



Department of Bioengineering

UNIVERSITY OF COLORADO DENVER | ANSCHUTZ MEDICAL CAMPUS

Bioengineering Heroes in the COVID-19 Response

Introduction

The mission of the [CU Denver | Anschutz Department of Bioengineering](#) is to improve human health through the application of engineering principles, ideas, methods and inventions in order to solve important clinical problems. Never in its 10-year history has the department had a clearer opportunity to act out this mission together than in the COVID-19 pandemic. Many of our faculty and students have emerged as not only leaders in the department but as true heroes in the COVID response.

The novel coronavirus outbreak placed significant strain on local and national resources, including the supplies of ventilators and personal protective equipment (PPE) so critical to medical care and protection of health workers. Colorado Governor Jared Polis called for innovative solutions to these challenges, and the CU Denver Department of Bioengineering eagerly jumped into action.

From joining the governor’s Innovation Response Team Task Force to shifting courses to focus squarely on the crisis, read on to learn how the Department of Bioengineering is engaging students, faculty, and lab facilities to improve the health and safety of patients and providers during the pandemic.

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FACE SHIELD TESTING FOR INNOVATION RESPONSE TEAM TASK FORCE

On March 22, Colorado Governor Jared Polis announced the creation of a new task force to address impending shortages of ventilators, personal protective equipment (PPE), and other resources critical to the COVID-19 response. As a part of the Colorado Innovation Response Team Task Force, Bioengineering Chair Robin Shandas offered the resources and technical expertise of the CU Denver | Anschutz Department of Bioengineering to support the state’s efforts against the novel coronavirus pandemic.

Many innovators around Colorado have been quickly developing PPE prototypes as possible solutions to the shortages. While this rapid innovation to address medical supply needs is incredibly important, it must be paired with quality assurance to be truly beneficial. It is critical that the equipment is not put to use until it is proven to actually be protective for the healthcare workers on the front lines – and this is where the Bioengineering team comes in.



Bioengineering student Anne Lyons conducts a face shield spray test in the Bioscience 2 testing lab.

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"I'm very proud to be part of a department that is able to rapidly integrate our expertise with large, multidisciplinary teams with strong leadership and commitment to the team."

Jennifer Wagner

Technical Lead for face shield testing

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The department's expertise in biomedical design, testing, and product development, paired with its state-of-the-art facilities on the Anschutz Medical Campus, made CU Denver BIOE the perfect option for running rapid PPE testing.

In less than a day after being assigned this task, the CU Denver | Anschutz team had the testing lab open and ready for product verification, with nearly 200 volunteers willing to assist with the project. Through this critical service and the work of the other Task Force team members, Colorado is able to rapidly innovate while ensuring protection for essential health workers across the Rocky Mountain Region.

To read more about the work of the PPE testing team, check out the April 2 article in [CU Anschutz Today](#).

ASSESSING SAFETY OF VENTILATOR USE WITH MULTIPLE PATIENTS

Bioengineering Associate Professor **Bradford Smith, PhD**, is an expert in pulmonary biomechanics, and his lab has extensively studied ventilator use in patients. When COVID-19 ventilator shortages gave rise to the idea of sharing ventilators between multiple patients, Smith was perfectly positioned to get involved.

In close collaboration with Bioengineering faculty colleagues **Vitaly Kheyfets, PhD**, **Jennifer Wagner**, and **Steven Lammers, PhD**, the team rapidly developed a lung model to test the biomechanical and physiological impacts of ventilator sharing on patients. They have also been optimizing ventilator

components to ensure adequate air flow to all patients according to the model, and are sharing the results.

“What we’re trying to do is determine how to safely connect multiple patients to one ventilator,” Smith explained. “This involves computer models to predict the distribution of ventilation to each patient and benchtop experiments using clinical ventilators to test our computational results. We are trying to devise algorithms to group patients who will share a ventilator, and controls to allow individual adjustment of gas delivery.”

The findings are already being disseminated with the goal of aiding clinical decision-making on how to best care for multiple critical patients when ventilators are in short supply. The faculty team has submitted several grants to fund this important research.

To learn more about their work, you can read a preprint of the article entitled “Use of a Single Ventilator to Support Multiple Patients: Modeling Tidal Volume Response to Heterogeneous Lung Mechanics,” which can be accessed via this QR code.



COLLABORATIONS TO TEST NOVEL VENTILATOR

In an exciting series of experiments, collaborators from CU Medicine (Dr. Karsten Bartels, Dr. Vikhyat Bebarta, Tara Hendry-Hofer), CU Bioengineering (**Dr. Bradford Smith**), and the CSU Energy Institute (Dr. Bryan Willson) demonstrated safe and effective in vivo performance of a novel mechanical ventilator that was rapidly designed and produced by Woodward Inc. in Fort Collins Colorado.

This team brings together academic and industry specialists in engineering, critical care, and lung physiology to address the critical shortage of mechanical ventilators caused by the COVID-19 pandemic.

MODIFYING BIPAP MACHINES TO ADDRESS VENTILATOR SHORTAGES

Faced with an impending shortage of ventilators in Colorado due to COVID-19, a group of Boulder Health and CU Anschutz doctors and researchers began reviewing protocols and solutions developed to address such equipment shortages. The team was comprised of Bioengineering PhD students **Madeline Blankenship** and **Amy Zhang**, doctors Clark Berngard, Thomas Minor, and Shannon O'Brien, and Bioengineering Associate Professor **Bradford Smith**.

One viable solution the team has been working on is using bi-level home ventilators (BiPAPs) for use with intubated patients as detailed by a protocol from Mount Sinai researchers. Each BiPAP requires a substantial amount of additional equipment to be safely used for invasive ventilation. While preparing to implement BiPAP modifications in Colorado, it became clear to the team that the additional equipment available varies widely from hospital to hospital, so alternate configurations would be necessary. In addition, training clinicians to safely modify and operate BiPAP machines while under the stress of pandemic conditions was recognized as a critical need.

Because implementing a program to safely modify BiPAP machines would require training material that allowed a broader range of configurations, the team created a series of graphical protocol cards. These can be easily used "on-the-go" or left at the bedside with equipment. These cards include alternate configurations, a shift change checklist, and key safety warnings.

The team is now working to address other training and equipment needs that are facing Colorado healthcare workers during the COVID-19 crisis.

ADDRESSING NATIONAL AND INTERNATIONAL PPE CONCERNS



Casey Howard

Bioengineering Senior Instructor **Casey Howard** has taken an active role in the local and national COVID innovation response. She has been connecting with stakeholders in Colorado and across the country, including representatives from public health, medicine, Engineers Without Borders, and medical device entrepreneurs to address urgent needs for the COVID response. This community of experts has been brainstorming how they utilize the expertise of biomedical engineers across the country to make progress on many different fronts, and are have put together projects to get biomedical engineering students engaged in COVID problem-solving as well.

Howard is working closely with May Chu, an epidemiologist and Clinical Professor in the Colorado School of Public Health known for her work with the Centers for Disease Control and Prevention and the World Health Organization. Together, Howard and Chu are working with the CDC to test Decontamination procedures for PPE as well as possible alternative solutions to shortages in the US and beyond.

Howard is also working with Dr. Dan Olson, a pediatric infectious disease doctor in the CU Anschutz School of Medicine and the Center for Global Health, on behalf of the Trifinio clinic in Guatemala. Howard and Olson, co-instructors of the [Bioengineering global health course](#) that travels to the clinic each year, are closely monitoring the impact of COVID-19 on the ability of the site to provide care for the population. The two have been actively identifying solutions for PPE and ventilators for the clinic and partners as they face supply shortages.

Specifically, they are working on designing and prototyping a laminar flow hood that can be used during PCR tests at the clinic and then sterilized to minimize contamination. They are also considering designs for a UV apparatus that the clinical staff in Guatemala could use to sterilize N95 masks.

Bioengineering student **Odalis Castro** traveled to the clinic previously as a student in the Bioengineering global health course, and eagerly joined the project when contacted by Howard. Odalis and several other students have been working hard on designing the UV lightbox to disinfect laboratory equipment for the Trifinio clinic. As a group, they have had a quick turnaround time for the design and will begin testing their ideas soon.



Odalis Castro



Richard Weir, PhD

Bioengineering Associate Professor **Richard Weir, PhD**, has been working with Dr. Cristos Ifantides of UC Health and Bioengineering graduate students **Mary Bevilacqua** and **Jahmel Jordon** as well as lab members **Stephanie Lorelli** and **Stephen Huddle**, to develop reusable PPE prototypes that can integrate existing industrial filters and medical filter materials into approved mask designs for easier reuse. Additionally, the Weir Lab has extensive 3D printing capabilities, and has been offering their services to help other bioengineering faculty prototype their designs as needed.

DIY PPE SHORTAGE SOLUTIONS

In addition to running her Bio-Inspired Pulmonary Engineering Lab, **Chelsea Magin, PhD** has been working hard to help in the COVID response, both through her research and through volunteering her time. Magin collaborates frequently with National Jewish Hospital, the #1 hospital for respiratory care in the country, located in Denver. Magin worked closely with pulmonologist Patricia George, MD and the occupational health team at National Jewish to optimize a homemade mask pattern. After working with local sewers and finalizing the design, the team got the pattern approved by the hospital. The final pattern is posted on the National Jewish Hospital [website](#), and contains a host of information about the purpose for the pattern, FAQs about the mask safety and materials, and ways to donate masks to National Jewish.

Many Bioengineering students, along with their families and significant others, have been sewing homemade masks according to the pattern Chelsea Magin and the team at National Jewish developed, and plan to donate a significant number to the hospital.

Magin has also worked with Bioengineering Chair **Robin Shandas** to conduct a materials analysis for 3D-printed face shields. This information is being used to provide guidance for statewide efforts to encourage 3D-printed PPE. She has also been working on a grant application with Professor Shandas to help support the Bioengineering Department lead an effort to create design documents and testing for DIY PPE that is being made across the state.



BIOINFORMATICS INFORMING DECISION-MAKING

Dave Albers, PhD an Associate Professor of Pediatrics - Informatics and Data Science and the Center for Bioengineering has been conducting important work for the COVID response. He is working with the CU Anschutz School of Medicine, Division of Pulmonary Science and Critical Care, as well as representatives from UC Health and the EPIC-EHR team to predict mortality and ventilator use. The goal of their work is to provide the best data-driven modeling-based information possible for the triage team. The hospital triage team is comprised of medical doctors, lawyers, and bioethicists who are tasked with deciding how to distribute ventilators and resources in the event that the hospital has to ration ventilators.



Albers specifically took charge of the computational pieces and machine learning components of the project. These pieces of decision support were pushed into the live EPIC system this week, and the models are being updated as more COVID data is made available. The predictive models get updated every 24 hours, and the patient scores get updated every 10 minutes. This information is being distributed to clinicians so they are aware of this important work; in a time where hospitals are considering their surge capacities and crisis standards, the work that Albers and the team is doing is of paramount importance for patients and the healthcare system as a whole.

COVID COURSEWORK

Along with universities across the nation, CU Denver | Anschutz Bioengineering rapidly moved courses online in March in accordance with public health recommendations and state mandates. While this posed considerable challenges for hands-on engineering courses, the Bioengineering Junior Design course instructors saw an opportunity.

The spring junior design course is geared towards teaching the many technical design skills future engineers need to learn for future projects, and are often based on clinical problems from across the spectrum of health issues that Anschutz clinicians share with the department. However, in the quick changeover to online, instructors **Jennifer Wagner** and **Steve Lammers** decided to not only modify content delivery, but to switch course content to allow students to focus their projects on creating solutions to COVID problems.

According to Wagner, they have already seen great benefits of making the change. The novel coronavirus pandemic has helped to underscore the important role bioengineers serve in the medical world and provide excellent, real-world case studies for projects. Additionally, the circumstances of the response have helped to highlight engineering ethics topics the course discusses as well.

Though the circumstances of the course have made traditional learning schooling challenging, instructors have been creative by including take-home design kits, online design discussions, virtual project management, and other components to ensure that the junior design course during COVID is one that the students will never forget.

NATIONAL BIOMEDICAL ENGINEERING TEACHING COLLABORATION

BIOE instructor **Casey Howard** has been incredibly impactful on the COVID response, both within the CU Denver | Anschutz Department of Bioengineering as well as on a national level.

Howard and others in the BioDesign Instructors Group for Innovation, Design and Entrepreneurship Alliance (**BIG-IDEA**) group created a repository of teaching information they could share with each other as they faced the challenge of putting hands-on engineering courses online. This document began to grow, more collaborators joined, and it was shared through social media to other established groups of the biomedical engineering education world, including the BME Women Faculty and American Society for Engineering Education.

What began as a simple google document sharing ideas has snowballed into a robust resource for the many faculty who access the document a day. It has also led to more discussions about curriculum ideas, case studies, and even peer-to-peer project ideas shared across institutions. As Howard and collaborator Jennifer R. Amos write in a recently published editorial, “this time away from classrooms and labs was a time to come together as a community.” To read more about this exciting project, read their editorial in [Annals of Biomedical Engineering](#).

STUDENT HEROES IN THE COVID RESPONSE

Many CU Denver | Anschutz students have actively become involved in COVID work. From researching testing protocols to supporting lab efforts remotely to sewing masks in their spare time, students have been an important component of the department's COVID response.

BIOE PhD student **Amy Zhang** has taken a major role in coordinating student projects. Working closely with Casey Howard and other Bioengineering instructors, Amy has ensured that students have the information they need and direction to get working. In addition to this work, Amy and fellow Bioengineering PhD student **Madeline Blankenship** have been working closely with Brad Smith and other researchers to modify BiPAP machines for use in the event of a shortage of traditional hospital ventilators.

BIOE undergraduate student **Tony Pagliaro** is using searching existing literature and recommendations to come up with ideas for a better DIY ventilator design. He, along with BIOE graduate student **Amanda Benjamin**, have been working to identify specifications and requirements for PEEP valves that can be used for DIY ventilators. Their goal is to locate a source to purchase them or find a way to get 1,000 valves built in a week, and then develop test plans to ensure functionality in the valves.

BIOE undergraduates **Kyra Flores** and **Zack Johnson** have been developing testing plans for PPE, and are identifying equipment specifications and needs to perform tests. **Kat Garvey** and **Jessica McPhee**, also bioengineering undergrads, have been working to identify test plans and a test matrix specifically for mask testing based on existing standards. BIOE senior **Seth Drake** has been researching polypropylene sources for a potential reusable mask solution, and has been able to help prepare masks to be seen for testing.

Students **Jonathan Platt** and **Thomas Caracena** are working with Research Instructor **Steve Lammers** on rapid ventilator design and ventilator repair out of anticipation for this to be an area of need. These students are working to understand the components and function of a ventilator in order to identify parts for ventilator repair that could be purchased at a hardware or auto-supply store for maximum ease in fixing ventilators as quickly as possible.

Bioengineering senior **Anne Lyons** has been working with **Jennifer Wagner** on rapidly bringing face shield testing to Bioscience 2, and has been helping with the in-person testing and evaluations.

MD-MS student **Jahmel Jordon** and MS student **Mary Bevilacqua** have worked with Dr. Richard Weir on PPE solutions, conducting research on materials, prototyping, and testing.

BIOE student **Odalis Castro** has been working hard on PPE solutions for Guatemala. When not working on the project or her schoolwork, she volunteers as a Spanish interpreter for telehealth calls at a free clinic in Aurora, CO.

These students, along with many others, have made the department incredibly proud for all they've done - on top of their rigorous engineering course load - to be effective members of the COVID response.

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“As I reflect on this experience, just a few weeks ago we were sitting in a class learning how to methodically and systematically solve open-ended, real-world engineering problems.

Today, I feel like I am truly contributing to a problem that really needs a real-world solution.”

Odalis Castro
BS-Bioengineering Student

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For more information or inquiries, please call 303-724-5893 or email bioengineering@cuanschutz.edu