Democratization of Immersive Virtual Reality (VR) Content Creation Through a VR Authoring Tool: The Evolution of Training.

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ABSTRACT

Background:
University of Illinois tackles disruptive innovation in medical education by enabling professors to directly create immersive Virtual Reality (VR) content without previous VR or coding experience. An internally-developed VR authoring tool (Enduvo, Inc., Peoria, IL) was built to limit cost and content creation time, allowing subject matter experts to create asynchronous VR educational content, with assessment. This manuscript describes research and development of VR authoring within a healthcare and education system.

Methods:
The initial problem/solution fit analyzed the role of 3D printing of complex congenital heart defects. We sought to eliminate 3D printing costs by viewing models in VR instead of 3D printed form. Within VR, surgeons verbally demonstrate findings; capture of these teaching moments was developed into VR authoring software. Since deployment, 229 VR lectures have been created by 36 educators, without prior VR experience. We witness 75-80% lecture length reduction compared to powerpoint. For example, we translated Mass Casualty Incident (MCI) triage training into VR. This topic is typically 2-4 hours of didactics, then table-top or large-scale live exercise, which is costly, time-consuming and lacks consistent competency testing. In contrast, the VR lecture and competency testing are performed in under an hour.

Results:
VR experiences were created allowing individual competency training and evaluation for primary MCI objectives. The 6-module VR experience has learning objectives, competency measures and final MCI simulation where learners perform timed triage of 12 victims. A pilot group of 18 medical personnel demonstrated improvement in triage skills after training completion.

Conclusion:
VR promises effective, efficient training, allowing scalable distribution of training with competency training metrics. Future study initiatives are needed across military specialties, particularly fields with high-stakes tasks that are difficult to simulate in other training environments, tasks with low acceptable margin of error, and tasks where expertise is scarce and difficult to distribute.

ABOUT THE AUTHORS

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BACKGROUND

The University of Illinois tackles disruptive innovation in medical education by enabling professors to directly create immersive VR content without previous VR or coding experience. Impactful VR educational content has historically been created by computer scientist teams that interacted with subject matter experts to create custom educational VR experiences. This process is time-consuming, costly, and interjects layers between expert and learner. An internally-developed VR authoring tool (Enduvo, Inc., Peoria, IL) was built to limit cost and time of VR content creation, allowing subject matter experts to directly create asynchronous VR educational content, with assessment. This manuscript describes the research and development of VR authoring capability within a healthcare and education system through the application of lean business model principles to translational healthcare research.

The University of Illinois and Jump Simulation teamed up under a research endowment known as the Jump Applied Research for Community Health through Engineering and Simulation (Jump ARCHES) which combines engineers with clinicians as coinvestigators on new research projects. Through seed and follow-on grants, practicing clinicians uniquely positioned to identify problems within the clinical workflow are partnered with engineers equipped to apply their expertise toward solutions. Given that one of the objectives of the endowment is to generate commercially viable technology, it is important to consider commercial research and development principles as an alternative to traditional academic research approaches. Building on principles of design thinking (Kolko, 2015) and business model toolkits (Osterwalder, 2015) a gated advanced development process was created to guide decision making around resource utilization for taking an idea toward commercially viable product within the translational healthcare research space. The details of the process are beyond the scope of this document, but are briefly described here:

- Value: problem definition and evaluation of good problem/solution fit
- Feasibility: technical feasibility of solution as well as potential for financial viability
- Prototype: research guided minimum viable product development
- Commercialization: defining potential for market fit and business model testing
- Scale: external efforts toward successful launch of product

METHODS

Value of 3D

The initial problem/solution fit analyzed the role of 3D printing of complex congenital heart disease to improve understanding. The morphologic arrangement of intracardiac structures is a foundational component the treatment strategy and particularly relevant for surgical planning in pediatric cardiology. Thus, in the field of medicine, complex congenital heart disease is the perfect substrate for exploration of three-dimensional visualization solutions. With the explosion of consumer grade 3D printers, the problem-solution fit between complex congenital heart disease and the availability of 3D printing solutions became evident (Hadeed, 2018; Vukicevic, 2017; Peng, 2016; Schick, 2016; Wang, 2016). At the core of the value that is demonstrated in literature is the improved understanding that the treating physician gains when interacting with a three-dimensional complex congenital heart (Hadeed, 2018). Engineering resources available through Jump Simulation allowed for rapid prototyping of 3D printed models for congenital heart disease. With minimal resource utilization, it was feasible to create patient- specific 3D model prototypes. Since 2013, over 100 hearts have gone through the 3D modeling process at our institution impacting surgical planning through the well documented improved understanding value. Early on in this process, investigation into potential commercialization opportunities revealed no clear path to a viable model due to the high cost and lack of reimbursement.

Transition to VR

Thanks to generous philanthropy, commitment from our institution toward the 3D modeling program ensured long term viability as a local service, however, we revisited our advanced development process with the intent to increase financial sustainability of the program by investigating more cost-effective methods of 3D visualization. Using engineering expertise within Jump Simulation, we sought to eliminate the cost of 3D printing by simply viewing the 3D models in virtual reality (VR) rather than in physical 3D printed form. For a period of 3 – 6 months in 2016, all congenital cardiac surgical planning cases required the treating clinician to review a heart in VR prior to 3D printing the heart. In each case, the clinician declared they achieved the same value of the improved understanding through interactions with the virtual 3D model and of the 15 cases reviewed in this manner, none were 3D printed. Once again, an investigation into commercialization revealed no clear path toward a viable business model around this use case. However, we observed that many students and residents were asking to come review hearts to better understand the various cases. It was only because we were asking the question of "what more can we get out of this technology?" that we saw an opportunity around medical education.

Struggles with creating tool tips in VR

Now with a new focus of education, we circled back to the start of the problem-solution fit value analysis. We interviewed many users about what a VR educational experience would look like. Participants submitted "paper prototypes" of what educational content would look like. Many of these examples are similar to existing custom VR experiences that are rapidly increasing in the educational space. The idea was focused on how to add instructional material around the 3D model, for example, when the user would look at, or select a part of the model, information relevant to that component would pop up, allowing the user to navigate around a complex model and be presented with the educational material in an interactive fashion. The proposals were solid, however, when investigating the cost of development of a single experience, the cost of creating immersive VR content was found to be as high as $10,000 per minute of VR experience and was projected to be greater than $100,000 in total. This was due to the unique coding experience required, combined with the number of coding hours needed. By assessing the technical and financial feasibility of this project, we were able to prevent moving onto prototype on this project. Yet, during this phase, we continued to utilize the VR as a means for the clinicians and surgeons to review cases prior to surgery. We observed that, when in the VR environment and when the surgeon would have that moment of clarity around the problem, they would naturally want to share their excitement around the new understanding by discussing the case while demonstrating their findings. Practically speaking, the expert, using oral communication and gestures of interaction around the 3D object, would impart their expertise. It was this moment that dramatically changed our focus from creating custom content to simply capturing the expert as they interacted in the virtual environment. We once again circled back to the technical and financial feasibility of this format which revealed a much lower cost and less technical effort. For this new educational format, we had demonstrated good value through a feasible project. With Value and Feasibility checkpoints completed, we secured research funding to transition into the next phase of prototype development.

Prototype Development

The first minimum viable product (MVP) or prototype, allowed the user to import 3D models as well as 2D images and videos into the space. The user could then arrange the assets within the virtual environment prior to recording a 5-minute 4D (3D data over time) experience. The early prototype would not save the recording, and would only keep it on the disk as long as the program was open. During this phase, a simple lecture on Tetralogy of Fallot (a type of congenital heart disease) was recorded many times, so that user after user could experience it and provide feedback as to the educational value of the content. The participants were each interviewed and the results were overwhelmingly positive. Therefore, based on this MVP feedback, we continued development to allow us to begin to save to disc. Due to a lack of understanding of how big these file formats would become, a 5-minute technical limitation was set in place. Under this constraint, a congenital heart disease primer (lecture series) was created by stringing together a series of 5-minute experiences with each section discussing one concept. Once again, a group of college-level users were run through the VR experiences as part of a broader educational activity. Following the experience, informal feedback was acquired. The users expressed significant appreciation toward the 5-minute sections as it provided a natural break point for them to review the concept before moving onto the next topic. The effect is most similar to the *Just in Time Teaching* strategy of breaking information into small segments (Formica, 2010). Multiple users reported feeling as though the professor was present in the room with them despite the avatar only being limited to a pair of glasses and controllers. The users also stated if felt like a personal experience where the professor was talking to them individually rather than talking to the world as is common in a YouTube-style lecture. Additionally, VR's inherent ability to limit external stimuli (distractors) was witnessed through an unexpected direct observation. During the 5 month feedback period, not a single user exited the experience to answer a call or text which was estimated to have occurred 25% of the time.

Based on the initial user feedback, despite solving the 5-minute technical challenge, a conscious decision was made to maintain a concept or learning objective centric model.

Developing Instructional Design Methodology for VR

Anchored around this idea of blocking educational delivery into 5-minute concepts (complete with assessment), we created the following definition:

> *An Enduvo learning objective is a measurable concept. When preparing a lesson in Enduvo, the educator should consider that which he/she can convey, through oral communication while interacting with 3D and 2D assets, around a single concept in 5 minutes or less. This information should be captured in a learning objective format with an action verb followed by up to a 15 word "what statement". For example: "Identify the elements of the myocardial conduction system." Or "List the pathologic components of Tetralogy of Fallot." This terminal learning objective or concept centric focus is completed by including a series of task-based assessments which are intended to help the learner assess their understanding of the concept.*

The key idea here is that within VR, a proper instructional design methodology, affords the opportunity to create an asynchronous scaffolding experience. While scaffolding, as described by Vygotsgy (Wood, 1976) relates to synchronous instruction, we propose that capturing an instructor's interactions in a 3D space, within a proper format, can transition to an asynchronous event. If we can record the expert (or more knowledgeable other) as they are imparting their expertise, is it possible to maximize learner engagement and retention through unique instructional design methodology. The creator breaks up their lecture into 5-minute sections according to the definition above; additionally, the creator is encouraged to develop a series of task-based assessments for each concept that attempt to provide self-evaluation of knowledge and comprehension. This concept of enhancing learning through inclusion of retrieval tasks is well established (Karpicke, 2008) Additionally, the 5-minute learning objective or concept-centric model, invites the educator to match up retrieval tasks (questions) to each 5-minute concept in a distributive pattern which further enhances learning over blocked questions at the end of a lecture (Szpunar, 2013; Kapp, 2015) The first iteration of this task based assessments require the student to select from a series of arrows that are placed in the 3-D space pointing at various answers/objects; this is analogous to a multiple choice question, except in 3-D space. Of the more than 20 power point lectures (usually hour long lectures) that have been converted into this instructional design methodology, we have yet to encounter one that is longer than 15 minutes of recorded content. We are consistently witnessing a 75-80% reduction in lecture length, this has been anecdotally witnessed in over 20 lectures in our lab. The efficacy of knowledge transfer, in addition to the observed significant reduction in lecture length, is the subject of an upcoming research study. The end result is a lecture with 3-5 concepts (5-minute learning objectives) complete with task-based assessment after each concept discussion. Inspecting the differences between a standard power point lecture and the converted VR lecture, we notice two elements. Expectedly, in a traditional power point format, when an expert discusses a complex 3D concept such as anterior cruciate ligament (ACL) insertion and orientation within the knee, multiple perspectives must be shown over multiple slides to indicate the lateral insertion angles, anterior/posterior orientations as well as superior and inferior aspects. Conversely, in the 3D virtual environment, the expert is able to show the anatomy in a single instance since the learner can investigate all of the angles at once around the 3D object. This dramatically decreases the time that is required by the educator reviewing each slide, freeing them to focus on the actual anatomy instead. However, unexpectedly, this 80% reduction was preserved even when we converted several power point lectures where 3D content was not included. What we have discovered, especially in technical training, as Tufte opined and General "Mad-dog" Mattis confirmed, "power point makes us stupid" (Tufte, 2006). Anyone who has be trained on how to deliver a slide-based lecture is taught to build the content to the lowest common denominator. This results in taking the educational content and adapting it to a linear delivery method and stretching it out so that not too much information is covered by any single slide. We observe that when educators just blindly take their existing slides and place them all around them in the VR space, the delivery of the content is much more organic where the information is conveyed much more efficiently. This is the same delivery method that is achieved in a 1-on-1 mentoring session, but because we have allowed power point and the lecture format to invade so many facets of training, we have forgotten how much more effective and efficient 1-on-1 training with physical artifacts can be. VR affords us the opportunity to capture this for scalable distribution in a digital media format.

Application of VR authoring tool

Since its deployment within the University, 229 individual VR lectures containing a range of 1 – 9 learning objectives each have been created targeting medical education, resident procedural training and technical training. 30 professors and 6 medical students (peer educators), without prior VR experience have successfully utilized the tool to create domain-specific VR lectures. When we review the evolution of content creation, we increase our insight into the impact of applying this VR-based instructional design methodology. Initially, educators were using the format to capture a single concept. Many clinical vignettes around case-specific pathologies were created in this manner. The next step was to convert existing power point lectures into this format. While this effort uncovered the 80% reduction pattern, the result is that we have many 10- to 15-minute lectures which are very well received, but students are left wanting more.

The current state of content creation has evolved from translating power point lectures into tackling broader topics in whole. For example, the entire third year medical student EKG lecture series (and nursing series) which totaled over 6 hours of lectures was captured into a single EKG lesson consisting of 18 learning objectives. The total recorded time was 75 minutes.
With this focused mindset of creating content to solve a broader lesson goal, we find that when starting from scratch, we are able to translate a weekend activity into less than an hour of VR content. A fetal echo screening seminar which taught screening guidelines to sonographers has traditionally been an entire Saturday event. When the content was taught in VR (including fetal 3D model with image overlays) the entire seminar was captured in 40 minutes.

Of particular interest is our effort at translating an entire Mass Casualty Incident (MCI) triage training event into VR. Similarly, this topic is typically taught through a didactic session lasting 2-4 hours, then is tested in an exercise format which can be a table-top exercise or a large-scale live exercise using actors, mannequins, or other simulated victims. The training is costly and time-consuming to plan and execute and consistent competency testing for triage skills is often lacking. In contrast, in VR the entire lecture and competency testing can be performed in less than an hour (Riech, 2018).

VR Authoring a use case: Mass Casualty Incident Triage Training

To investigate the effectiveness of using VR for MCI triage, a VR system was utilized that included the HTC Vive hardware (Xindian District, New Taipei City, Taiwan) and Enduvo software. This technology was used to create a mass casualty triage trainer within the VR environment. The educational objectives were to, a) understand core tasks of MCI triage, b) describe standard patient classifications of MCI triage, known as triage categories, and c) demonstrate rapid triage assessment of injured patients. In addition to the learning objectives, every attempt was made to eliminate technology bias for testing. The training program was geared to all levels of learners, including experienced first-responders and includes an overview of mass casualty principles and practice appropriate for first-time learners, including Fire Department Personnel, prehospital Emergency Medical Services personnel, and hospital staff. Learners must perform a VR tutorial prior to entering the MCI scenario. The tutorial includes orientation to the educational methodology in VR demonstrating training and assessment. The learning module components are:

i. Intro
ii. Triage principles
iii. Triage cards
iv. How to triage in MCI Scenario
v. Pre-test
vi. Final exam

In the first 5-minute learning objective module, the instructor, an experienced Emergency Physician, introduces themselves and describes the learning objectives for the module. They will ensure that the learner has completed the VR tutorial prior to moving to the next element. Within the VR environment, the instructor directs the learners to take advantage of the training program with best practices as they relate to the professor's style of teaching. They will provide a general outline of the learning objective sections describing the purpose of each module and direct the students to move through the sections in order, completing the task-based assessment at the end of each module. These task-based assessments are in the form of multiple-choice questions, with colored 3D arrows positioned around the 2D and 3D instructional artifacts. The learner chooses an answer by selecting an arrow, then checking their answer by pointing their handset at the progress bar. As shown on the left of the photo in Figure 1, correct answers are indicated by a check-mark and incorrect answers are indicated by an "X", giving the learner instant feedback.

In the next learning objective module, the instructor introduces a rapid process of evaluating patients and categorizing them by severity of injury, known as 'triage'. The instructor introduces triage principles and covers the relevant information surrounding a triage decision-based algorithm and triage cards, which are used to mark the patients once they are categorize. Starting with the ambulatory or "walking wounded" victims, the instructor describes each decision point covering the decision-making process through all categories from green to black. Also covered is the relative time it should take to work through the entire triage algorithm, with a goal of less than 30-60 seconds per victim. The instructor also introduces the triage cards and how they are employed in the field, describing how to tear off the appropriate triage category and place them on the victim. Task-based assessment will provide self-correction around the algorithm as well as triage cards, as learners can review material and attempt the question again if they have an incorrect answer (Figure 1).

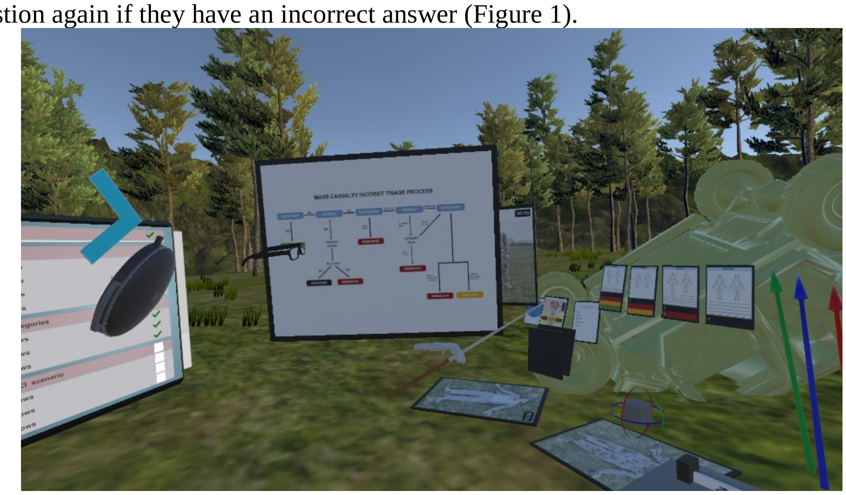

Figure 1

In the third 5-minute learning objective module, the instructor reviews the key vital signs which are assessed during the triage process. The instructor also links the vital signs and physical exam findings to the triage algorithm and demonstrates how they map to the appropriate triage card. The focus is on expedient decision making around the triage algorithm. Physical exam findings include presence or absence of a pulse (pulse is yes, or no), respiratory rate, perfusion, and mental status, which are incorporated into the video clips. Vital surrogates for the entire course will be covered in the pre-test section. Task-based assessment will provide self-correction around the vitals as they relate to the algorithm. Victims are presented to the learner in short cineloop videos, and appear with moulaged injuries such as open calvarium injury with exposed brain matter, lower extremity amputation, and burns. Similar moulaged victim videos are demonstrated in the training modules as well as the post-test.

In the fourth training module, the learner is given an overview on how to triage in MCI Scenario. In this 5- minute learning objective module, the instructor reviews the comprehensive actions that the learner will take, building on the components delivered in the previous learning objectives in a cognitive task progression manner. The instructor will emphasize the best-practice of moving through the pool of victims in a systematic manner to avoid overlooking victims, to maximize efficiency, and to avoid the pitfall of moving to victims perceived as the most critical first as well as pitfall of addressing the most vocal victims first. Task-based assessment will provide self-correction around the approach to an MCI scenario. Learners will specifically address the walking wounded first, and cover other knowledge points such as tracking the numbers of victims within each triage category to up-channel this information to Medical Control.

The fifth learning objective module is a pretest. In this module, the instructor prepares the learner for the final assessment by introducing the surrogates for vital signs (Figure 2). The goal is to minimize the limitations of the VR environment compared to a live victim. For example, in the videos, breathing is visualized, pulse is represented by an assistant tapping on the victim's wrist and adequate capillary refill is demonstrated by another assistant squeezing the victim's other hand. A single hand squeeze versus 2-hand squeeze of the victim's hand if inadequate capillary refill is to be demonstrated. Mental status is demonstrated by a purposeful head nod of the victim, and finally, cervical stability is performed by a third assistant bystander. The instructor also orients the learner to the looping mechanism of the videos, expressing that at least a 15- second focused observation should provide them with all of the information they need to triage the patient. The learner will also be oriented to the timer which is not tracked, but is utilized by the learner to establish the expectation that they must keep track of time. Two examples of patient triage are provided and the instructor walks through the triage algorithm. At this time, the test is demonstrated as well. The learner is encouraged to practice the expedient triage timing on the two pre-test items. A task-based assessment will provide self-correction around the triage card determination. The learner will be presented with 2 video patients and then is asked to assign a triage category based on the patient assessment elements they have just been taught. One victim example will be utilized from the description above and one example which is has not been shown so the user can get a sense of what will be expected in the testing scenario. The questions are asked with one victim prominently displayed on the ground and an arrow is over each of the triage cards with the correct card selected.

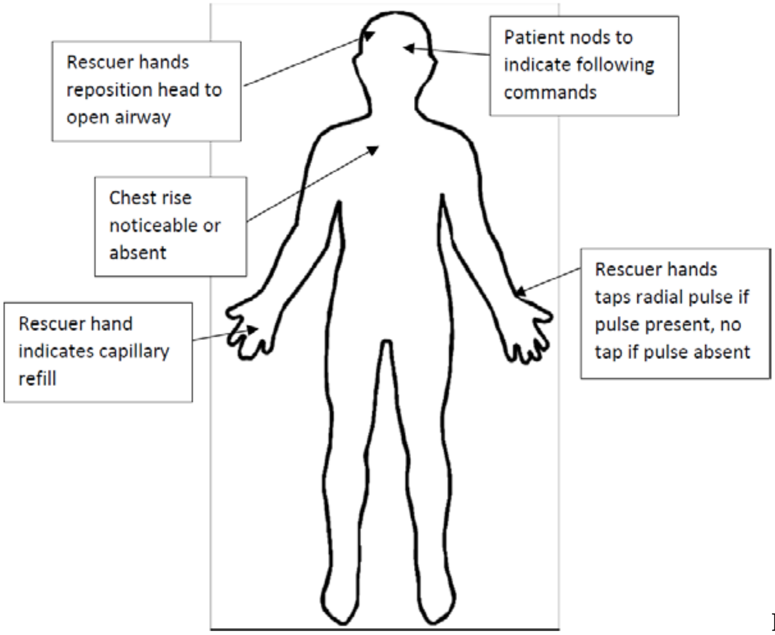

Figure 2

In the sixth and final learning objective, a post-test is given in the form of a Mass Casualty Incident with 12 moulaged victims. The learner will be instructed how to move through the test and that the overall timing begins when they select the first assessment task. The learner will enter the assessment battlefield scenario by selecting the first assessment task. The learner will encounter a single victim on the ground in front of them with the triage cards above the victim. A triage algorithm is visible for reference. The learner will rapidly assess the vitals according to the defined surrogates. They will then select the correct triage card and check their answer. Once correct, they will move to the next assessment task repeating the selection. The learner should run through the triage scenario in rapid succession until all 12 victims are triaged, as referenced with green checks in the task bar. The software will track the time it takes for the user to complete all 12 tasks. An incorrect triage category selection should not prompt randomly picking the other cards until the right answer is chosen. Rather, it should prompt the learner to exit and review the algorithm.

RESULTS

To test the MCI module, an initial pilot of 18 learners comprised of registered nurses and Emergency Medicine attending and resident physicians ranging in years of clinical experience from 0-31 years was performed. Participants completed the MCI module, then answered a 12-question survey to assess their prior experience level, comfort level with triage material before and after the VR experience, and comparison to conventional training modalities. In the pilot, 2 learners were not confident, 12 learners were somewhat confident and 4 were very confident in triage principles prior to the VR training. After program completion, 10 additional learners rated themselves as completely confident in triage principles. No learners who completed the training rated themselves as 'not confident' in their triage skills afterward (Figure 3). 66% of participants felt they could triage patients completely independently, and an additional 33% felt they could function independently with some supervision for safe practice or only intermittent direction. No learners felt they would require constant direction or hands-on guidance to perform triage after completing the course (Figure 4). Of 14 learners who previously underwent mass casualty triage training in a different setting (in-seat training, computer-based training, MCI exercise with live actors or mannequins, MCI with paper scenarios, or tabletop exercises), 3 learners rated the VR experience as comparable to their prior training, and 11 felt the VR experience better prepared them for MCI than their prior training program(s) (Figure 5). In terms of ease of use, 17 of the 18 learners rated the technology somewhat simple or very simple to use. Training time averaged 25 min compared to 2-4 hours in conventional training.

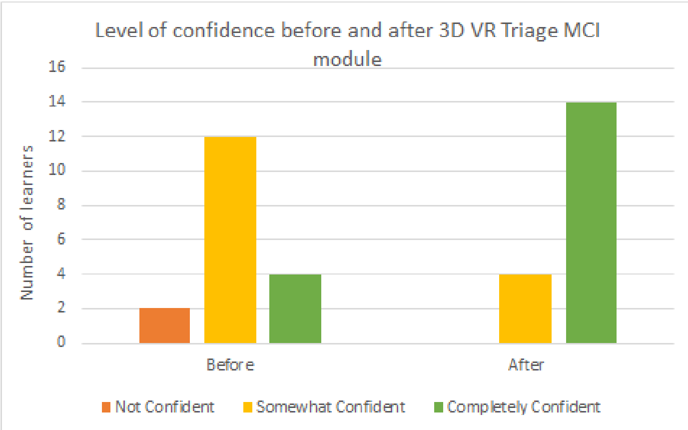

Figure3

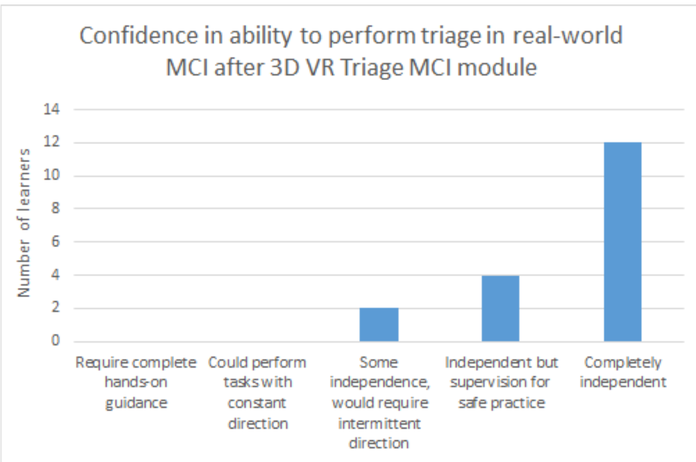

Figure 4

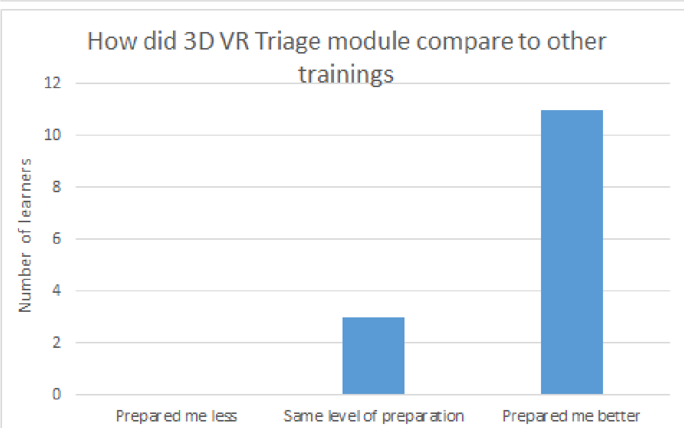

Figure 5

CONCLUSION

The value of a proper innovation pipeline within academic translational research centers cannot be overstated. This manuscript describes the research and development activities which occurred within the University of Illinois' ARCHES program through the filter of gated decision making. The purpose of capturing the VR authoring tool's creation narrative is to demonstrate how lean business model principles can accelerate academic research and development efforts toward sustainable solutions. Without gated, purposedriven, decision making, we would have likely created a custom VR lecture around Tetralogy of Fallot, however, the power of the process pivoted development efforts toward the described VR authoring tool solution. While initially focused on surgical planning, the process directed efforts toward communication and training. This unique format has opened many more opportunities for further research and development around a wide range of educational and training conundrums.

Training presents unique challenges in high-stakes environments like medicine, aviation and aircraft maintenance. Lessons learned from the evolution from 3D cardiac modeling to an immersive training environment are being adapted to military training. In both civilian and military settings, conventional training methods poorly replicate real-world scenarios, whether the topic is cardiac surgical planning, or combat training. Repetitive practice is expensive and time-intensive. This VR authoring tool creates more effective, efficient training in immersive educational format for scalable distribution of specific expertise. Future study initiatives are needed across the spectrum of military specialties.

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