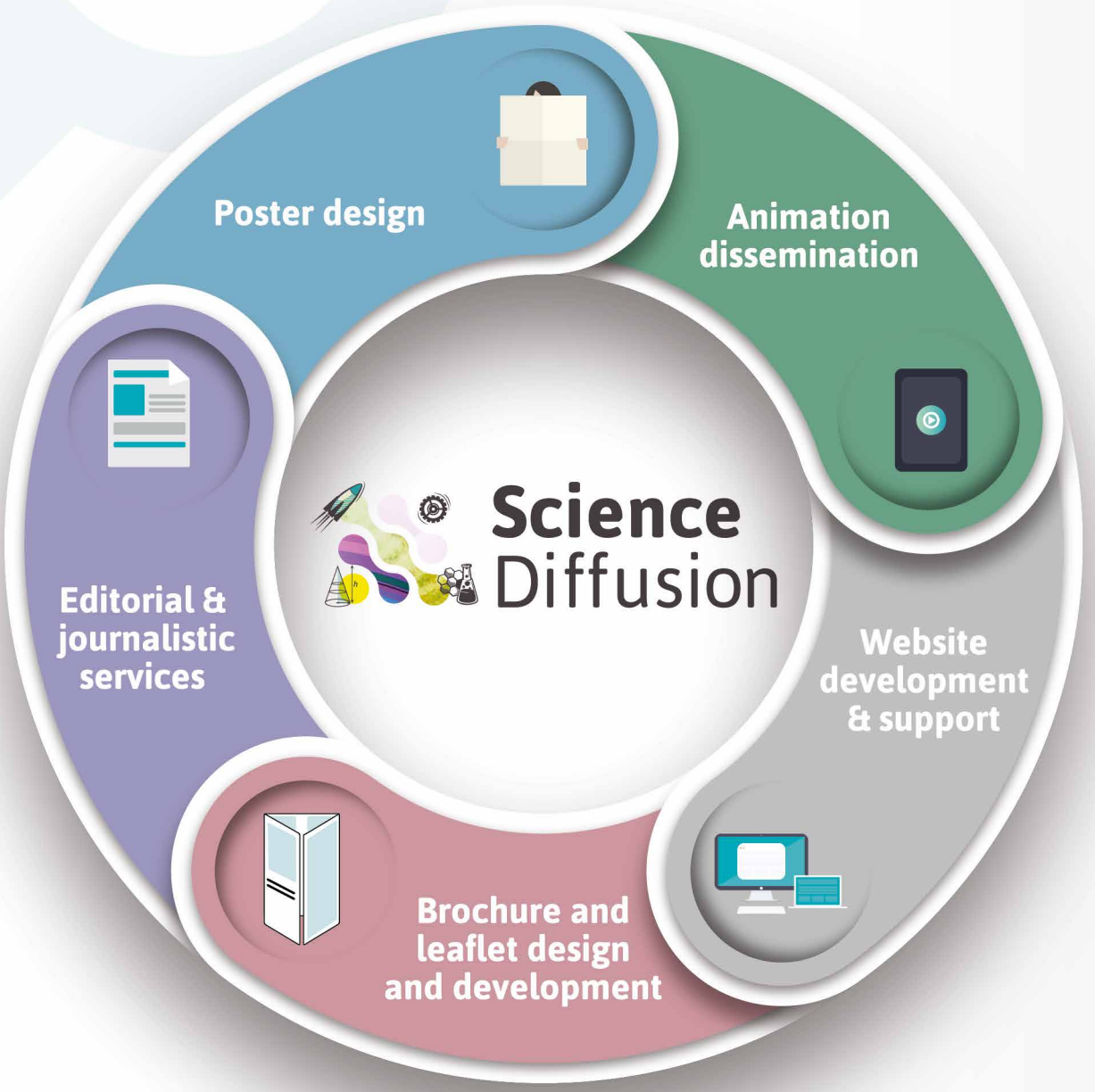
SciPod is moving science communication into the 21st century, providing you with an unlimited, informative and comprehensive series of scientific research audiobooks to keep society and science connected.
So what are you waiting for?
It's free, it's fun, it's only one click away:
www.scipod.global

SCIPOD

For more information, visit www.scipod.global

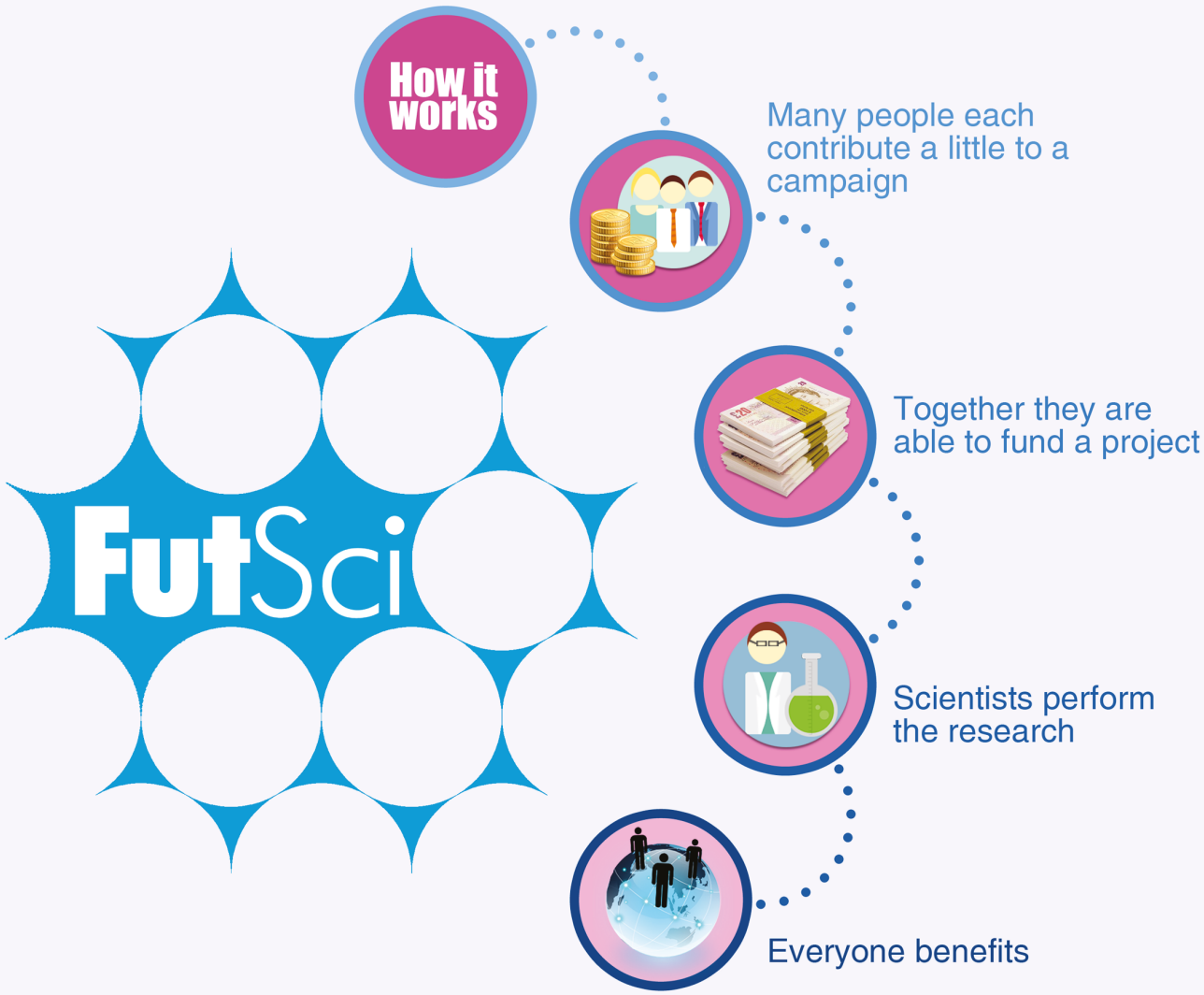
Do you want to increase the **visibility** and **accessibility** of your **research?**

Contact us today to discuss your dissemination needs and find out how we can help.



W: www.sciencediffusion.com **E:** info@sciencediffusion.com

Fund Your Research!
Crowdfunding for Life Sciences



Who we are and what we offer:

FutSci is designed by scientists and dedicated to raising funds for all Life Science Research, Innovation and Technology projects. We work closely with scientists, providing tailored support at every step of the crowdfunding process. All our campaigns are peer reviewed.

Who we work with and what we fund:

At FutSci, researchers, institutes, charities or companies can post any project in need of funding, at any stage.

Contact us for a free consultation at info@futsci.com

Visit us at www.FutSci.com

Join the science crowdfunding community @FutSciNow and @FutSciFund