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Exploring Immersive Technology at APL

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CONVEY: Connecting STEM Outreach Now Using VIE Education for Youth

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AR VR MR

ABSTRACT

As part of the CONVEY (Connecting STEM Outreach Now Using VIE Education for Youth) program, a multidisciplinary Johns Hopkins University Applied Physics Laboratory (APL) team designed a mixed reality workshop to provide experiential instruction to children in families with wounded warriors. The goal of the workshop was to improve participants' understanding of their family members' conditions; of specific topics in biology, anatomy, and engineering; and of current and future rehabilitative technologies. The hope was that this increased and personalized understanding might motivate them to pursue careers in science, technology, engineering, and mathematics (STEM). This effort, commissioned by the Office of Naval Research, leveraged both traditional learning methods and immersive technologies. Using a modified version of the VIE (which stands for Virtual Integration Environment)—the virtual training platform APL developed to help amputees quickly adapt to operating its revolutionary Modular Prosthetic Limb—the team created a number of scenarios in virtual and mixed reality to enhance the lesson-based activities. This article outlines the approaches for developing these immersive scenarios, documents the technologies and capabilities used, and presents the program's measures of effectiveness.

INTRODUCTION

Despite significant advances in medical care and rehabilitative services, the challenges faced by many of our wounded warriors returning home after treatment cannot be overstated. The hardships these individuals and their families endure can be compounded by family members' incomplete understanding of the service members' functional limitations and post-injury experiences. Today's immersive technologies can enable family members to take part in virtual reality (VR) and mixed reality (MR) scenarios that can convey the experience and viewpoint of the wounded warrior.

The advent of high-quality consumer-grade VR and MR technologies offers great potential for immersive scenarios to reach widespread audiences, including in educational programming such as science, technology, engineering, and mathematics (STEM) activities. In addition to improving understanding through visual content presentation and experiential activities, such

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technologies may also increase empathy by immersing the user in another perspective.

The CONVEY (Connecting STEM Outreach Now Using VIE Education for Youth) program was initiated by the Office of Naval Research (ONR) with the goal of increasing the number of children who might pursue STEM careers, motivated by a greater understanding of and a desire to help their wounded family members. CONVEY was structured as a workshop to provide the children of wounded warriors with the background necessary to understand the experience of their wounded relatives and even to use simulated assistive technologies like prosthetic limbs.

The CONVEY workshop was organized into four modules that focused on relevant anatomy and technologies: the brain, the nervous system, the muscular system, and prosthetics and sensors. Instructional sessions, which included lecture, partner work, classroom discussion, and interactive games, were intermixed with hands-on activities using immersive technologies such as the Oculus Rift VR headset and the Microsoft HoloLens MR headset. When participating in immersive scenarios using these headsets, students could visualize the anatomical systems and components of the human body and experience controlling a prosthetic limb with various control interfaces, including a muscle-activity-based (i.e., myoelectric) controller frequently used by upper limb prosthesis users.[1,5]

Herein we document the design of the VR and MR scenarios used during the workshop. We describe how the built-in interaction-based functionalities of the immersion platforms (e.g., head movement, gaze tracking, gestures) were incorporated into the scenarios, and how additional sensor technologies were integrated to provide the user with additional means to track movements of the body and activation of muscles within the user's arm. We conclude with a presentation of the workshop's measures of effectiveness.

METHODS

Instructional and experiential immersion scenarios were developed with the Unity (Unity Technologies, San Francisco, CA) development environment for both MR and VR platforms. Immersion scenarios included a mixture of prosthetics-related tasks: students controlling their own arms, students visualizing their own arms and anatomical representations of arms in simulations, and students controlling prosthetic arms through various sensors. Some scenarios contained virtual content that was simply projected in front of the students for visual inspection. Others, such as in the scenarios based on the virtual prosthetic limb (see the section on VR scenarios), contained content that students could reposition, select, and even directly manipulate.

MR Scenarios

The workshop modules on anatomical systems in the body relied on an MR platform permitting students to visualize the model's human anatomical structures and compare them with their own. These modules enabled them to gain a sense of the relative positions, scale, and connectivity of the brain, nerves, and muscles as compared with other parts of the body. Participants were free to move around the anatomical models, to enter the meshes of the models to examine structures deep to the anatomical surface, and through the use of gaze tracking and hand gestures recognized by the headset, to rotate, scale, and highlight specific muscles or anatomical regions. The APL team constructed different MR scenarios to highlight the regions of the brain, the peripheral nervous system, and the muscular systems.

Anatomical Model Generation

The anatomical human model (3DS Max Rigged Male Anatomy), procured through an online vendor (TurboSquid, New Orleans, LA), contained the muscular, nervous, and skeletal systems. The model was imported into Blender (Blender Foundation, Amsterdam, the Netherlands), an open-source computer-aided design (CAD) editor, so that specific structural content in the anatomical model could be extracted and exported into a file format that could be subsequently imported into Unity. An anatomical model with moving arm segments was developed for the muscular system module. The segments of the arm were connected using Unity hinge joint elements that had an anatomically accurate range of motion.[3,4]

MR Interactivity

For some elements of the human anatomical model, new custom object textures were generated in Adobe Illustrator (Adobe Inc., San Jose, CA) to allow the distinction of particular anatomical regions and features, such as lobes of the brain (Figure 1). This visual change in the mesh texture was applied when the user positioned the gaze cursor on a Unity collider element colocated with the anatomical region of interest.

The MR scenarios contained a transparent outline of the human form that overlapped with the highlighted anatomical structures, as well as a blue 3-D bounding box with interactive elements on each corner and edge to allow for rotation and scaling of the full model through pinch-and-grab HoloLens-supported gestures.

VR Scenarios

These immersive scenarios were designed to give students the experience of controlling an upper-extremity prosthetic. In the VR scenarios, the student's own upper arm was replaced in the virtual environment with a visualization of a full prosthetic limb whose position could be updated based on the kinematically tracked position of the student's corresponding arm. Using various optical, inertial, and physiological sensors providing position, orientation, and muscle activity, the virtual prosthetic limb was positioned within the virtual environment relative to the student's body by being displayed in an egocentric viewpoint. These sensor technologies were affixed to the VR headset and the student as outlined in Figure 2. As students moved their own arms or contracted particular muscle groups on their arms, they could direct the prosthetic limb within the virtual environment to make specific motions and to interact with virtual content and objects.

The APL team created multiple scenarios for the workshop to present the participants with representative actions a prosthetics user might need to take, including a pick-and-place playground that tested multi-segment movements and grasps with the hand, a catch game that tested timed limb positioning and grasping, and a table tennis game that tested timed limb positioning.

Virtual Integration Environment

To support the workshop modules focused on control of prosthetic limbs, the team developed a VR platform that leveraged the APL-developed Virtual Integration Environment (VIE) and Unity-based virtual Modular Prosthetic Limb (vMPL) frameworks, both

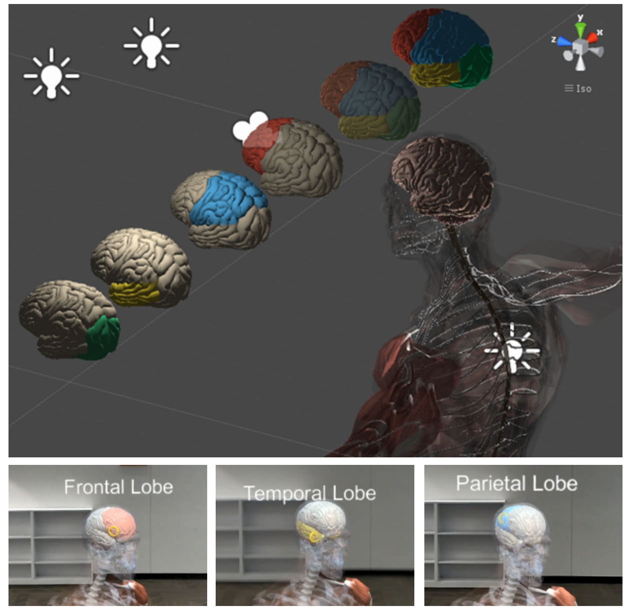


Figure 1. Visual presentation of human anatomical brain models. Variants of custom-generated UV textures to highlight each lobe of the brain are shown in the Unity developer window. The positions of lighting sources, which provide for better visibility of model features, are depicted within the virtual world. Students could select the different anatomical regions using the main HoloLens gaze cursor (yellow ring), as shown in the HoloLens screenshot images in the bottom panel.

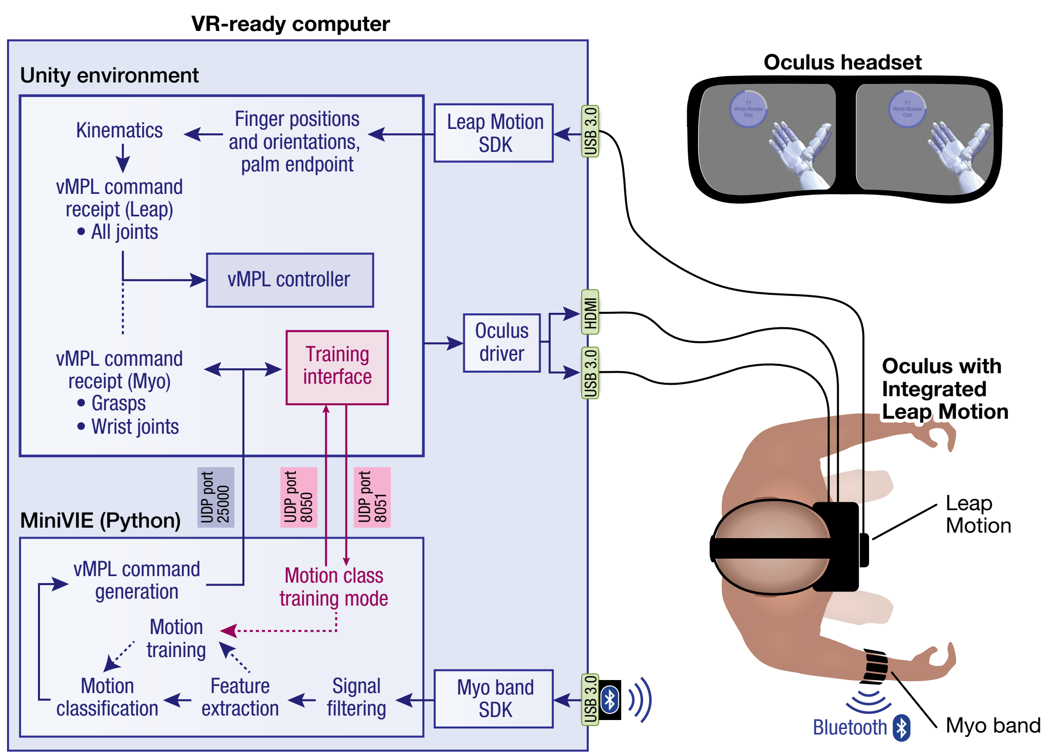


Figure 2. VR scenario for prosthetic control. The graphic highlights the various components, including the Oculus Rift VR headset, the Leap Motion optical kinematic tracker, the Myo band, the MiniVIE, and the vMPL.

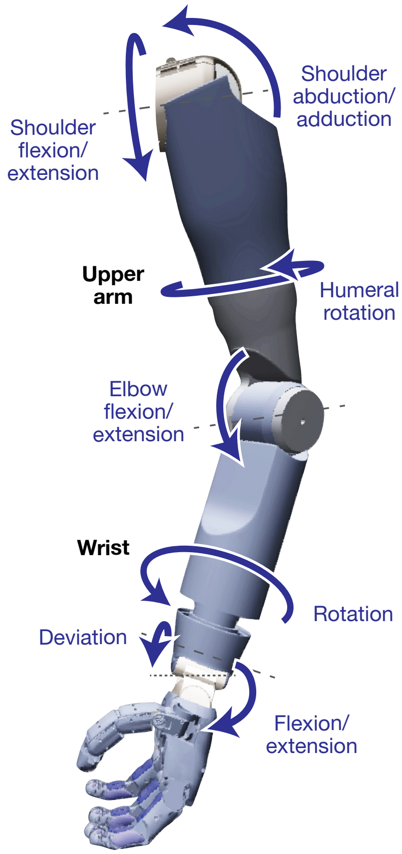


Figure 3. The vMPL. Developed for the DARPA Revolutionizing Prosthetics Program, it provides both a 3-D graphical visualization and a physical simulation of a prosthetic limb containing 26 articulating joints (upper arm, fingers) and 17 independently controllable virtual motors.

developed for the Defense Advanced Research Projects Agency (DARPA) Revolutionizing Prosthetics Program[1,3,5,6] (Figure 3). The prosthetic-based VR scenarios also used some capabilities built into the publicly available MiniVIE,[6] which provides a control interface with wearable sensors such as the Myo electromyographic (EMG) armband (North Inc., formerly Thalmic Labs, Kitchener, Ontario).[2]

User Control Modalities for the vMPL

Imparting a range of experiences for controlling a prosthetic limb within the virtual environment was an important goal for the workshop, so the APL team developed a novel hybrid control interface that would allow independent or shared control of the vMPL using a variety of sensor modalities. With an optical kinematic tracker such as the Leap Motion (Leap Motion, Inc., San Francisco, CA; now Ultraleap, Mountain View, CA), a full reconstruction of the student's arm joints and positions was available to be directly mapped to the hand and wrist joints of the vMPL, permitting inverse kinematic inference of the upper arm joint angles. These reconstructed joint angles allowed the vMPL, as visualized within the VR headset, to mimic the movements of the user in the real world, emulating the movements in real time.

Alternatively, the positioning and movement of the vMPL could be directed by integrating sensor information provided from both optical sensors and wearable sensors measuring muscle activation (such as the Myo band), providing for a hybrid optical and EMG mode. In this hybrid mode, the hinge joint angles of the vMPL's upper arm position (shoulder, humeral rotation, elbow flexion) were still controlled by joint angles from the full-limb reconstruction provided by processing the Leap Motion sensor data. The wrist and hand movements of the vMPL were thus controlled via pattern recognition of EMG signals collected from muscle activation in the forearm of the student. The pattern recognition algorithm permitted the identification of a single movement class at a time, thus permitting the student to control only an individual vMPL joint at a time. This pattern recognition scheme is one typically used by prosthesis users and requires training and familiarization to perfect.[2] Over the course of the event, workshop participants transitioned from pure Leap Motion-based control of the full arm to the hybrid Leap + EMG control mode with reduced simultaneous movement control. The goal was for the students to gain perspective on the experiences and challenges of real-world prosthesis users.

The system used a number of software applications to collect data from the various sensors, to train specific movements using the Myo band, and to control and visualize the vMPL within the Unity environment (see Figure 3). In addition to the Leap Motion and Myo band, the vMPL used various sensors in the Oculus Rift headset to track the user's inertia and position within the virtual environment. Tracking the reference frame of the student's head informed the system where to place the shoulder of the rigged vMPL system respective to the student by using a fixed positional offset from the head position to the center of the vMPL shoulder position.

Leap Motion Control of the vMPL

The Leap Motion hand tracker was mounted to the front of the Oculus Rift headset such that the student's hands could be seen from the sensor's cameras. The Leap Motion provided positional and rotational data about the user's fingers, palm, wrist, and elbow.

The angles for the fingers were calculated by rotating each bone to the origin using the inverse of its own rotation quaternion. This same inverse rotation was applied to the preceding finger segment. Next, the dot product was taken between the basis vectors for the segments and the axis of rotation of the finger joint, resulting in vectors closest to the plane of rotation.

The angles for the upper arm segments of the vMPL were calculated using a modified iterative Jacobian

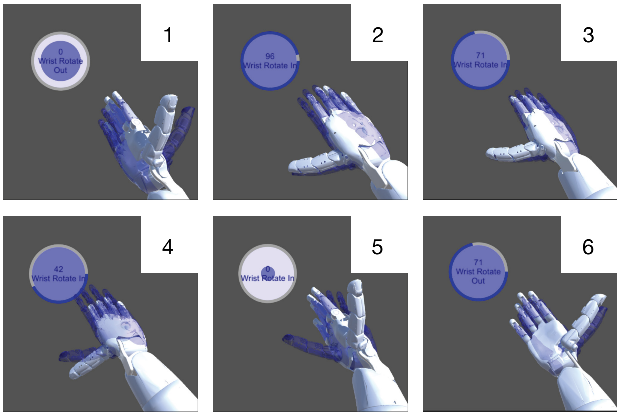


Figure 4. Training routine for the Myo band's control of specific joints in the vMPL. The workshop participant was directed to make and hold specific flexions while muscle activity was recorded and used to train a movement classifier.

method of inverse kinematics. Several inverse kinematic systems were instantiated, causing each vMPL to reach its destination position defined by the Leap Motion sensor data.

Myo Band Control of the vMPL

The Myo armband is a wearable sensor with eight electrical contact pads that record surface electromyography (sEMG) data from the proximal muscles in the arm. Using functionality built into the MiniVIE, these streaming data can be used to train machine learning algorithms to detect poses of the hand and wrist. These poses can be relayed to the vMPL to effect movement in the limb joints.

A training routine incorporated into the vMPL scenario stepped the student through a number of hand and wrist movements (Figure 4). Data from the Leap Motion informed the student of their real-time hand position and orientation to help assure them that they were performing the correct movements through each training step. The student's muscle activity from the various flexions during the training routine was recorded and used to build a classifier to discriminate each trained movement.

RESULTS

Students who participated in the CONVEY workshops were asked to provide their opinions about STEM fields, as well as about their knowledge of basic human anatomy, before and after each two-day workshop. After the workshops, the 42 total students, aged 9–15 (grades 4–10), reported increased confidence when participating in science activities, increased agreement that science would help them earn a living, and an increased desire to imagine creating new technologies (Table 1). All students increased their knowledge on the anatomical topics covered in the CONVEY curriculum: the human brain, the human nervous system, and the human muscular system. A majority of the students in one of the two workshops reported learning about at least two new career options, and their interest levels in pursuing a career in science, math, or the medical sciences increased by 10%. A majority reported that the technology used during the workshop, including the HoloLens, Oculus Rift, and Myo band, helped them learn about the human body.

DISCUSSION

The APL team generated a number of MR and VR scenarios to provide CONVEY workshop attendees with instructional and experiential activities focused on prosthetics. The intent was to leverage these immersive scenarios to help these family members of wounded warriors better understand the experience of having a functional limitation or even a prosthesis and to inspire them to pursue careers in STEM. Emerging research efforts are similarly exploring the potential of immersive scenarios in VR and MR for generating experiences that may convey perspective or have a therapeutic effect. As VR and MR headsets improve in image resolution, latency, field of view, and cost, these immersive scenarios will be able to reach a larger user group and provide the means for low-cost clinical and therapeutic tools to improve understanding and increase empathy for users in a variety of conditions and situations.

ACKNOWLEDGMENTS: We gratefully acknowledge our collaborators at the Uniformed Services University of the Health Sciences and Walter Reed National Military Medical Center for support in organizing and hosting the CONVEY workshops. We thank Dr. Peter Squire for his vision and support of this activity and for STEM outreach and education.

REFERENCES

[1]R. S. Armiger, F. V. Tenore, W. E. Bishop, J. D. Beaty, M. M. Bridges, J. M. Burck, et al., "A real-time Virtual Integration Environment for neuroprosthetics and rehabilitation," *Johns Hopkins APL Tech. Dig.*, vol. 30, no. 3, pp. 198–206, 2011.

[2]W. Haris, J. Lesho, A. Chi, and R. Armiger, "Low-cost pattern recognition based multi-digit myoelectric hand prosthesis," presented at the American Academy of Orthotists & Prosthetists 43rd Academy Annual Meeting & Scientific Symposium, 2017.

[3]A. D. Ravitz, M. P. McLoughlin, J. D. Beaty, F. V. Tenore, M. S. Johannes, S. A. Swetz, et al., "Revolutionizing Prosthetics—phase 3," *Johns Hopkins APL Tech. Dig.*, vol. 31, no. 4, pp. 366–376, 2013.

[4]B. Wester, M. Para, A. Sivakumar, M. Kutzer, K. Katyal, A. Ravitz, et al., "Experimental validation of imposed safety regions for neural controlled human patient self-feeding using the modular prosthetic limb," in *IEEE Int. Conf. Intell. Robots Syst.*, 2013.

[5]B. Wester, K. Fischer, T. Gion, G. Hotson, J. Downey, M. Fifer, et al., "Development of Virtual Integration Environment sensing capabilities for the Modular Prosthetic Limb," presented at Nueroscience 2014, the Society for Neuroscience annual meeting, 2014.

[6]R. S. Armiger, "MiniVIE," https://bitbucket.org/rarmiger/minivie.

Table 1. Workshop assessments

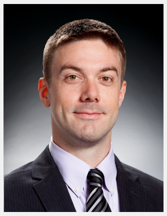
Question	Workshop 1			Workshop 2		
	Before (%)[a]	After (%)[b]	Difference	Before (%)[c]	After (%)[d]	Difference
1. I am sure of myself when I do science						
Strongly Agree	23.5	45.0	21.5	23.8	40.9	+17.1
Agree	58.8	45.0	–13.8	57.1	50.0	–7.1
Neither Agree nor Disagree	17.6	10.0	–7.6	19.0	9.1	–9.9
Disagree	0.0	0.0	0.0	0.0	0.0	0.0
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
2. I expect to use science when I get out of school						
Strongly Agree	35.3	75.0	39.7	33.3	40.9	+7.6
Agree	52.9	20.0	–32.9	33.3	40.9	+7.6
Neither Agree nor Disagree	11.8	5.0	–6.8	28.6	13.6	–15
Disagree	0.0	0.0	0.0	4.8	4.5	–0.3
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
3. Knowing science will help me earn a living						
Strongly Agree	41.2	55.0	13.8	38.1	36.4	–1.7
Agree	47.1	25.0	–22.1	47.6	50.0	+2.4
Neither Agree nor Disagree	11.8	20.0	8.2	9.5	13.6	+4.1
Disagree	0.0	0.0	0.0	4.8	0.0	–4.8
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
4. I like to imagine creating new technologies						
Strongly Agree	23.5	55.0	31.5	47.6	68.2	+20.6
Agree	47.1	30.0	–17.1	28.6	18.2	–10.4
Neither Agree nor Disagree	23.5	15.0	–8.5	19.0	9.1	–9.9
Disagree	5.9	0.0	–5.9	4.8	4.5	–0.3
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
5. If I learn engineering, then I can improve things that people use everyday						
Strongly Agree	52.9	55.0	+2.1	42.9	50.0	+7.1
Agree	41.2	30.0	–11.2	47.6	40.9	–6.7
Neither Agree nor Disagree	5.9	10.0	+4.1	9.5	9.1	–0.4
Disagree	0.0	5.0	+5.0	0.0	0.0	0.0
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
6. Designing technologies will be important for my future work						
Strongly Agree	41.2	45.0	+3.8	42.9	40.9	–2.0
Agree	23.5	20.0	–3.5	19.0	36.4	+17.4
Neither Agree nor Disagree	35.3	30.0	–5.3	28.6	18.2	–10.4
Disagree	0.0	5.0	+5.0	4.8	0.0	–4.8
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
7. I would like to use creativity and innovation in my future work						
Strongly Agree	47.1	60.0	+12.9	61.9	68.2	+6.3
Agree	47.1	35.0	–12.1	33.3	22.7	–10.6
Neither Agree nor Disagree	5.9	0.0	–5.9	0.0	9.1	+9.1
Disagree	0.0	5.0	+5.0	0.0	0.0	0.0
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
8. Knowing how to use math and science together will allow me to invent useful things						
Strongly Agree	47.1	65.0	+17.9	38.1	45.5	+7.4
Agree	47.1	20.0	–27	52.4	40.9	–11.5
Neither Agree nor Disagree	6	15	+9	4.8	13.6	+8.8
Disagree	0	0.0	0.0	0.0	0.0	0.0
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
9. I would consider a career in either science, math, or medical sciences						
Strongly Agree	35.3	45.0	+9.7	38.1	31.8	–6.3
Agree	29.4	30.0	+0.6	38.1	27.3	–10.8
Neither Agree nor Disagree	29.4	25.0	–4.4	14.3	36.4	+22.1
Disagree	5.9	0.0	–5.9	4.8	4.5	–0.3
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
10. I believe scientists and engineers can help wounded warriors						
Strongly Agree	76.5	85.0	+8.5	61.9	68.2	+6.3
Agree	23.5	15.0	–8.5	33.3	27.3	–6.0
Neither Agree nor Disagree	0.0	0.0	0.0	0.0	4.5	+4.5
Disagree	0.0	0.0	0.0	0.0	0.0	0.0
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
11. I am interested in a career in medicine, including opportunities in the military						
Strongly Agree	11.8	35.0	+23.2	14.3	13.6	–0.7
Agree	52.9	25.0	–27.9	23.8	18.2	–5.6
Neither Agree nor Disagree	29.4	40.0	+10.6	42.9	40.9	–2.0
Disagree	5.9	0.0	–5.9	14.3	27.3	+13.0
Strongly Disagree	0.0	0.0	0.0	0.0	0.0	0.0
No Answer	0.0	0.0	0.0	4.7	0.0	–4.7

continues

Table 1. Workshop assessments *(continued)*

Question	Workshop 1			Workshop 2		
	Before (%)[a]	After (%)[b]	Difference	Before (%)[c]	After (%)[d]	Difference
12. Please list any three things you know about the human brain						
All three correct	41.2	65.0	+23.8	38.1	68.2	+30.1
At least one correct	52.9	20.0	–32.9	33.3	27.3	–6.0
Blank	5.9	15.0	+9.1	28.6	4.5	–24.1
13. Please list any three things you know about the human nervous system						
All three correct	23.5	40.0	+16.5	0.0	36.4	+36.4
At least one correct	35.3	35.0	–0.3	14.3	40.9	+26.6
Blank	41.2	25.0	–16.2	85.7[e]	22.7	–63.0
14. Please list any three things you know about the human muscular or skeletal system						
All three correct	29.4	45.0	+15.6	0.0	54.5	+54.5
At least one correct	47.1	25.0	–22.1	14.3	36.4	+22.1
Blank	23.5	30.0	+6.5	85.7[e]	9.1	–76.6
15. Please indicate at least two career paths you learned about through this workshop						
1	N/A	65.0	N/A	N/A	50.0	N/A
2	N/A	35.0	N/A	N/A	4.5	N/A
None	N/A	0.0	N/A	N/A	45.5	N/A
16. Please rate the following equipment in usability						
HoloLens						
1	N/A	0.0	N/A	N/A	0.0	N/A
2	N/A	0.0	N/A	N/A	4.5	N/A
3	N/A	0.0	N/A	N/A	9.1	N/A
4	N/A	25.0	N/A	N/A	18.2	N/A
5 – Most Usable	N/A	65.0	N/A	N/A	59.1	N/A
Blank	N/A	10.0	N/A	N/A	9.1	N/A
Oculus Rift						
1	N/A	0.0	N/A	N/A	0.0	N/A
2	N/A	0.0	N/A	N/A	4.5	N/A
3	N/A	0.0	N/A	N/A	4.5	N/A
4	N/A	20.0	N/A	N/A	18.2	N/A
5 – Most Usable	N/A	70.0	N/A	N/A	63.6	N/A
Blank	N/A	10.0	N/A	N/A	9.1	N/A
Myo Band						
1	N/A	0.0	N/A	N/A	4.5	N/A
2	N/A	5.0	N/A	N/A	18.2	N/A
3	N/A	30.0	N/A	N/A	18.5	N/A
4	N/A	25.0	N/A	N/A	27.3	N/A
5 – Most Usable	N/A	30.0	N/A	N/A	22.7	N/A
Blank	N/A	10.0	N/A	N/A	9.1	N/A
17. Please rate how the following equipment helped you learn about the human body						
HoloLens						
1	N/A	0.0	N/A	N/A	0.0	N/A
2	N/A	5.0	N/A	N/A	9.1	N/A
3	N/A	5.0	N/A	N/A	13.6	N/A
4	N/A	35.0	N/A	N/A	18.2	N/A
5 – Most Helpful	N/A	45.0	N/A	N/A	50.0	N/A
Blank	N/A	10.0	N/A	N/A	9.1	N/A
Oculus Rift						
1	N/A	10.0	N/A	N/A	9.1	N/A
2	N/A	5.0	N/A	N/A	9.1	N/A
3	N/A	20.0	N/A	N/A	0.0	N/A
4	N/A	30.0	N/A	N/A	22.7	N/A
5 – Most Helpful	N/A	25.0	N/A	N/A	50.0	N/A
Blank	N/A	10.0	N/A	N/A	9.1	N/A
Myo Band						
1	N/A	0.0	N/A	N/A	13.6	N/A
2	N/A	5.0	N/A	N/A	4.5	N/A
3	N/A	20.0	N/A	N/A	4.5	N/A
4	N/A	30.0	N/A	N/A	18.2	N/A
5 – Most Helpful	N/A	35.0	N/A	N/A	50.0	N/A
Blank	N/A	10.0	N/A	N/A	9.1	N/A

[a] 17 respondents
[b] 20 respondents
[c] 21 respondents
[d] 22 respondents
[e] Confusion in pre-assessment; many left second page blank (included question about nervous and muscular system)



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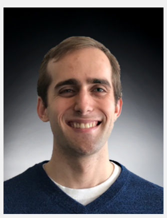
Brock A. Wester is a project manager and supervisor of the Neuroscience Group in APL's Research and Exploratory Development Department. He holds a BS in computer engineering from the Georgia Institute of Technology and a PhD in biomedical engineering from Emory University. Brock's current research efforts span connectomics, neuro big data, neuroprosthetics, user interfaces, and immersion (VR/AR/MR). He is the project manager on the Machine Intelligence from Cortical Networks (MICrONS) project, principal investigator on an NIH grant focused on the development of neuro big-data resources and of the Revolutionizing Prosthetics program, and vice chair of the Johns Hopkins Engineering for Professionals Applied Biomedical Engineering program. Before joining APL, Brock was the co-founder and chief technology officer of NanoGrip Technologies, which developed and commercially produced multiple-degree-of-freedom micromanipulation tools for micro-assembly, mechanical testing, and biological interfacing. His email address is brock.wester@jhuapl.edu.



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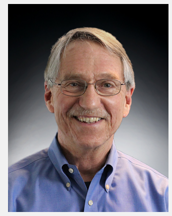

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Daniel M. Portwood is a technical writer in the APL's Communications Department. He has a BA in English from the University of Virginia; an MA in journalism from the University of Maryland, concentrating on how science is communicated in the press; and an MS in technical communication management from Mercer University School of Engineering, including study of instructional design, website information design, and usability testing. For the APL STEM Program Office's ONR-sponsored CONVEY workshop, he worked on the curriculum development team, developing content for the four modules on the brain, nervous system, muscular system, and advanced prosthetics to give learners foundational knowledge to reinforce their experience with the virtual reality and augmented reality sessions of the workshop. His email address is daniel.portwood@jhuapl.edu.

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James Beaty holds a BS in biomedical engineering from Johns Hopkins University, a PhD in biomedical engineering from Yale University, and an MBA from the University of Pennsylvania. He has 15 years of machine learning and project management experience in the areas of brain–computer and brain–machine interfaces and neuroprosthetics. He currently works for Norwegian Energy Solutions and Services in Arlington, Virginia. His email address is jbeaty1997@gmail.com.

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Dwight Carr is the section supervisor and program manager of the Science, Technology, Engineering, and Mathematics (STEM) Program Management Office in APL's Talent Services Department. He holds a BS in biology from Howard University and an MS in electrical and computer engineering from Johns Hopkins University (JHU). He is pursuing an EdD in education from JHU. Dwight is an expert in STEM outreach and education and has served as the program manager for APL's program since its inception in 2011. He established APL's first centralized STEM initiative; architected the strategy, structure, and content of the STEM programs; and has shepherded them into reality. As a result of his vision, leadership, and dedication, over 25,000 students have been exposed to STEM through APL's programs. By creating and implementing recognized, trail-blazing programs that are unique and scalable, Dwight has established APL as a leader in STEM educational outreach. His email address is dwight.carr@jhuapl.edu.