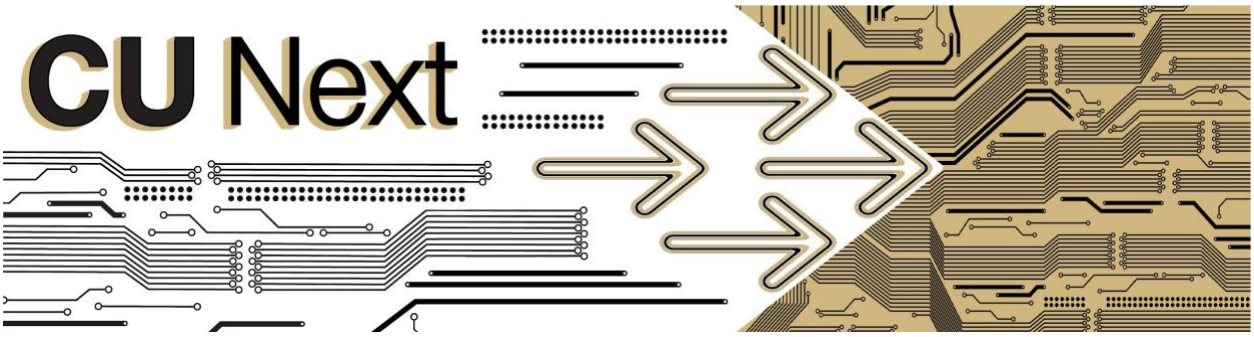

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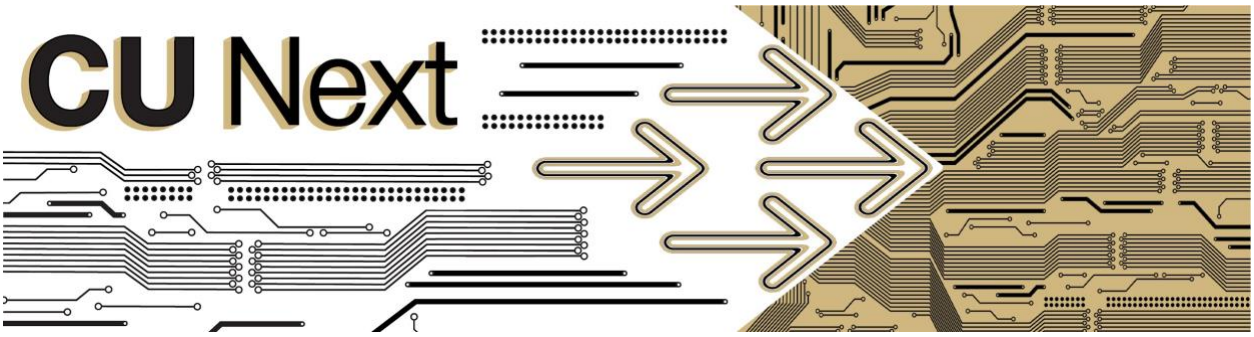
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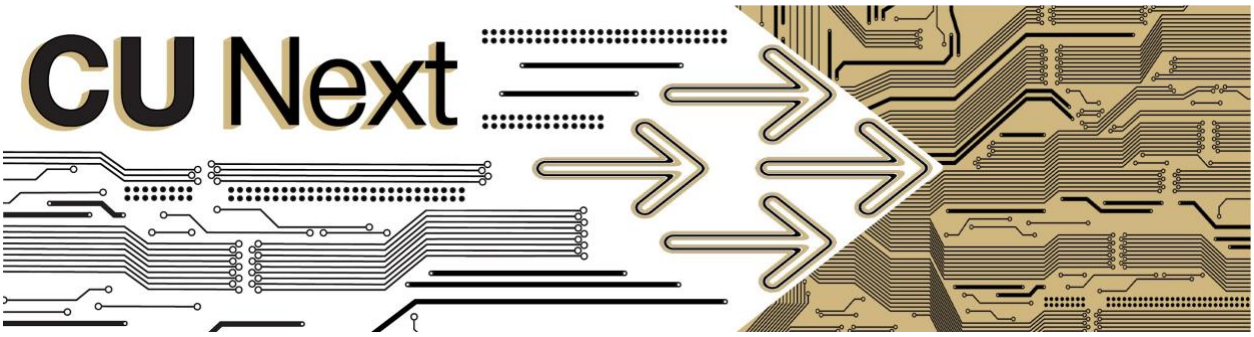

Title: Merging Engineering & Medicine by Integrating Technology into Immersive, Hands-on Human Spaceflight Courses

Final report, December 15, 2025

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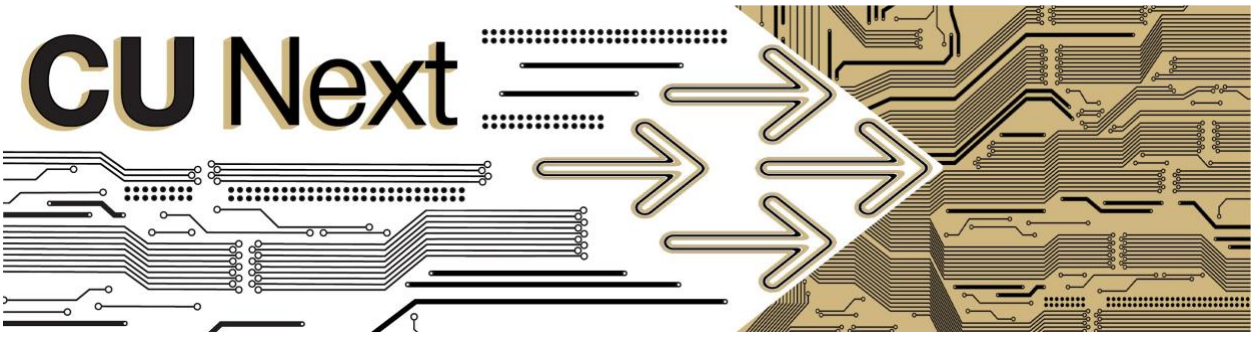
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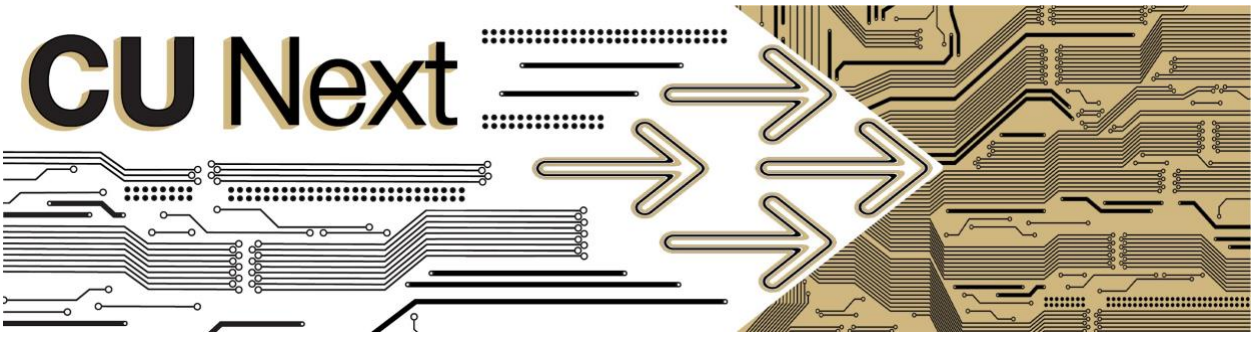
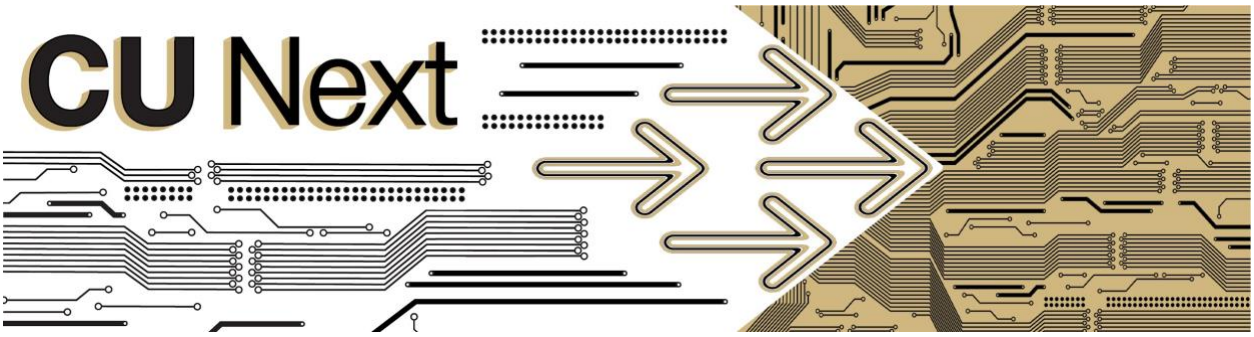


Description of the project and the goals of the project

The objective of this project was to amplify student learning outcomes in human spaceflight medicine by integrating technology into three hands-on engineering and medicine courses. These courses are the core constituents of the joint MD-MS degree program between CU Anschutz and Boulder campuses.

Human spaceflight continues to advance dramatically. There are more successful commercial spaceflight companies than at any other time in history, and government spaceflight programs have renewed interest in exploration missions to the Moon and Mars that are only increasing. The University of Colorado is uniquely positioned to serve this rapidly growing industry, and this has been a focus throughout this project. Toward this goal, the execution of this project has been completed in tandem with the inaugural years of the unique MD-MS program that enables medical students to earn an MS degree in engineering during their time earning their MDs. The course development that was a focus of this project is in alignment with this MD-MS program, and our results from this effort discuss the development, execution, evaluation, and adaptation of these courses to meet the unique educational needs of this program.

The three courses that were the focal point of this project are 1) ASEN 5226 Medicine in Space and Surface Environments (MiSSE), 2) ASEN 5018 Graduate Projects (GP), and 3) a novel space and austere environment medicine elective course. The goals for each of these courses varied based on curricular needs, with the focus for MiSSE on improving a pre-existing course by integrating technology that enables hands-on space medicine and operations simulations at a Mars analog habitat, the focus for GP on design, fabrication, and field testing of a spacecraft Medical Bay under relevant engineering constraints, and the focus for the new elective course on engaging first-year medical students in peer-to-peer learning to demonstrate the utility of integrating aritificial intelligence and novel engineered medical devices into future medical delivery.



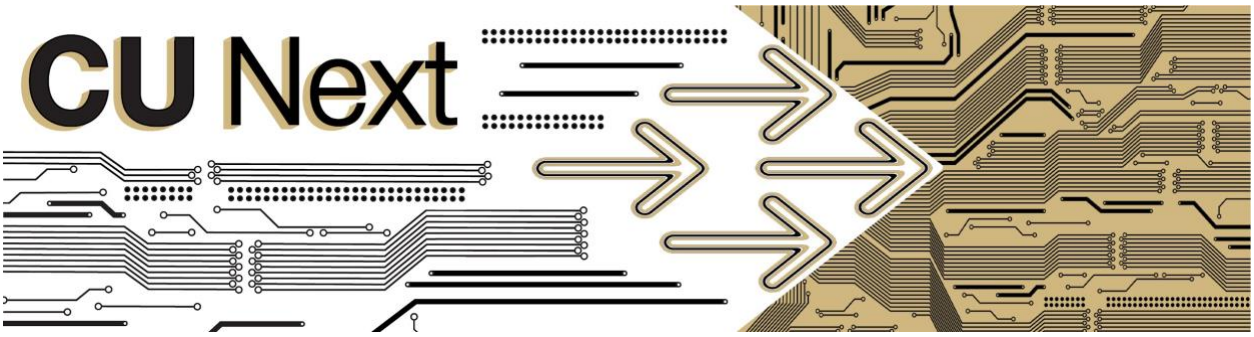
Lessons learned

- What has your team accomplished?

Our team has successfully offered the MiSSE course three times during the period of performance for the CU Next grant, and a fourth iteration is planned for Spring 2026. The medical elective course, Space and Austere Medicine, was offered twice, and three semesters of the GP course resulted in the fabrication and testing of the MEC portable medical bay that was successfully used to augment the MiSSE course in Spring 2024 and 2025. We have also worked to expand the connections between medicine and engineering through a new journal club focused on papers related to both disciplines, with one student from medicine and one from engineering working together to present papers to a small group.

Lastly, we have made an effort to incorporate growing areas of engineering interest into our educational programs—specifically, we developed a human-robot teaming project for the MiSSE course that was successfully implemented in Spring 2025. Table 1 shows the schedule of project deliverables and our progress on each item throughout the period of performance. In the following paragraphs, we have included highlights from each of the educational components.

Table 1. Schedule of project deliverables. Rows in grey were put forth in the original proposal, and rows in white are new additions to the project toward the goal of integrating medicine and engineering. Green cells are



completed items, red cells are planned items that will not be completed, and yellow cells are planned items throughout the remainder of the grant.

	Year 1			Year 2			Year 3			Year 4		
	F22	Sp23	Su23	F23	Sp24	Su24	F24	Sp25	Su25	F25	Sp26	Su26
MiSSE course offered												
Space and Austere Medicine (IDPT 5041) course offered												
GP course offered												
Post-course assessment												
NEW SpaceMed Jclub												
NEW Robotics-focused project for MiSSE												

Integration of the MEC medical bay into the MDRS field week:

In Spring 2024, the graduate projects portion of the grant crossed over from design and validation into implementation in the field. We took the MEC out to the Mars Desert Research Station (MDRS) for the week of field instruction for the Medicine in Space Surface Environments (MiSSE) course. The trailer provided a high-fidelity simulation environment for students to conduct patient assessment (shown in Figure 1). The medical equipment and informatics integrated into the trailer contributed to more "ecologically relevant" scenarios and augmented students' learning. The MEC was used again in the Spring 2025 iteration of the course and is planned for deployment again in Spring 2026.


Figure 1. Left: MEC medical trailer parked outside of the MDRS habitat; Right: Students in the medical trailer during an EVA simulation.

Medical Elective:

A new elective course titled "Space and Austere Medicine" (IDPT 5041) was offered to first-year medical students by co-I Anderson. It integrates engineering principles with wilderness and aerospace medicine. This course attracted 15 participants, including both CU-Anschutz and CU-Boulder students. They received instruction from 10 rotating physician-educators, covering topics related to austere medical environments. Feedback from students emphasized the impact of the course on their medical education.

Medicine in Space and Surface Environments (MiSSE):

Hardware acquired using CU NEXT funding continues to enhance the quality of the course; this includes GPS units, handheld ultrasound, and a Sked stretcher. The course had 20 students, each of whom received training in medical care in remote and extreme environments, as well as certification in Wilderness First Aid and CPR. A week-long spaceflight simulation in a Mars habitat in Utah was a key component of this hands-on learning experience and was augmented by the implementation of the medical trailer and its integration into simulated extravehicular activities.

Human-robot teaming project for MiSSE 2025:

Given the growing prevalence of robotic systems and their potential for supporting future space exploration missions and medical procedures on Earth, it is important that our students gain some familiarity with the capabilities of these systems and how they should be incorporated into the operational workflow. We successfully executed a human-robot teaming project in the 2025 iteration of the MiSSE course. Students planned their own EVAs with a quadruped robot as a medical assistant in the field. The students decided

how to best utilize the robotic system and how to integrate it into their teams. Figure 2 shows the students out on their simulated EVAs with the robotic medical assistant.

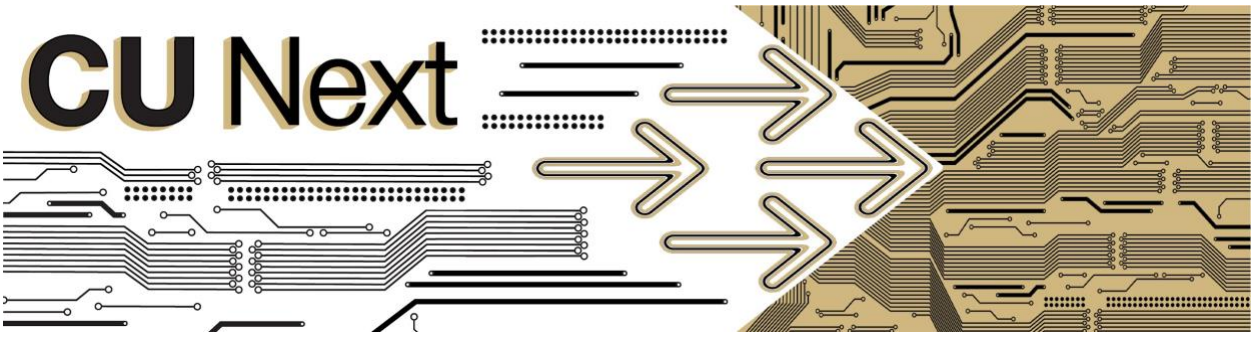
Figure 2. Students working with the quadruped robot during simulated EVAs that students also planned with their project teams. The quadruped robot carried a payload of medical supplies.

- What are the challenges you encountered?

The primary challenge was defining a cohesive assessment paradigm across three distinct courses. Each course operates at the intersection of medicine and engineering, making it difficult to apply traditional assessment models from either discipline. While rudimentary assessment plans were established for each course, the team has been consulted with CU experts and developed IRB protocols for assessments. We have also been thinking about the challenge of continuing this suite of educational activities and are seeking different avenues for both financial and staffing support to maintain the program beyond the lifetime of this grant.

- Did you modify your direction? If yes, in what ways?

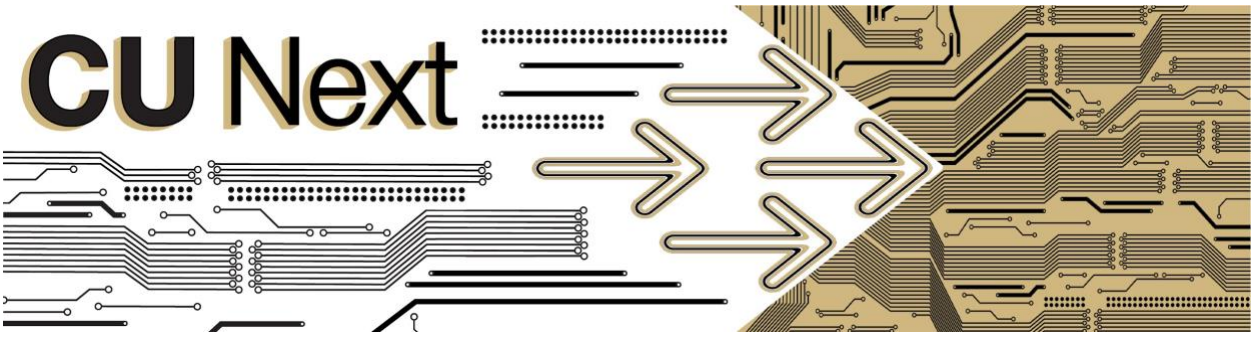
For the last two years of the grant period of performance, we implemented a phased plan to manage workload and timing, given changing faculty availability. Some aspects, like spacesuit simulators, have been moved to future goals for the continuation of this work. Additionally, the team adjusted timelines for new course development and hardware acquisition while also adding in elements to enrich the suite of educational activities, including the ongoing space medicine journal club. Two core team members were either on sabbatical (Hayman) or left CU (Easter), so co-Is Anderson and Arquilla worked to identify the most critical pieces of this year's efforts and maintain those effectively with the



reduced team.

- Did the collaboration evolve, grow, encounter obstacles or challenges? Please provide all examples.

The collaboration between the Anschutz and Boulder campuses continues to be productive, bolstered by ongoing dialogue with external partners like Star Harbor and Sierra Space. There is potential for further collaboration with these commercial spaceflight companies as the program grows. We also have close connections with SpaceX (with former co-I Easter now working there), and we hope to leverage this connection to provide educational opportunities to our students. From the Boullder engineering side, we are expanding the engineering disciplines that are integrated into the MiSSE course by incorporating a project focused on robotics and autonomy. This opens up opportunities for collaboration with the new CU Boulder Robotics Program that is in its second year.

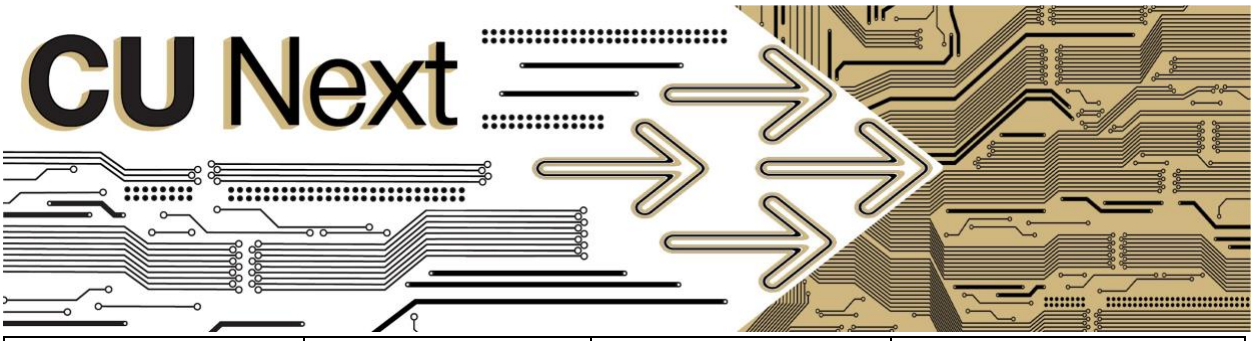


Results - Data and analysis relative to learning outcomes

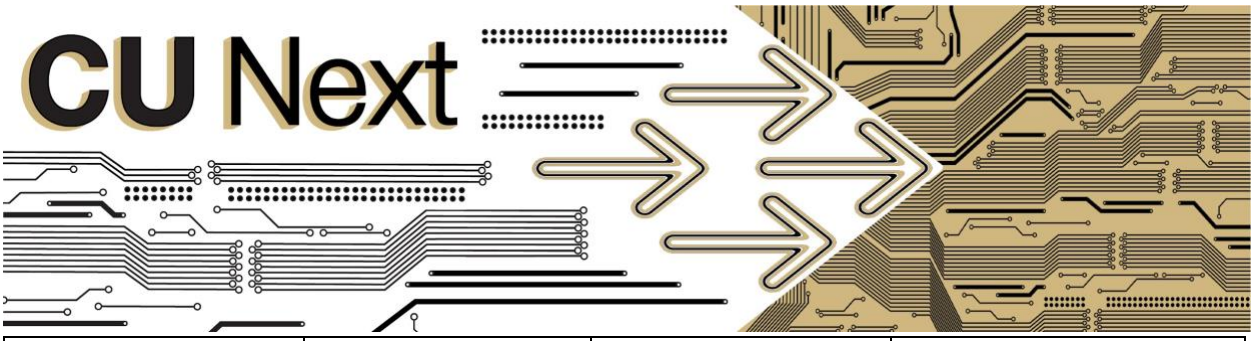
Survey data on each of our courses was collected over the years of administration, demonstrating consistently that students highly value their experiences in these courses, find the educational outcomes and approach to instruction unique, and highlight the opportunity for hands-on learning as a major benefit. To illustrate this, we have included the following table with comments from students who participated in the Spring 2025 iteration of the MiSSE course. The first two columns include feedback on the classroom portion of the course focused on teaching wilderness first aid (WFA), while the second two columns include feedback on the week-long field simulation at the Mars Desert Research Station (MDRS).

Some of the highlighted themes that were prevalent include 1) the value of hands-on instruction, 2) the value of building an immersive educational environment at MDRS, and 3) the diverse group of instructors were valued not only for their educational contributions, but also for the chance to ask them about their career paths and pursue further mentorship. Students also highlighted the utility of the MEC medical trailer developed in the graduate projects portion of this grant. On the negative side, the sponteneity of the course was perceived differently by different students. Adaptability and response to off-nominal scenarios are elements we believe are important to the educational outcomes of the course, but it is good to be aware of students' reactions to shifting conditions.

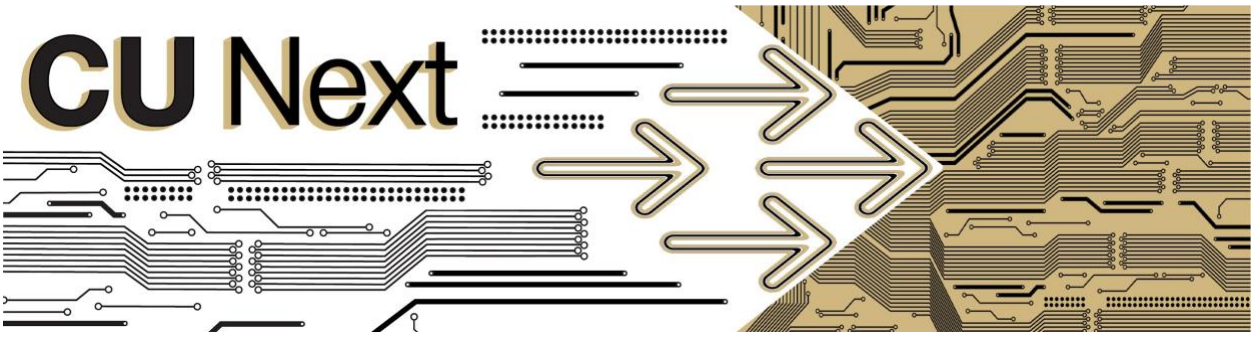
What aspects of the WFA training were instructionally effective?	**What instructional aspects of the WFA training could be improved?**	**What aspects of the field portion were effective?**	**What instructional and simulational aspects of the field portion could be improved?**
david's an engaging, knowledgeable, amicable individual, who is compelling to pay attention to. loved every bit of learning from him. ***really liked the hands-on / scenario portions, as they made the classroom learning feel more real & applicable***.	more applications to space	all of it. i didn't want to leave after just 1 week. a great ***immersive experience***, where ***classmates & instructors alike seemed like resources for info / learning / teaching moments.***	unsure tbh. ***maybe this would be a gripe for some people, but i kind of enjoyed being told 10 mins before something that something was going to happen; made it feel more real-world / astronaut-to-MCC.***
hands-on practice with things like splinting, practice outside, doing a practice patient assessment every week		debrief was always really helpful. simulated EVAs were helpful/doing medical work out in the field. ***going back to the MEC and talking through the medical aspects was also helpful***	I think ***having a lecture earlier in the week about comms would be helpful***; we mainly learned through feedback/debriefs. Also more details about the EVA specifics before leaving to the field component probably would have resulted in fewer last-min changes to our project EVA plans, but I



			know things come up so that wasn't that big of a deal.
Most of it! Especially the ***hands-on demonstrations and scenarios***.	Clearer information on the slides for more detailed note-taking.	All of it!! It was really great!	The only thing is to have a better projector, but it was not a real issue.
The lecture presentations had the right level of detail to be concise but informative. The most effective aspect of the WFA training was doing the ***hands-on patient assessment scenarios outside of the classroom***. My favorite was the one we did outside! ***Being outside with multiple patients made it feel more real and urgent***.	The connections to space medicine at the end of some lectures were good, but I think it would've been nice to get more of that before the MDRS trip.	Honestly, every aspect was effective; the team of instructors, the lectures, the (planned and surprise!) EVAs, the EVA debriefs, the ***instructor Q&A panel (I really enjoyed this),*** the group camping and food prep (including the camping food!), the MDRS facilities. The ***instructors pushing us to "stay in sim" also made the experience much more effective for me***.	Nothing comes to mind. ***Although some of the EVAs were frustrating, that was kind of the point - all part of an incredible learning experience!*** Too bad there were no simple tips and tricks for astronaut selection :)
David was very engaging, presentations were generally easy to understand and the practice sessions and ***demos were super helpful***.	The simulations were great. A good mix of some we could prepare for and others that we had to figure out on the fly. The rotation of positions were good too. The classes were also super interesting and I thought the instructors were great.		Only thing I can think of is it would be nice to have radios that when multiple people are talking you hear both rather than it cutting off someone and people aren't usually aware that there was a message they didn't get. That's how the military radios I've used have operated which is helpful for deconflicting comms. Not sure if that could be changed with settings or require whole new radios though.
An aspect of the WFA that was effective was the **use of medical equipment before MDRS** to increase comfortability	Give more scenario and triage practice leading up to MDRS.	***Great connection with the instructional team allowing me to go out of my comfort and take risks in my leadership and skills.***	For how difficult it is to manage the trip there isn't anything I can comment needs improvement. Keep making the simulation FUN and adventurous.
the ***hands on simulations of patient assessments***	continue to develop the integration between WFA and space medicine. maybe before each WFA lecture there could be a brief discussion on how what we're about to learn applies to space exploration	really all of them. ***I found the mix of instruction and simulations during the field portion to be perfectly diverse yet balanced***.	I would have liked an introductory Q/A prior to the closing Q/A where we could hear about the career paths and generally get to know the instructors early on in the week. A few times early on I was wanting to ask instructors questions about their background which would've helped me frame their lectures but knew that we were going to have the Q/A at the end of the week so I held off.
The WFA training was very well structured and clear. The instructors demonstrated a strong command of the material and were able to relate wilderness first aid	While the training was strong overall, it could benefit from slightly more time allocated to practicing complex scenarios. Some sessions felt a bit rushed, and having	The ***field portion was incredibly immersive and well executed***. The use of suits, rovers, and habitat protocols created a realistic and engaging simulation. The daily	***Having a clear and detailed schedule would be ideal, especially for participants who prefer to know in advance what is on the agenda each day***. Additionally, placing more emphasis on balancing scientific



techniques to the specific challenges of a Mars simulation, which made the content more engaging and relevant. The ***hands-on practice scenarios were particularly effective in reinforcing key concepts and decision-making under pressure***.	additional opportunities for debriefs after scenarios would help solidify the lessons learned. It would also be beneficial to ***create more space for participants without prior medical experience to practice and build confidence. At times, it felt like those with medical backgrounds took over the majority of the cases, which could make others feel hesitant to engage fully***.	mission planning meetings and debriefs were also very effective for reflecting on both technical skills and teamwork under simulated conditions.	operations with mission safety would strengthen the realism of the training even further.
I think the ***demonstrations and practical exercises were really helpful in nailing down all the necessary steps***. Especially when the "victim" could give feedback on the end about what you missed.	While the textbook was a good parallel guide, there was a lot less overlap than expected. The textbook often discussed multiple ways to perform certain medical protocols, but we only used one (splinting, rolling, ABC vs CAB, etc.).	Essentially all of it. ***Both the lectures and the EVAs were incredibly effective at helping us understand the difficulties in a Mars mission***. They complemented each other really well.	I think ***the only lecture that felt a bit disconnected was the mass casualty incident lecture***. We kept preparing for an MCI on our EVAs when we didn't have any. That may be an intentional psych-out, but it made it feel a bit out of place. Arguably, the team-planned EVAs could have been considered an MCI, but we didn't have enough time to treat it as anything other than a rapid evac.
Lecture slides were thorough and engaging.	Should spend more time reviewing and practicing splinting techniques.	The lectures were effective and provided helpful information. The EVAs provided a good opportunity to apply what we learned and reflect on how to improve.	The communications lecture/discussion should be done as early as possible in the course since it's so crucial to the success of missions and most participants do not have an operational background or experience with it.
The ***hands on learning*** and way in which the material was sectioned into different injury types was helpful	Weird issue but the file type of the David's slides were really weird. It would be helpful to have them as PDFs	The ***EVAs were immersive*** and the wide variety of missions and scenarios was fun	



Overall conclusions, recommendations, and outcomes

Our educational programs at the intersection of medicine and engineering are ever-evolving, and while this creates challenges for us, we have realized that this is a primary strength of the educational experiences we strive to provide for our students. We keep abreast of the changing landscape of human spaceflight and use our updated knowledge to adjust and augment our courses. Below are specific conclusions and recommendations from the three courses supported by this grant.

- There is a lot of potential educational benefit from students learning more about instructors' career paths, not just content delivery. Who you bring into the classroom matters, not just for technical expertise, but also for their capacity for mentorship and willingness to share their individual paths to where they are now.

- There is an important balance between didactics and hands-on learning that we should continue to strike in our courses.

- It is a persistent challenge to manage different levels of student experience with either engineering or medicine in the classroom. Successful management should enable students with deeper knowledge in one area to share their expertise but not dominate the learning environment.

- Each student reacts to aspects of the educational environment differently. We saw this from feedback on the MiSSE 2025 course, with some students stating that the "surprises" during the field week improved the realism and their immersion in the course, while others reacted negatively to more spontaneous changes. No course will satisfy every student's needs, but we can develop ways for students to adapt to each instructional environment based on their own needs and include these strategies in our course infrastructure.