出國報告（出國類別：進修）

跨領域醫用視覺化技術培植計畫

服務機關：國立臺灣大學醫學院附設醫院

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派赴國家：美國

出國期間：111 年 8 月 1 日至 113 年 6 月 30 日

報告日期：113 年 9 月 26 日

壹、摘要

每位學醫的人在成長過程中，一定都曾經仰賴某幅精妙的示意圖，從中理解複雜的生理機轉、人體結構，而我們卻鮮少思考過：這些精美的圖像究竟從何而來？

在人類醫學發展史上，其實一直有著這麼一群人，他們默默地將艱澀難懂的醫學知識消化，並翻譯成美觀又有助於理解的圖像，他們本身可能來自藝術圈、也可能同時有著深厚的醫學實力，而這群人便是「醫學繪圖師」（Medical illustrators）。

「醫學繪圖師」這個職業在臺灣相當少見，藝術界的朋友都不見得聽過；醫學繪圖有其獨特性，對創作者醫學知識涵養要求極高，畢竟與一般藝術品不同，醫學繪圖必須既飽含藝術價值又無科學謬誤，因為它不單供人欣賞，更背負著傳達醫學知識與教育的使命。

過去兩年，在臺大醫院及國科會的贊助下，張育瑄醫師在Johns Hopkins主修醫學視覺，這是一門已經有上百年歷史的學科，但在台灣從未正式發展。回顧兩年進修萬分充實，不但將基礎醫學重上過一次，也多學了非常多軟體和技巧工具，可以做到很多過去連想都不敢想像的事，這年頭要當醫學繪圖師已經不是只有會「畫畫」這麼簡單了。

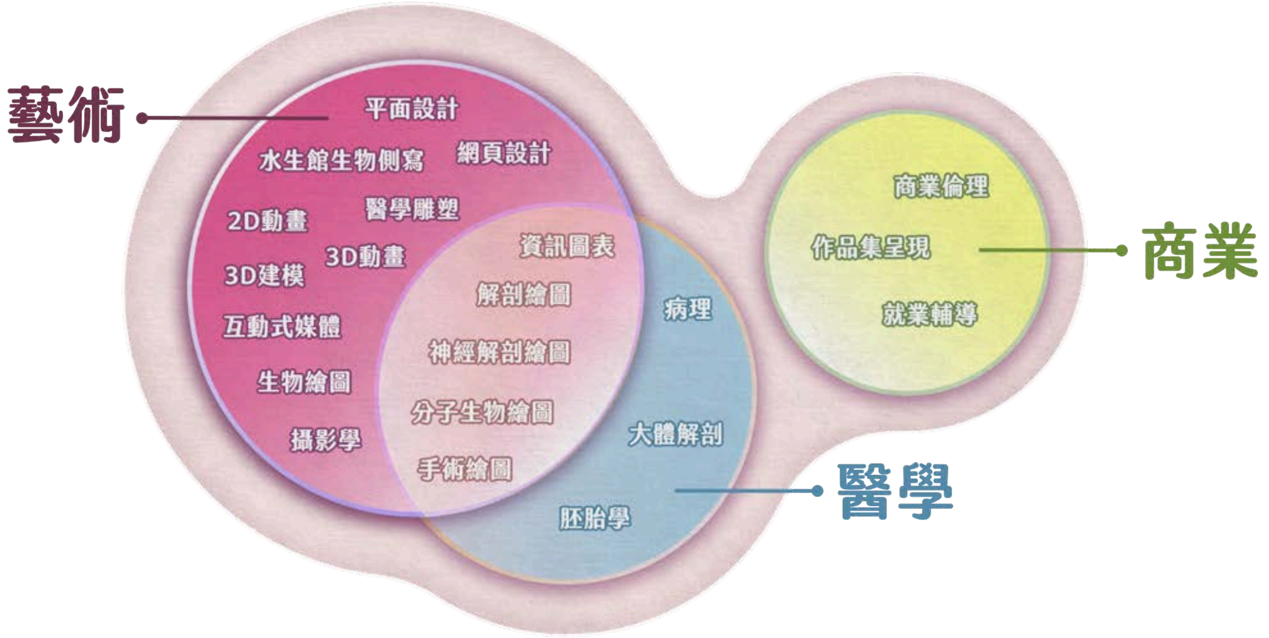
貳、目次

叁、本文

一、目的

「視覺」對於學習是非常重要的感官，許多研究支持相較於單純文字來說，加入視覺化元素對人類吸收知識有更高的效果。有鑑於此，將各式視覺化媒體融入醫學，已然成了近年來的國際趨勢，無論是在醫學教育、醫病溝通，抑或是醫學研究，我們都可以看到越來越多學者善用各種資源闡述完整的醫學故事。

醫學視覺化在歐美已是十分成熟的專業，每年更由學會舉辦年會及認證考試，核發專業醫學繪圖師執照(Certified Medical Illustrator， CMI)，全球目前經醫學繪圖師學會 (Association of Medical Illustrators; 成立於 1945 年) 認證之正統碩士等級培訓機構共 10 所 (分布於美國四所、加拿大一所、英國三所、荷蘭一所、法國一所)。其中以 Johns Hopkins 醫學院底下的 Art as Applied to Medicine 部門歷史最為悠久，成立於 1911 年，是全球第一所專門訓練「醫學視覺化」人才之機構，其為期兩年多元的訓練內容跨足三大領域（藝術、醫學、商業）課程：解剖繪圖、水生館生物側寫、攝影學、生物繪圖、刊物封面設計、醫學雕塑、資訊圖表、2D 動畫、3D 建模、3D 動畫、商業倫理、平面設計、互動式媒體、手術繪圖、分子生物繪圖...等。



而台灣乃至亞洲，至今都仍未發展出成熟的醫學視覺化市場或學術培育認證環境，相關部門之設立也只有林口長庚醫院與台北醫學大學，但負責人皆未接受正規醫學視覺訓練，靠的是自學經驗養成，缺乏完整系統性學習；因此在經錄取後，經臺大醫院於 2022 年核准，我遠赴該部門接受兩年扎實的「醫學視覺化」訓練，以期未來能在台灣貢獻所學。

二、過程

（一）緣起

　　大學時意外找到醫學繪圖師（Medical illustrator）這個職業時，才赫然發現原來我的興趣「視覺藝術」跟專業「醫學」，是真的可以走在一起的。這樣的職業在台灣很罕見，因為必須具備將醫學翻譯成圖像的能力，連藝術界的朋友都不見得聽過，一開始在諮詢的時候碰了不少壁，很少有人知道零基礎的我需要什麼樣的協助。

　　在北美目前只有五所由AMI (Association of Medical Illustrators，不是心臟病)認證的機構在做訓練，分別為：

- 📍Augusta University：MSMI degree (2 years)
- 📍University of Illinois at Chicago：M.S. degree (2 years)
- 📍Johns Hopkins University School of Medicine：M.A. degree (2 years)
- 📍University of Toronto：M.Sc.BMC degree (2 years)
- 📍Rochester Institute of Technology：MFA Medical Illustration (2 years)

　　認真研究他們的課綱會發現，每一間學校都因為自身條件而有其獨特的定位。有些科學的部分多一點、有的偏藝術、有的著重2D繪圖、有的偏重3D或動畫，課程比重至少呈現出三條光譜：

- 🔘生物——醫學
- 🔘醫學——藝術
- 🔘傳統2D——現代3D

　　這些研究所大都看似沒有特別高的入學要求，有的甚至不需要GRE，但它們的共同點是都需要繳交「**作品集**」，十分講求學生硬實力，一種「什麼都別廢話，先看看你畫工如何」的態度；因此想申請這些學校，從簡單暴力的作品集海選中脫穎而出，繪畫技巧必須磨練。畢竟醫學繪圖師跨足醫學與藝術界，不但在歐美工作機會多，收入在藝術界來說也十分穩定，根據AMI針對會員的例行性普查(2018；北美為主)，一般全職醫學插畫/動畫師年收入約落在新台幣200－500萬之間，入學競爭激烈可想而知，像Hopkins每年全球只釋出4-7位訓練名額。

（2022錄取作品集節錄）

（二）研究所申請

說起來對於藝術，不論是繪圖修圖到攝影，從小到大充其量我都只是個「業餘」愛好者。2018年升主治醫師前開始思考，從事了一輩子專到不能再專的專業，卻不知怎麼定義在一個領域到底要到什麼程度才算是專業，最後決定用最俗氣的目標：學位，讓自己從不專業翻身，也因此全球最早也最稀罕的Hopkins學程便成了我的努力目標，尤其對醫師來說，醫學繪圖是以**實用性**導向的，約翰斯・霍普金斯醫學院**醫學應用藝術部門**（Johns Hopkins School of Medicine, Department of Art as Applied to Medicine）開辦的**生醫繪圖碩士**（Medical & Biological Illustration program; MBI）背後有這麼強大的醫院和醫學院體系支持，無疑有著它的優勢。MBI在醫學 ⇌ 藝術的光譜上有著恰到好處的安排，更不用說這個獨特的部門最早由Max Brödel 成立於1911年，和醫學院有著無比深厚而長遠的連結和歷史底蘊。而這樣顯而易見的優勢意味著競爭激烈；如何在簡單暴力的作品集海選中脫穎而出變得相當重要，也對半路出家的我而言是最大的挑戰。

靠自己土法煉鋼無師自通肯定是不夠了，坊間巨X等商業機構又太過匠氣，且純操作技法指導非我所需，找了很多資料最後鎖定離醫院近的**赫綵電腦設計學院**，師資都是業界翹楚底蘊十足，上課著重創作而非炫技，幸運位置也剛好就在原本生活圈內，這一泡就是一年多，自摸自學了十幾年的Adobe Photoshop技巧、速度和製圖觀念，終於得到一點提升。

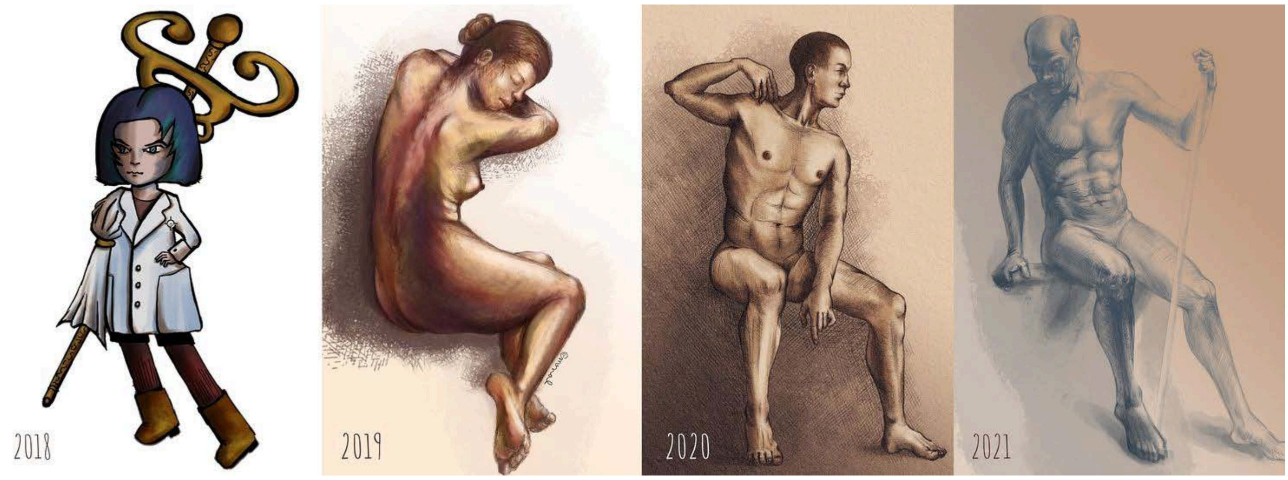
然而我看著目標大學的申請範例，滿滿學院風人物肌肉骨骼刻劃，和商業電繪比起來，怎麼看都是另一個世界的東西。一直以來都是學習電腦繪圖的我，對手繪其實十分抗拒且陌生，總覺得時間成本高，不能按復原鍵，又總需購置各種耗材，但在赫綵遲遲無法學習所謂傳統美術精神的情況下，抱著姑且一試的心情，報名了**師大進修推廣學院**的美術學程，素描、水彩、人物肖像一切從零開始。赫綵加師大，配上原本的臨床工作，從此開啟了崩潰半工半讀 人生。

就這樣，家裡客廳開始出現了畫架、畫布、一罐罐防水噴膠，塞爆的筆筒裡盡是筆刷、碳筆、彩色鉛筆，地板上各種精彩的斑駁和顏色，也開始習慣隨身攜帶畫本跟鉛筆，認識了師大很厲害的**林德平**老師，在他身上總算是看到了一個傳統科班出身學成歸國的藝術家風範，也認識了各種媒材的使用方式和常見技法。

（師大進修推廣學院的美術作業）

然而即便如此，還是害怕被問起：『作品集準備得怎麼樣了？』雖然覺得比起一開始大有進步，但還是總覺得缺了甚麼惴惴不安，覺得自己距離專業還有很大的距離，而且還是不知所謂的專業指的是甚麼？只是覺得漂亮就可以了嗎？這時開始覺得或許問題出在團體班上課，很難深入地和老師討論每一個作品或做比較針對性的練習，經過赫綵的介紹，因緣際會地認識了師大美術系畢業、留美動畫師**蔡翎繡**老師。

老師很嚴格，一筆一畫都不許我馬虎，我也的確欠訓練並需要各種觀念校正；老師自己也不斷進修，讓傳統科班出身的她，無論傳統手繪、電繪都精通，完全就是我需要的一盞明燈；在她的指導下，我漸漸開始知道一幅作品除了看得順眼之外，要追求的是什麼，作品裡也慢慢有了一點細節，可以放大看了，此時的我至少終於克服了不敢畫人體肖像的恐懼，人物與靜物不同，我們太熟悉，稍有不慎任誰都可以看出破綻。時至今日，看著當年自己作品三年來的蛻變，不禁感嘆半路出家的斜槓從來沒有想像中容易，投入的精神金錢時間難以計數，投緣的引路人更是可遇而不可求。



（2018至2021準備Hopkins作品集期間的作品蛻變）

很幸運地，後來在經過老師兩年的魔鬼訓練，終於通過了錄取率不到10%的作品集海選，進入面試的過程。雖然從小到大，每個醫師都會經過無數「面試」過關斬將，視訊跨國面試還是相對新鮮。最大的不同是「時間」上的長短，Hopkins馬拉松式面試分兩階段，總共要和教授們及系主任談上兩個小時。

這麼長時間的靈魂拷問，會讓人逐漸褪去偽裝，除了那些常見考古題：☑ 自我介紹 ☑ 為什麼選這間學校？☑ 為什麼對這個領域有興趣？☑ 對這個領域了解多少？☑ 自己最滿意/最不滿意的作品？☑ 談談自己過去的研究論文 ☑ 為什麼要選你？

比較不同的是多了許多針對個人**人格特質**的討論：☑覺得自己的優勢/劣勢是什麼？☑覺得自己在團體當中扮演的是什麼角色？☑覺得自己在同事/老師/學生眼中是什麼樣的人？☑ 人生當中最有成就感/最挫折的時候是什麼時候？☑ 壓力大的時候怎麼排解？☑ 轉行過程的心路歷程。

另外一個很大的不同是，考生也有許多反過來對考官提問的機會，而考官也會非常認真的回答；除了學校在挑選學生之外，學生也應該挑選最適合自己的學校。

（三）課程內容

兩年前的這個時候，學校傳來了未來一年的課程規劃，我沒有想到研究所的課可以排到這麼滿，不但每天週一到週五滿堂，寒暑假也各只有一個禮拜，因為現代醫學視覺化要學的內容實在太多，兩年必修就高達83學分。

Fall 2022

ME.120.708	Introduction to Design
ME.120.719	Anatomical Ilustration and Radiological Visualization
ME.120.720	Vector Illustration
ME.120.721	Raster Tone Illustration
ME.120.722	Introduction to 3D Modeling and Animation
ME.130.600	Scientific Foundations of Medicine-Human Anatomy

Spring 2023

ME.120.714	Editorial and Conceptual Illustration
ME.120.715	Biological Illustration
ME.120.716	Medical Sculpture
ME.120.717	Photography
ME.120.723	2D Animation
ME.120.727	Neuroanatomy for the Medical Illustrator
ME.120.728	3D Animation

Summer 2023

ME.120.712	Graphic Design
ME.120.726	Molecular and Cellular Visualization
ME.120.755	Business Practices for the Medical Illustrator
ME.120.756	Operating Room Sketching
ME.120.807	Design of Interactive Learning Expe

Fall 2023

ME.120.724	Web Animation, Interactivity and De
ME.120.750	Surgical Illustration
ME.120.754	Research and Thesis
ME.120.757	Scientific Communication
ME.300.713	Pathology for Graduate Students: Basic Mechanisms

Spring 2024

ME.120.754	Research and Thesis
ME.120.758	The Portfolio

（兩年課程內容）

三、心得

（一）醫學生教育

這個學程十分特別的一點，也可以說是亮點，便是其醫學課程是直接與Hopkins的醫學生一起上的，即使大體解剖也是跟著一起接受大小考試與實際操作，沒有任何減免或優待，這也使我親身體驗了這邊的高等醫學教育，如同在另一個平行宇宙將一部分的人生重新來過，感受真美式教育的洗禮。與多年前自己第一次上大體解剖最大的不同，是由於COVID的影響，一開學就有1/3左右的醫學生確診隔離中，一時間竟然出現大體老師快比學生還多的情況，每台大約只有1-2名學生，實際動手的機會大增。而大體老師多樣性也高出許多，畢竟比在台灣多了人種的差異性；大體老師浸泡方式應該也比多年前進步了，手感不再堅硬不已。

（解剖室的區域，與醫學生一起開大體的地方）

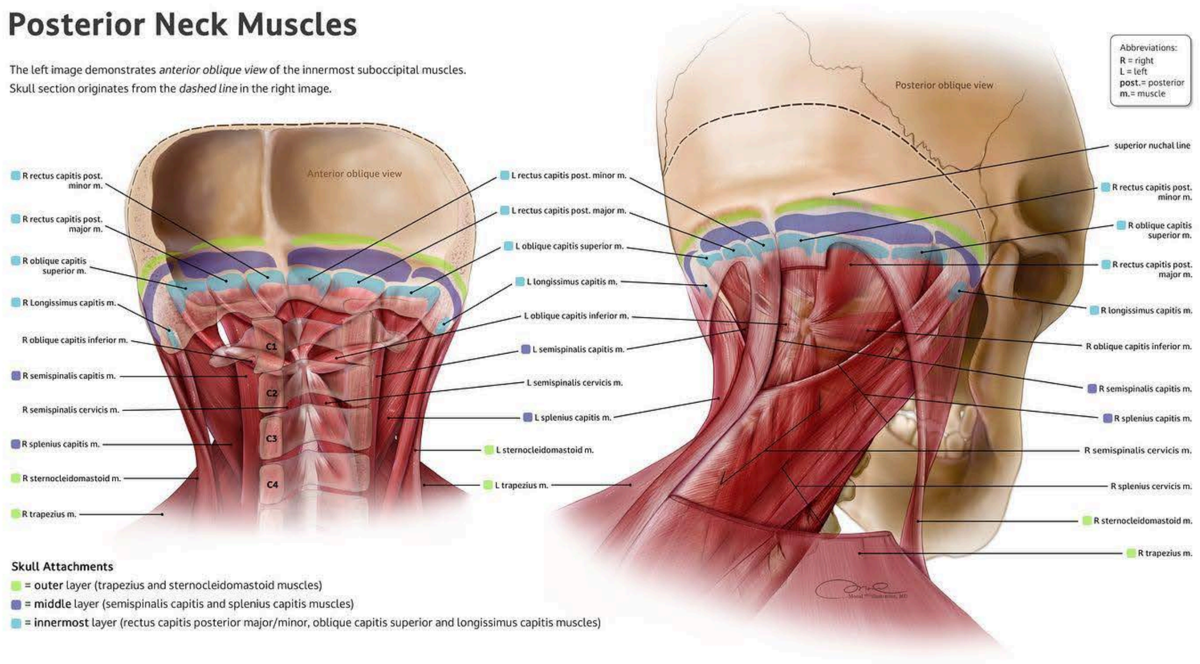
比較不能適應的是自由的教學方式，基本上是鼓勵學生自行探索，大堂課是模組形式，揉合了許多臨床的內容，資訊量非常龐大，Hopkins的課程也意外地十分注重『放射醫學影像』的部分，大概是課程佔比的20-30%左右，也強調希望學生從cross-section去理解人體內部的立體結構關係。我們每天實際坐在講堂中的時間，除了解剖外，大概只有1-2小時，其餘都是線上課程，完全鼓勵學生自行運用時間學習。就連大體跑考，也是自己找時間在家裡線上考，期限內線上收卷；不見學生洩題或把考題截圖，也沒有太刁鑽的題目，沒有考古題也就不需要一直推出更難的考題；相較於成績，大家似乎更在意是否真的有把重要的東西學起來，形成良好的正向回饋。

醫學系也變得十分重視學生的「心理健康」，不但計分由分數高低改為Pass/Fail減少同儕間比較心態，大考完下午也會舉辦各種身心放鬆的團體活動。

（二）藝術教育

在正式繪畫之前總有各種“發想”的過程，亞裔的背景給予了我一些不一樣的靈感，過程中同學眉飛色舞地分享著各種不同新知，得到許多收穫，吸收新知的熱情也奇妙地再度被點燃，我覺得自己從一個主治醫師被砍掉重練，一切好像又從零開始，但也期待見到被重新塑造的自己。標準流程包括：

1. Pitch ideas and research：發想與收集資料。
2. Thumbnailing：製作畫面縮圖。
3. Aquiring specimens：拿到觀察對象的實際生物樣本，習慣不用『想像』的，每個角度跟結構都必須有憑有據，和寫論文一樣。
4. Model setup：為了準確觀察主角生物和環境之間的互動與實際光影結構，盡可能製作一些場景模型，像我的專題就必須先用黏土決定最終想要的蟲體"姿勢"，再把塑膠毛毛蟲燒彎成那個角度。
5. Transfer sketches：把自己拍攝的模型、標本照片用描圖紙或是燈箱『描』下來後，畫成簡單素描，未來掃進電腦做更精細的雕琢。
6. Critique：有點類似在醫院的MM，作品完成時系上有教過我們、沒教過我們的教授，會全部聚集在一起，對大家的作品品頭論足，每個大型Project結束的必備活動，幸好大都沒有在醫院報告那種電力十足的劍拔奴張，而且可以收集到許多很棒的意見，因為很多教授都是第一次看到作品，第一眼的直覺有時候最準。



（三）維度上升，3D建模

除了2D平面繪圖之外，因為這個學程我開始學習3D建模，這對我來說是非常陌生的領域，脫離了Adobe的舒適圈，全新的軟體全新的思維模式。過去在臨床上比較常使用的是先天性心臟病的3D重組，一樣是3D，卻跟從無到有的建模一點關係都沒有，需要學習的東西非常多，教授們也不斷趕著進度，想把所有技巧在短時間內都教給我們。每天七八小時的3D課程，被自己轉得頭暈目眩，一整天下來都有嚴重的暈眩感。雖說如此，對於未來繪圖上也多了一樣強大的利器。

雖然目前國內的大宗需求仍然是2D的平面醫學繪圖，但其實3D做出來的靜態圖像，常可用於匯入平面繪圖，且可以加快修改的速度，已完成的醫材等物件在3D的世界可以任意旋

轉再利用，不單只在動畫領域發展，兩者相輔相成，相關的訓練對醫學繪圖師來說絕對還是有必要的；很多東西在臨床上用了很多年，從來沒有仔細觀察過它們的稜稜角角：

Monal Chang
3D models built for Central Venous Catheter Education Module, 2024
Maxon Cinema 4D, Redshift

（碩士論文中醫材3D建模成果）

（四）3D列印的應用：Clinical Anaplastology

有些患者或許因頭頸部癌症、意外創傷、或先天性疾病，在面部上出現了難以忽略的缺陷，而顏面又對一個人的外觀有著很大程度的影響；我們可能不會一眼注意到別人肢體上的缺陷，因為手腳義肢容易使用衣物遮擋，但面部的缺陷卻往往嚴重影響患者的社交及生活。

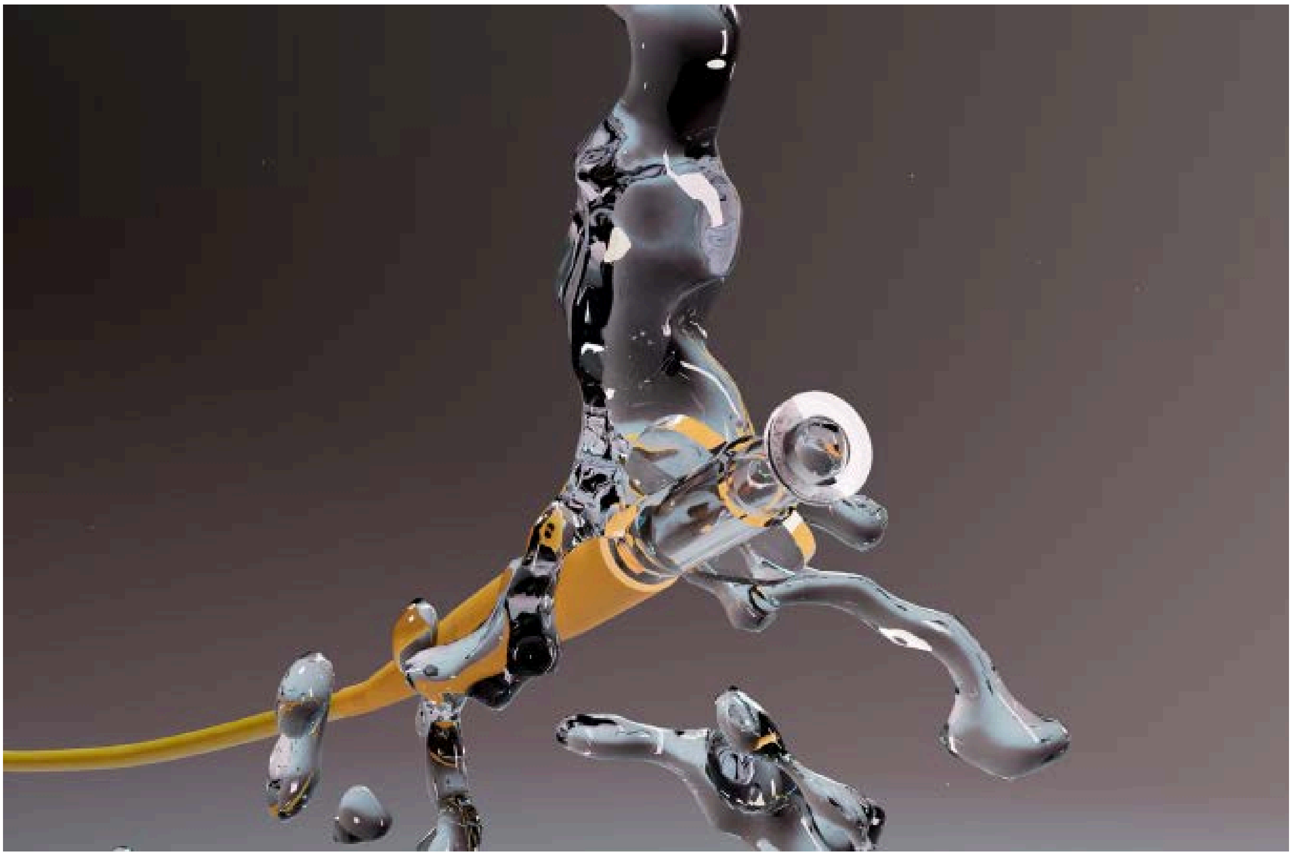
在我們科部底下就有這麼一個部門，專研如何製作出維妙維肖、渾然天成般的擬真面部義肢；在這個部門裡，有各種雕塑、製模和3D列印的相關器材，牆上掛滿擬真的人類眼睛鼻子耳朵，每天都會有患者前來諮詢客製，這也是為什麼我們科部一直以來的防疫措施都比照「臨床部門」辦理，因為有門診區。

身為隔壁棚的生醫繪圖碩班，我們也被分派見習，得以實際學習取模、建模、實物及數位雕塑的技巧；而他們從去年也悄悄開班，開始收自己的學生啦。當然這邊也不是只做面部的義肢，也有做手腳的部分，我更貢獻出我的雙腳，讓他們取模(Impression)，為一位天生缺少腳掌的13歲妹妹重建義肢，因為全科只有身為亞裔女子的我腳夠小，想到我的雙腳形狀將成為別人的義肢，感覺好特別啊！

（五）3D動畫與住院醫師教育

多年前在血管攝影室學習的時候，即使有強大學長們留下的各種珍貴紀錄也翻了書，但手做的東西，尤其是介入治療這種「眼見不著 手也摸不到」的微創術式，終究飽含了太多經驗和手感，和外科有很大的不同，對於甚麼都沒見過的初學者來說上手不易，更不好解釋給病人理解。去病房解釋病情時，常常要攜帶紙筆現場「畫」給病人及家屬看，企圖讓他們理解明天在血管攝影室會發生甚麼樣的事情、為什麼傷口可以這麼小。

即使我本身喜歡畫畫，但那時就夢想有一天，能不能看到更生動、針對初學者或是病患的介入治療相關教材，也因此在3D動畫專題自由選題時，我便毫不猶豫地提出了各式各樣針對年輕住院醫師的介入治療相關主題，很感謝教授們雖然對這些主題不如其他熟悉，也毅然決然地陪我踏上這趟旅程，對我百般信任。



（動態液體3D動畫成品）

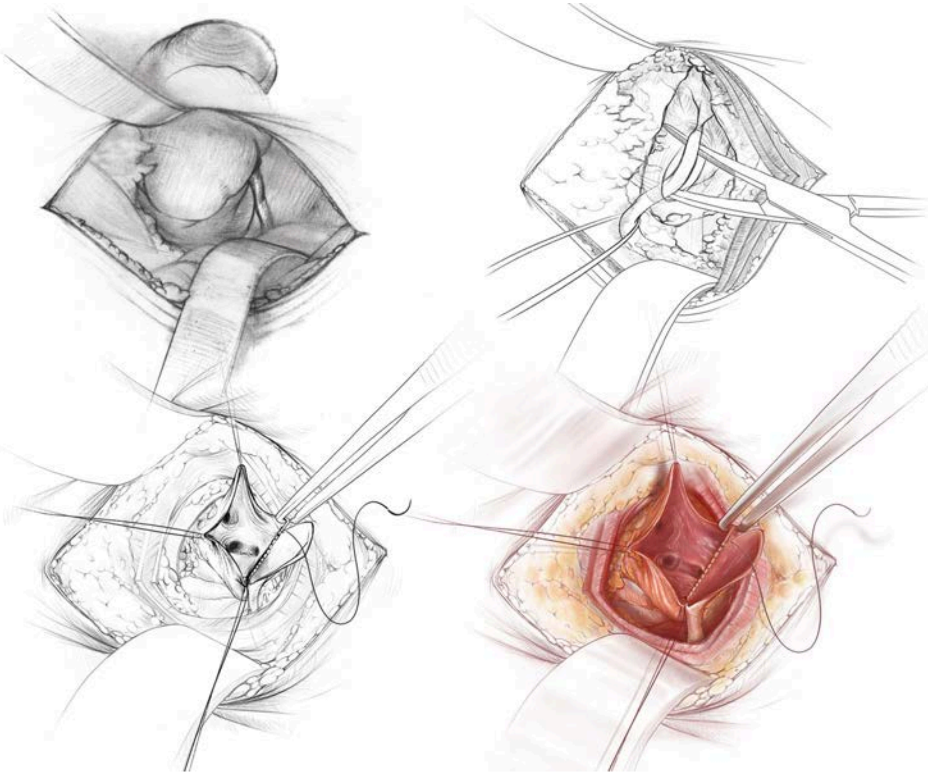
這個主題最大的困難點在於畫面中充滿各種「動態液體」，這對初學動畫者來說無疑是個挑戰，十分感謝教授們不厭其煩地跟我一起破解難題，連週末都不間斷地和我分享他們測試的結果，讓我真的學到很多很多。這個專題為期四個月，是每年碩一最龐大且艱鉅的任務；教授還被我盧到將「算圖農場」上線 (一個由二十幾台主機連線共同運作的電腦叢集)，用更快的算圖速度來應付各種動態液體，為了讓「農場」正常運作，教授幾乎週週加班，每當有同學向他反映「農場」又發生問題，他的表情都要比哭還難看。

3D動畫一般在業界會是團隊合作的結果，但為了學習，我們每個人都是「單人團隊」，一部動畫的完成，從最開始的腳本、分鏡，乃至最後製作字幕、與聲優合作，真的是非常耗時費心的過程，但我們終究是完成了。

（六）刀房見習，手術繪圖

刀房速寫就是在不染污的情況下，站在主刀醫師後方，快速用紙筆紀錄下開刀的每個步驟，沒有相機沒有攝影機也沒有橡皮擦，因為刀房不能有屑屑；身為繪圖圈新血的欠缺與不足漸漸開始顯露出來，畢竟高效的速寫和型態表現都很吃功底，而我一直以來都是目標明確地為了作品集為了作業而做的特殊訓練。

和所有刀房一樣，在刀房裡另一個挑戰是人際關係的建立，我有點作弊地用了醫師背景的優勢，但偶爾來不及自報家門的時候，也會領略各種人情冷暖和現實，更佩服同學們的不易與艱難，即使是在Hopkins，醫學繪圖師這個職業常常還是讓人感到陌生，大部分人並不知道拿著鉛筆圖紙站在那邊"塗鴉"的人，必須經歷過哪些訓練、其實跟醫學生上了十分類似的基礎醫學課程。



（七）交換學生

Hopkins和其他學校的學生一直以來都有交換學生的交流活動，近年來進行交流的對象主要是位於喬治亞州的**奧古斯塔大學醫學繪圖系** (Augusta University, Department of Medical Illustration)。今年輪到我們去喬治亞州，為期四天，從巴爾的摩出發開車要十個小時左右，在台灣真的很少有機會可以一口氣坐這麼久的車，全系租了四台車一路向南，最感人的是教授們全程陪我們公路旅行，還堅持當司機開了來回20小時的車！完全把學生們都當自己的小孩照顧。

奧古斯塔很重視3D立體相關課程，他們的成品許多都是3D或互動式影音作品，不過近年來Hopkins也越來越重視這塊；南部的風土民情很不一樣，體驗了一把微出國的感受，調

皮的教授們中途不忘帶大家偷拐去小景點玩耍，也許久沒有和六個女生睡同一間寢室，幸好我們這屆感情超好，能夠在他鄉遇到如此志同道合的一小群人真是本次留學最幸運的事。

(Hopkins與Augusta師生合影)

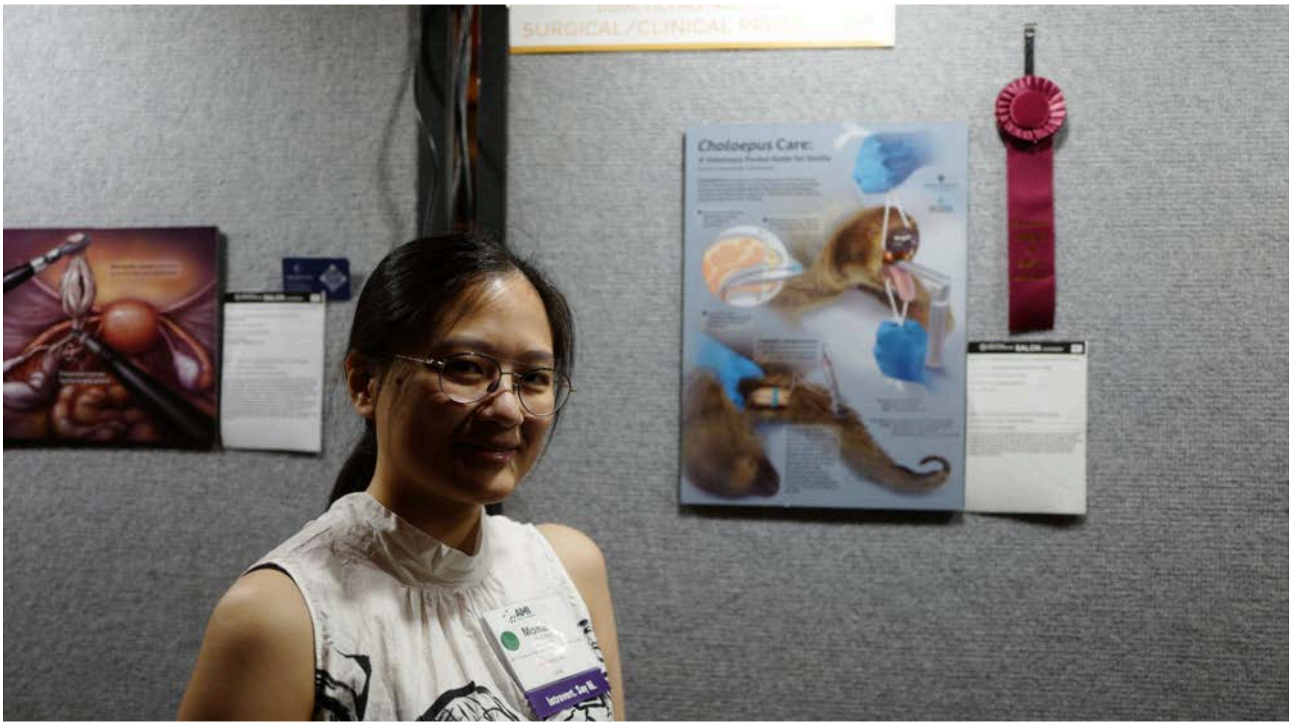
（八）醫學繪圖師年會

除了學校課程以外，每年Hopkins師生也會組團參與**醫學繪圖師年會**(Association of Medical Illustrator Annual)，每年年會都針對參展（Salon）的作品頒發獎項，養兵千日就用在這時。醫學繪圖師的盛會，與一般以醫師為主的醫學會最大的不同在於講者本質的「多樣性」，幾場講座下來，講師集合了畫家、動畫師、解剖學教授、企業家、律師、軍方、醫師等各式專業人才，台下化身海綿享受被各種嶄新觀點沖刷撞擊的過程。醫學視覺是個很獨特的社群，在面對醫學、討論軟體操作時展現專家氣質，卻同時有著藝術家放蕩不羈的靈魂。

意外收穫是在中場休息和晚餐時認識各方好手，每個最後來到這裡的與會者背後都有著驚人的人生經歷，大家也十分樂於與「陌生人」分享自己是怎麼一步一步走到這裡，即便可能只是在排酒吧時意外對到眼；**樂於分享**與**接受新知**算是這個社群很大的特色，而我也正學習放下亞洲人的矜持並在去廁所的路上隨時準備與別人說嗨。

令我意外的是遇到了不少比我年輕的女醫師，在這個場合，當人們發現你是MD時，會友善的幫你與其他MD介紹認識，她們多數走著與我完全相反的職業路線，有的先從研究所畢業後毅然踏上醫路、有的是在醫學系gap year時選擇完成研究所學業、還有人在歐洲拿到醫師執照、美洲拿到醫學繪圖師執照後，又正在準備亞洲家鄉的醫師執照；她們的勇氣讓我感嘆自己實在太晚才受到啟發。過去的自己總是容易在找到舒適圈後默默決定就此生根、喜歡計較做某件事情是否划算，殊不知人生最浪費的時間往往是躊躇不前的時候；不論是在繪畫上精雕細琢某個可能放大後根本看不到的細節，抑或是探索各種專業領域挑戰人生的可能性，從這些人身上我看到了各種「不怕浪費時間的勇氣」。

（2022年會現場）



（2023年會張育瑄作品獲頒**學生組術式類，二等獎**）

（九）戶外教學

1. Andrew Wyeth Studio
   我們系的戶外教學不意外的當然是帶去美術館，這次造訪的是位於費城的「Brandywine Museum of Art」以及「Andrew Wyeth故居工作室」。Andrew Wyeth一家祖孫三代都是非常厲害的畫家，是美國20世紀末的知名藝術家，主攻水彩、蛋彩畫（興盛於文藝復興時期，一種將蛋液加入顏料的作畫方式。

Wyeth的作品多取材自生活非常寫實，也因此是我們系重要的學習對象之一。他作畫的習慣是一定要與作畫對象，不管是人或物，長時間面對面相處，而不只是看著照片，照片有時候還是缺少實體的靈氣和神韻，我們的訓練過程也算是傳承這樣的精神。Wyeth在費城1940-2009期間的工作室被非常完整地保存了下來，能夠身歷其境的踏足藝術家工作的地方是非常棒的經驗，看他如何布置窗戶控制採光、擺放工具、嚴格挑選雞蛋 (一定要某間超市的特大級白殼雞蛋才行) 而且他的工作室裡永遠都有一面非常大的鏡子，觀察作品的"鏡像"可以抓到一些原本看不到的細節。

2. 美軍基地

北美醫學繪圖師和美軍的連結早至南北戰爭時期就開始了，戰爭、傳染病帶來了許多醫學實錄的需求；到了現代，軍用醫學視覺化的運用已經拓展至各式戰地模擬訓練，包括擬真的戰地檢傷、創傷處置、緊急救護，克服以往軍醫在正常情況下難以重現的擬真戰地訓練，甚至包括軍犬的急救模擬！當日最高潮是來到Wide Area Virtual Environment (WAVE)，基本上就是一個巨型虛擬場景，包括270度的大型投影，配上各

種聲光效果、甚至是氣味、假血(還有口味分辨有毒無毒)，彷彿置身槍林彈雨或是直升機上 (頭真的會暈)，在這種環境下考ACLS十分刺激。

3. 國家地理學會

說到黃色的長方型框框，不知道大部分人會想到什麼？這次的戶外教學來到『國家地理學會』(National Geographic Society) 位於華盛頓特區的總部！這間已經存在超過135年的教育組織，不管是電視頻道還是雜誌，應該都是家喻戶曉的重要人類歷史/科學教育資源，美國人習慣親切的叫它Nat Geo。大家都知道國家地理頻道/雜誌有厲害的攝影師，但其實它背後也有著強大的科學藝術家，負責把這些視覺呈現統整拼裝，甚至重新繪製；而我們這次的嚮導是總部的資深藝術總監Fernando Gomez Baptista，帶我們一窺國家地理雜誌背後的精采製作過程。國家地理的科學視覺化製作工法繁瑣而精緻，充滿職人等級的精神，在實際繪製之前，不但繪圖師要飛到當地考察，所有的動植物、建築結構、場景等都會用黏土、厚紙板或是保麗龍先製作成「模型」，用壓克力顏料上色後打光，最後才是實際繪製的流程；因為Fernando說身為科學藝術家，「只要眼睛看得到，就一定畫得出來」。Fernando帶我們參觀了他們像動畫攝影棚的工作室，這些「模型」精緻而擬真，根本本身就是藝術品了，很難想像它們只是用來觀察光影結構的「草稿」！也可以解釋為什麼國家地理的圖片們，有時候精緻到可能大家都以為是照片，但又呈現出自然界難以捕捉到的瞬間，其實那些都是用畫的！近年來，Fernando的團隊也把這些模型應用到「定格動畫」中，製作出風格獨特又平易近人的科學小短片。


4. New York Academy of Medicine

New York Academy of Medicine (NYAM)的館員Arlene Shaner讓我們來紐約時可以拜訪學會的醫學罕見珍本書庫，Hopkins的Welch Medical Library其實也有自己的醫學罕見藏書，可以不戴手套親手翻閱16世紀留下來的醫學圖譜，感覺非常神奇！Arlene對所有古老醫學圖書的歷史，從有著三國語言Andreas Vesalius的《論人體構造七卷 De Humani Corporis Fabrica Libri Septem》開始，全部都能如數家珍；學醫時一直以為Netter是唯一強大的醫學圖譜，真是大錯特錯！就連當年牛頓的宿敵Robert Hook都對科學繪圖做出了相當貢獻。最特別的是17世紀Govard Bidloo留下來的《Anatomia Humani Corporis》，雖然Arlene說Bidloo做人失敗到過世時沒人想為他寫悼詞，Bidloo圖譜的特色是細膩但去人格化，盡量把重點擺在眼前的器官上，當時的繪圖師連現場的蒼蠅都畫到畫面裡去，相當寫實有趣；當年的醫學繪圖師們要克服宗教、社會輿論及大體保存技術的不易，留下這些珍貴紀錄，推進著人類醫學的前進，是十分艱鉅的任務。

（十）食衣住行

巴爾的摩(Baltimore)市區的治安稍微讓人皺眉，而沒有甚麼比平安學成歸國重要，尋找租屋成了最重要的事，不想在人生地不熟、治安又不大好的城市拖著行李到處看房，幸好後疫情時代大部分建案都提供「線上看房」的服務；以往住國外時都是傍「超市」而居，這次也不例外，經推薦在碼頭邊（Inner Harbor）的超市附近找了個安全的落腳處。不過要搞懂「房租」的部分實在費了番功夫，這種統一管理的集合式住宅房租就像股票一樣高高低低，

隨著大環境改變，每天都可能跳出不同的金額可供點選，下好離手；雖然房租可能隨著入住日接近而逐漸下降，但也可能因此錯過想要的房型大小，過程真是各種磨礪心志。

巴爾的摩一入夜整個城市彷彿進入了另一個狀態；夜裡的巴爾的摩警察跟住院醫師一樣忙碌，我住的樓層比較高，每晚俯瞰這座城市，處處可見紅藍閃爍的警燈伴隨此起彼落的鳴笛。住了一陣子雖然沒有像當初想像的一樣，路上行人隨時一言不合拔槍相向，但大家都知道在某些時候，甚至任何時候都不要徒步踏足某些區域，而那些區域很不幸地就像蛋白一樣包裹著Hopkins的所有主要院區。為了讓大家平安上班上課，除了校車，原本校方每個月發放給每名學生約300 USD的計程車費，卻突然在我們這一屆喊卡，由校方統一安排Blue Jay Shuttles接送，我們這梯也就成了第一批實驗小白鼠。

（Hopkins體系內師生、醫院員工可使用的Blue Jay Shuttle）

Blue Jay Shuttle是一種共乘機制，在醫院方圓約1-1.5km的距離內，學生叫車後，由調度員派發小型廂型車輪流接送大家，時間限定早上九點前與下午五點半之後。其實不趕時間的話，這東繞西繞的共乘帶我去了很多原本不會經過的地方，反而可以好好看一看這座城市；但果不其然在其他科系相繼開學之後，這個系統就爆炸了；住在相對安全小區的我算是在這個範圍內的最邊緣，雖然看起來與醫院的直線距離不遠，但往往都是第一個上車最後一個下車，最高等待時間曾經高達50分鐘；至於自己開車的部分，在聽聞同學各種路邊停車，車窗被砸被偷、在停車場被搶劫的故事之後，就暫時沒有考慮了。

四、建議事項

遠赴美國接受兩年扎實的「醫學視覺化」訓練學成歸來，除在臺大醫院開辦展覽以外，也預備在臺大醫院申請成立具備可自產及監製醫學視覺化作品之部門「臺大醫學視覺化中心」，貢獻這兩年所見所學。

肆、附錄：畢業論文

DEVELOPMENT OF A SUSTAINABLE SERIOUS GAME TO SUPPORT CENTRAL VENOUS CATHETER PLACEMENT EDUCATION

by
Monal (Yu-Hsuan) Chang

A thesis submitted to Johns Hopkins University
in conformity with the requirements for the degree of
Master of Arts.

Baltimore, Maryland
March, 2024

Abstract

The central venous catheter kit, containing over 10 items, can overwhelm first-time trainees. To address this, we're creating a learning experience that merges an online module with 3D-printed models for medical trainees to start identifying these items in the kit before they learn how to perform the procedure.

The study comprised three primary phases. Phase I involved observing experienced medical professionals as they prepared a central venous catheter kit. This observation aimed to provide insights for designing a serious game tailored for trainees, which constituted Phase II. The serious game was developed by transforming medical instruments into 3D assets, creating an online interactive platform, and producing physical game pieces through 3D printing. In Phase III, both trainees and experts were engaged in a usability test to assess the effectiveness and user experience of the developed serious game.

Observing the experts underscored the significance of grouping instruments by function rather than assigning them fixed locations, emphasizing the need to adapt their organization to various environments encountered. For 3D-printed game pieces, all users preferred the 3D-printed miniature replicas over the semi-3D cards despite greater durability of the latter. All users firmly support introducing trainees to this serious game prior to working with the actual kits.

By leveraging 3D modeling, printing, animation, programming, web design, and AI, we

developed an integrated educational tool that will aid medical practitioners in optimizing the organization of sterile instruments for central venous catheter placement. Our experience lays the groundwork for future advancements in serious games for diverse medical procedures.

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Acknowledgements

I extend my deepest gratitude to the individuals whose expertise, guidance, and support were instrumental in the completion of this thesis project. ***Geoffrey Tobias Miller***, the Director of Johns Hopkins Simulation Center, served as my thesis preceptor, offering invaluable insights and resources that laid the foundation for the project's conception. His dedication to advancing medical education through simulation was pivotal in shaping the direction of this work. ***Jennifer Elizabeth Fairman***, faculty at Johns Hopkins Art as Applied to Medicine, provided invaluable guidance in ensuring the coherence and visual appeal of the project. Her expertise in art and design elevated the presentation of complex concepts within the thesis.

I am indebted to ***Micheal A. Rosen***, professor of Anesthesiology and Critical Care Medicine, for his assistance in navigating the institutional review board process and conducting eye-tracking data analysis. His expertise in research methodology and human factors psychology significantly enriched the project. Lastly, I would like to express my gratitude to ***Jeffrey Huang Day***, for his support and guidance in mastering Unity software and overcoming technical challenges in the development of the interactive module. His expertise and mentorship were instrumental in bringing the project to fruition.

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Introduction

A central venous catheter (CVC) is an indwelling large-bore catheter strategically placed within a major central vein, facilitating various medical interventions and therapies. The proficiency to adeptly establish a CVC stands as a vital skill set for modern physicians and is integral to the management of complex medical cases. (Kolikof et al., 2023)

Typically, a standard CVC kit comprises a repertoire of over ten distinct items, the exact number varying by the manufacturer (Kolikof et al., 2023), which can present a significant logistical challenge for users tasked with maintaining a sterile field by the bedside at the same time. Despite an extensive body of literature addressing the refinement and assessment of the learning curve for CVC placement for medical trainees (Baribeau et al., 2022; H.-E. Chen et al., 2020; Nguyen et al., 2014; Peltan et al., 2015; Rivera et al., 2023; Thomas et al., 2013; Wittler et al., 2016), a notable void exists in studies focusing on the arrangement of instruments in a CVC kit preceding the actual procedure, which may hold equal importance in ensuring successful placement. Often, instructional materials vaguely advise to "*assemble necessary equipments*" without detailing the specific tools required or, crucially, how to organize these tools effectively for the procedure.

Traditional healthcare education often leads to high costs and significant waste - up to 300 pounds of plastic per simulation center each semester. (Bathish et al., 2022) This issue is particularly pertinent to CVC kits, considering they cost about USD 300 each. Despite the reusability of some components, recycling challenges persist. Our study aims to cut waste and costs while boosting deliberate, repeated practice, crucial for effective learning. (Issenberg et al., 2005)

Serious games, beyond mere entertainment, are educational or behavior-modifying tools (Krishnamurthy et al., 2022). A systematic review on medical education shows clear benefits of incorporating serious games alongside traditional teaching (Gorbanev et al., 2018). Our study is the first of its kind that leverages eco-friendly serious games to teach medical trainees about (1) **CVC kit contents**, (2) **instrument setup optimization**, and (3) **instrument-procedure associations**, before actual CVC placement.

Materials and Methods

The study received exemption approval from the Office of Human Subjects Research Institutional Review Boards at Johns Hopkins, indicating it does not impact patient safety or clinical outcomes. The protocol rigorously followed the ethical standards outlined in the 1975 Declaration of Helsinki and was executed in a single tertiary referral hospital.

There were three major phases in our study: Phase I consisted of observing how experienced medical professionals prepare a CVC kit to inform game design in Phase II. After building the serious game in Phase II, the experts were recruited again to participate in a usability test in Phase III.

Phase I

Experts were defined as experienced physicians recruited from various departments in a tertiary medical center who had a minimum of five years of clinical experience. Prior to the observation, participants were provided with an online demographic survey to complete using Qualtrics (**Appendix 1**).

These experts were invited to the Simulation Center to perform CVC placements on manikins while wearing an eye-tracker. They were requested to prepare the CVC kit first and subsequently perform a CVC placement in the internal jugular vein. To evaluate their performances realistically, we gave them the actual CVC kits from the institution to eliminate potential confusion. Eye movements were monitored using a binocular eye tracking system (Tobii Pro Glasses 3) during the sessions. The eye-tracker underwent calibration after each use and was adjusted to suit individual eye prescriptions.

Once the experts completed the preparation of the kit, we briefly interrupted them for a quick discussion about their rationale for the arrangements on the table (**Appendix 2**). This discussion was audio-recorded by the eye-tracker to facilitate more accurate notetaking. The arrangements on the table were documented by taking top-down snapshots.

Once the observation resumed, we timed the Expert Group to determine the duration required to complete the CVC placement with their arrangement. Simultaneously, we documented their eye searching duration and visual gaze trajectory using the eye-tracker.

Phase II

Based off of experts' instrument arrangements, game building commences. We combined virtual online interactives with a 3D printed board game into a hybrid teaching tool. 3D printed game pieces offer a tactile dimension to the learning process, enhancing contextual memory through multisensory experiences (S. Chen et al., 2021), while an online virtual interactive improves accessibility and distribution of the educational materials.

Using WordPress, we built an online webpage that provides easy access to anyone with an internet connection. Upon visiting the site, users are greeted with a stop motion animation showcasing the real kit and its contents (unboxing video: https://vimeo.com/880766042) with links to biographies of the game developers. (**Figure 1**) Following this introduction, users are directed to an interactive Instrument List. This feature presents detailed information about each instrument, including their intended use and significance, enhancing the educational value of the game.

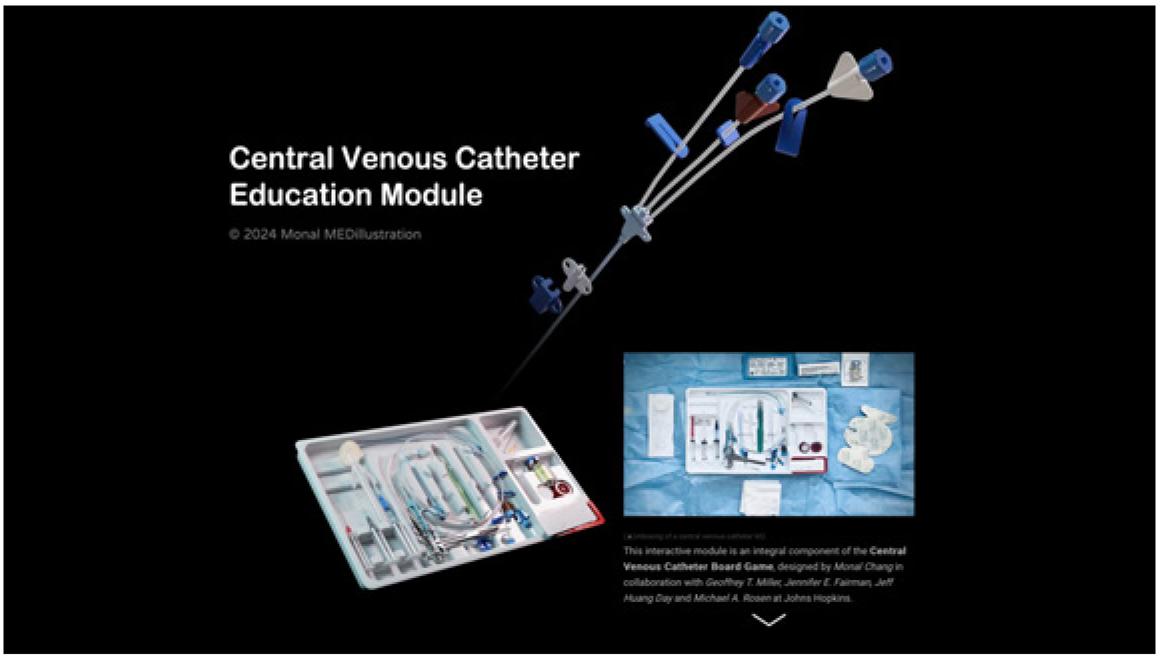

Figure 1. The homepage of the website hosting the online virtual modules. Not all text intended to be read.

Building Instrument 3D Models in Maxon Cinema 4D

For the effective development of our hybrid board game, it was necessary to create 3D models of all instruments in the CVC kit, as shown in **Figure 2**. These geometries were crafted from scratch utilizing tools such as Spline, Extrude, *Loft*, *Lathe*, *Sweep*, *Boole*, and *Volume Builder*, available in *Maxon Cinema 4D 2024.1* (C4D). *Redshift* rendering was employed for the material and lighting.

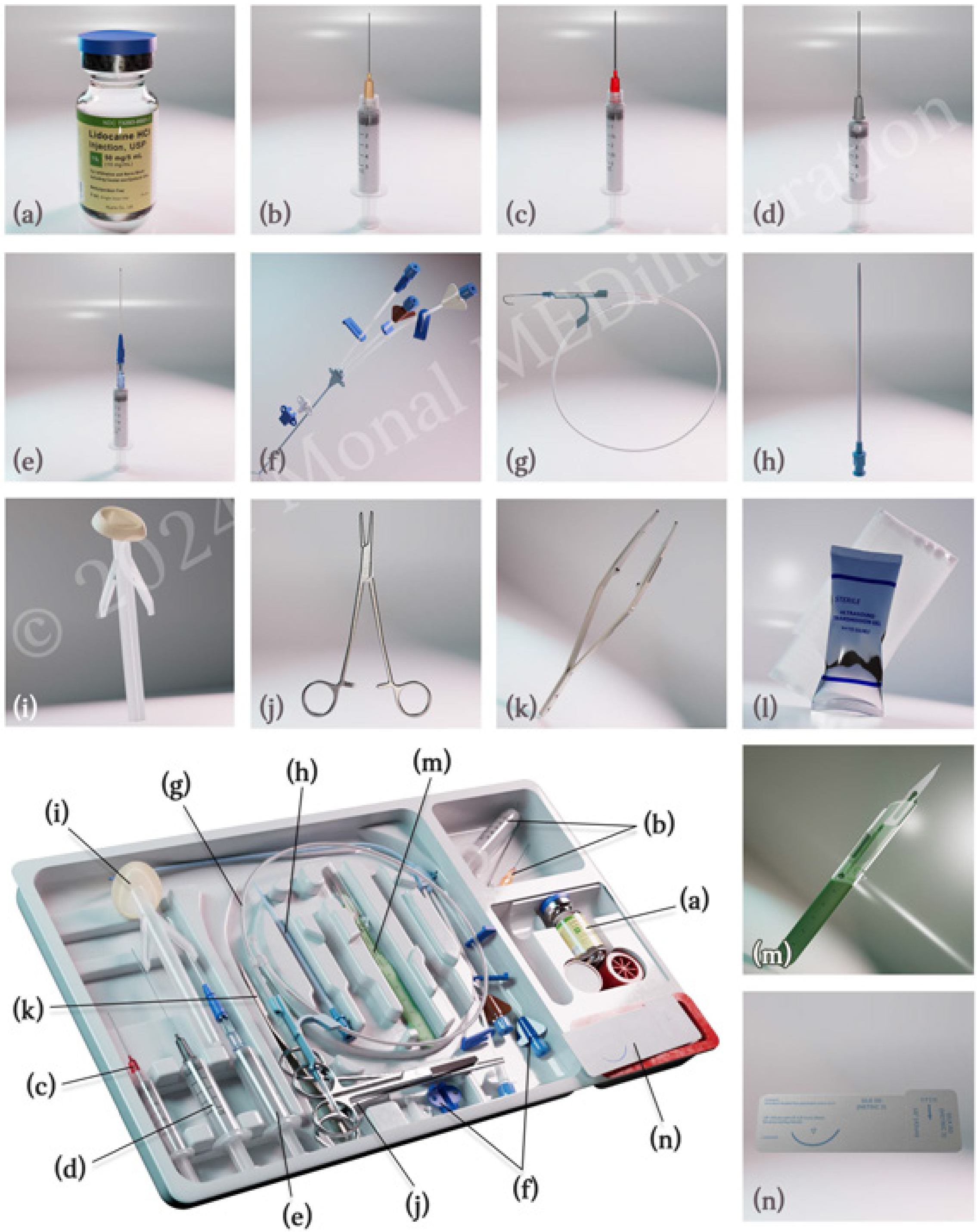

Figure 2. Rendered snapshots of various instruments from the central venous catheter kit, meticulously modeled and visualized utilizing Maxon Cinema 4D in conjunction with the Redshift rendering engine. (a) Lidocaine bottle (b) Injection needle and 5cc syringe (c) Blunt fill needle and 3cc syringe (d) Introducer needle and 5cc syringe (e) Cath-over needle and 5cc syringe (f) 3-Lumen Catheter (g) Guidewire (h) Dilator (i) ChloraPrep (j) Needle holder (k) Forceps (l) Echo gel pack and probe cover (m) Scalpel (n) Suture needle (o) CVC kit tray

The background reference image function in C4D was utilized to verify the accuracy of the geometries, ensuring they closely resemble the actual instruments. To use this function, one can either directly drag and drop the reference photo onto the working area or press *Shift+V* while clicking the empty space in the working area to access the "Back" tab in the Viewport Attributes to adjust the reference image.

Building the Online Instrument List in Unity

Using the prepared 3D models, we made 45-frame short clips in C4D and exported them as mp4s. Additionally, we rendered transparent background PNGs of each instrument. These assets were subsequently imported into the *Unity 2023.2.2f1* 2D suite. Opting for the 2D suite to develop the interactive elements was driven by the consideration that users do not require the ability to rotate the instruments in 3D space. Additionally, utilizing C4D enables the creation of more visually appealing assets with greater efficiency, streamlining the production.

For the **Instrument List**, we established a distinct scene for each instrument. In these scenes, the 45-frame clip was set to play in the background while the button corresponding to the specific instrument was highlighted, and its associated explainer text was displayed (**Figure 3a**). The rest of the buttons link to other instrument scenes using a SceneTransition script (**Figure 3b**, **Appendix 3**), playing a short sound effect when clicked. We also implemented a *CursorChanger* script, which alters the cursor to a hand icon when it hovers over these buttons, serving as an intuitive indicator of interactivity:

```
using UnityEngine;
using UnityEngine.EventSystems;

public class CursorChanger : MonoBehaviour, IPointerEnterHandler, IPointerExitHandler
{
    public Texture2D cursorTexture;
    public void OnPointerEnter(PointerEventData eventData)

    {
        Cursor.SetCursor(cursorTexture, Vector2.zero, CursorMode.Auto);
    }

    public void OnPointerExit(PointerEventData eventData)

    {
        Cursor.SetCursor(null, Vector2.zero, CursorMode.Auto);
    }
}
```

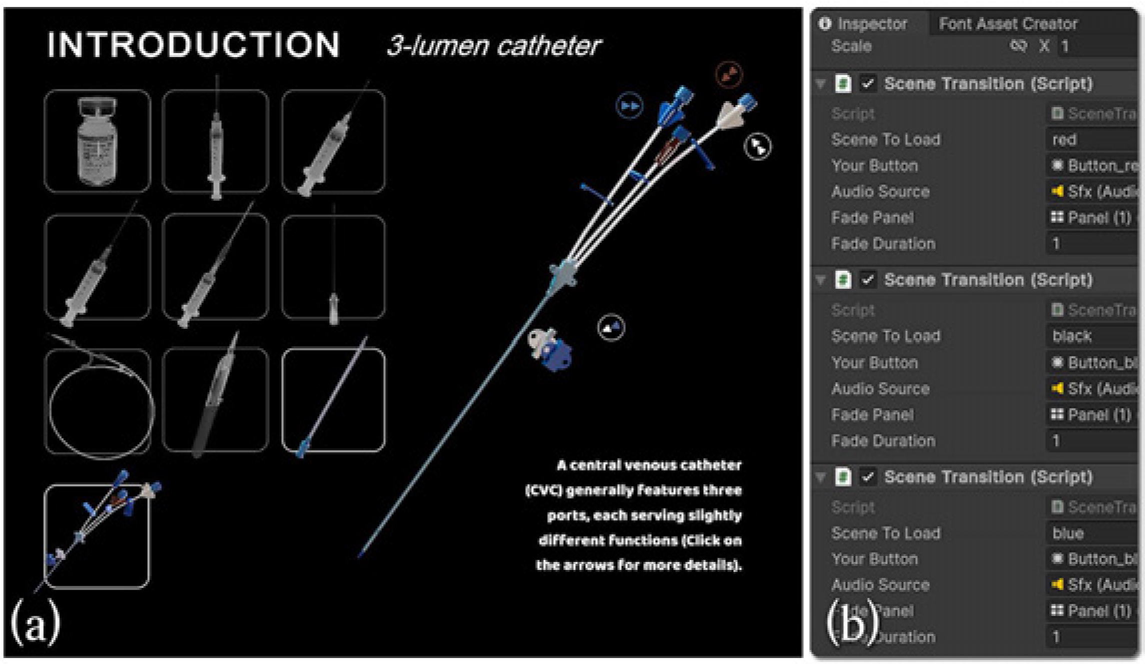

Figure 3. (a) An inventory page provides users with detailed information on specific instruments included in the central venous catheter kit. (b) The Inspector view in Unity demonstrates how each instrument's introductory page is interconnected, guiding users to its respective scenes where explanatory texts and a 45-frame short clip are showcased.

For the 45-frame clips to play smoothly in the background when prompted, we used VideoPlayers in Unity. This requires several steps to accomplish:

Step 1: Add a **RawImage** to Your UI

1. Add a RawImage: Right-click on the Canvas object, select UI, and then RawImage. This creates a new RawImage object as a child of the canvas.

2. Adjust the RawImage: Select the RawImage GameObject and adjust its size and position in the scene to fit the space the clips were to be displayed.

Step 2: Create a **Render Texture** to render the video onto the RawImage.

1. Create a Render Texture: In the Project window, right-click, go to Create ➜ Render Texture.

2. Assign the Render Texture to RawImage: Select the RawImage in the Hierarchy. In the Inspector, drag the Render Texture created into the Texture field of the RawImage previously created.

Step 3: Set Up the **Video Player**

1. Add a VideoPlayer component to the GameObject where you want to control the video playback.

2. Set the Source to **URL**. (***WebGL only supports URL.***) Enter the direct URL of your video that ends with .mp4 for example, not a shared link from Youtube or Vimeo. The video should be uploaded to a server that enables *Cross-Origin Resource Sharing (CORS)*, which is a security feature that controls whether web applications in one domain can access resources in another.

3. Set the Render Mode to Render Texture. Assign the Render Texture previously created to the Target Texture field.

Step 4: Scripting the VideoPlayer

Add this script to the GameObject that contains the VideoPlayer component:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.Video;

public class VideoPlayerController : MonoBehaviour
{
    private VideoPlayer videoPlayer;
     void Start()
    {
        videoPlayer = GetComponent<VideoPlayer>();
        videoPlayer.url = https://xxxxx.mp4;
        videoPlayer.Play();
    }
}
```

Step 5: Enable CORS in cPanel of host server

1. Log in to cPanel and open File Manager: Look for ‘File Manager’ in the cPanel dashboard and open it. The File Manager allows access to the files on the server.

2. Navigate to the Root Directory: Root directory is often named public_html or www.

3. Locate .htaccess File: Inside the root directory, look for the .htaccess file. (**Figure 4a**) It’s a hidden file, so the option to show hidden files (dotfiles) should be enabled in File Manager settings. If the .htaccess file doesn’t exist, create a new one instead.

4. Edit .htaccess File: Right-click on the .htaccess file and choose ‘Edit’ or ‘Code Edit’ to open it in the text editor.

5.Add CORS Configuration:

```
<IfModule mod_headers.c>
Header set Access-Control-Allow-Origin “*”
</IfModule>
```

Add the above code to the .htaccess file if it’s not already there under *#Enable CORS* for all domains. (**Figure 4b**) Save changes before closing the file.

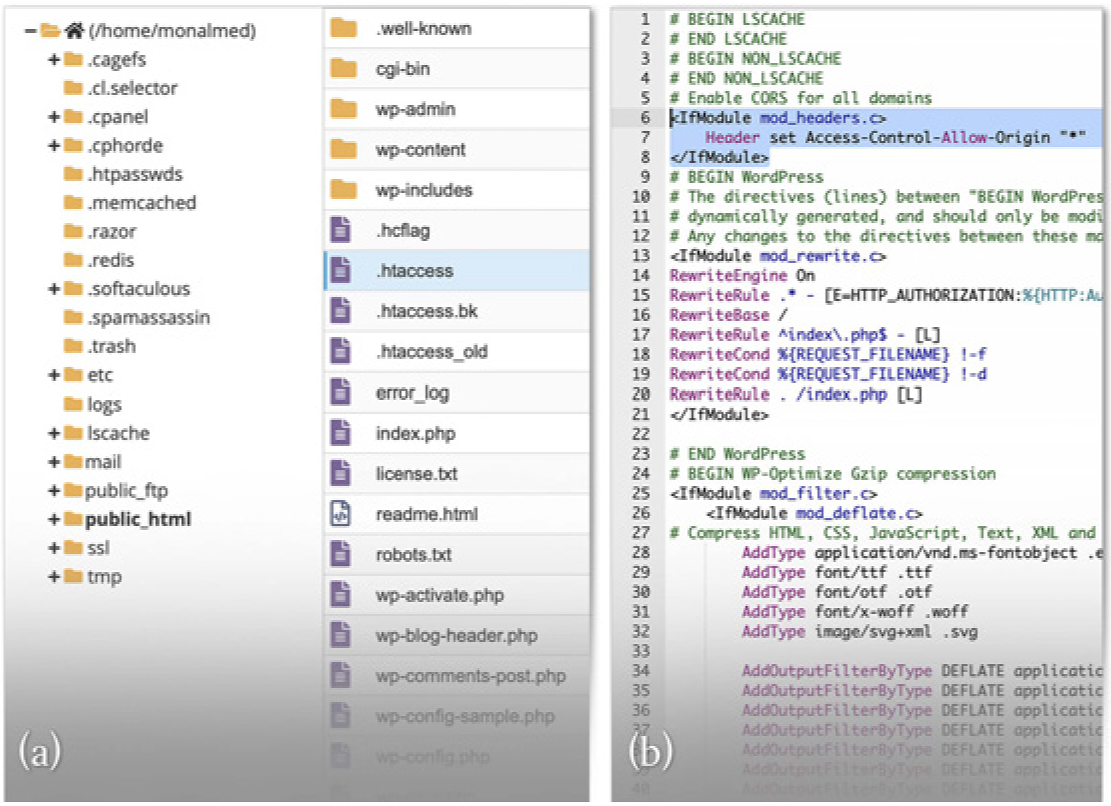

Figure 4. How to enable Cross-Origin Resource Sharing (CORS) on video hosting server. (a) In cPanel File Manager, the .htaccess file is usually hidden within the public_html folder. (b) Edit the .htaccess file and add the highlighted code.

The **Instrument List** WebGL application was uploaded to *simmer.io* and embedded into our landing webpage. A prompt that reads “*Now, please return to your board game and begin familiarizing yourselves with the kit through hands-on experience!*” follows the Instrument List to guide users back to the tangible aspect of the game.

3D Printing Game Pieces, Model Preparation

Using the same digital models, our original goal was to develop a non-functional **miniature replica** of the CVC kit to use as game pieces for our board game. These replicas would be 3D printed with a material durable enough to endure repeated use over time. This approach was aimed at providing a sustainable training tool, allowing trainees to learn to identify the contents of the kit without having to open and waste a sterilized kit for each training session. However, because most of the instruments contain delicate components, many of the models are so thin that they disintegrated during the 3D printing postproduction process. Following multiple tests, we ultimately chose *Shapeways Nylon 12 (Versatile Plastic)* for its superior elasticity and abrasion resistance. (**Figure 5**)

Figure 5. Photo of the 3D-printed miniature replicas versus the real central venous catheter kit.

We also created a series of models that function as "semi-3D" cards, as depicted in **Figure**

6. This adaptation provided a more supportive base from the platform, while still preserving some of the three-dimensional aspects we were aiming for. The approach allowed us to balance the need for durability with the desire to maintain a semblance of the original instruments.

Figure 6. Semi-3D cards that maintain aspects of the tactile dimensions of game pieces with enhanced durability and printing feasibility.

During the 3D printing process, we explored the feasibility of adding colors to the printed models and the method for importing polypaints from *Zbrush 2023.2.2* to C4D. The procedure began with saving the polypainted models as .obj files in Zbrush, which automatically generates a material file (.mtl). Although the model appears with a default white material upon initial loading in C4D, the polypaint information is retained within the *Vertex Color Tag* (**Figure 7a**) In standard rendering, create (or use an existing) default material, go to Color ➔ Texture▼ ➔ Effects ➔

Vertex Map ➜ Shader, and drag and drop the *Vertex Color Tag* into *Vertex Map*. (**Figure 7b**) In Redshift, the effect can be recreated by simply adding a *Vertex Attribute* node, connecting it to material color, and dragging the *Vertex Color Tag* into *attribute* Name. (**Figure 7c**)

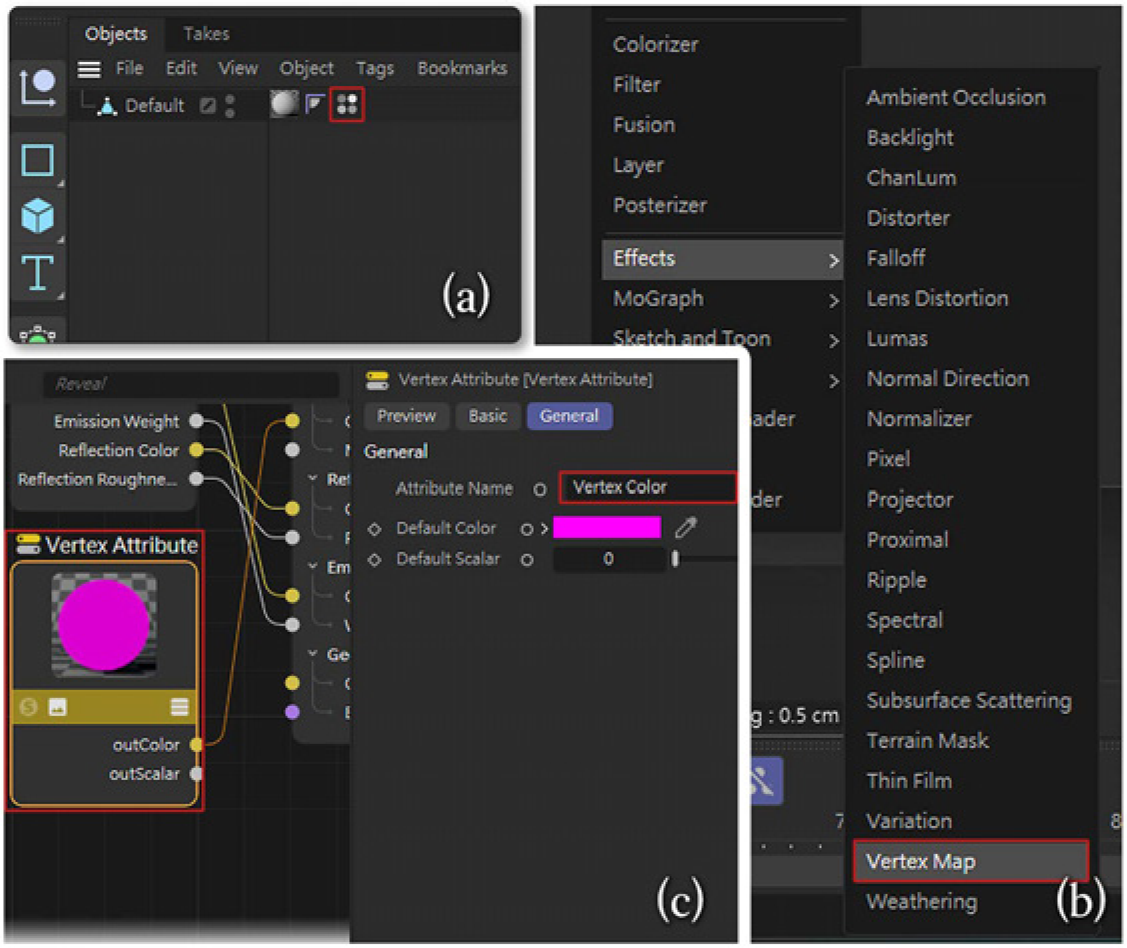

Figure 7. (a) Importing 3D models with polypaint directly from Maxon Zbrush to Cinema 4D via Vertex Color Tag. (b) Incorporate Vertex Color Tag with materials in standard rendering. (c) Incorporate Vertex Color Tag with materials in Redshift.

For multi-color 3D printing, first export models as *Wavefront OBJ* (*.obj) from C4D. ensuring ☑ *Vertex Colors* and ☑ *Invert Transparency* are checked in export settings. (**Figure 8**) Then, you can either send the object (.obj) and material (.mtl) files to the 3D printer or merge them into a .3mf file using software like 3D Builder, as C4D doesn't directly support .3mf conversion yet.

We contacted three distinct online 3D printing services: *Shapeways*, *i.materialize*, and the *Protolabs Network by Hubs*. Each of these services provides a wide selection of materials, offers instant online quotes, and guarantees a lead time with shipping completed within two weeks.

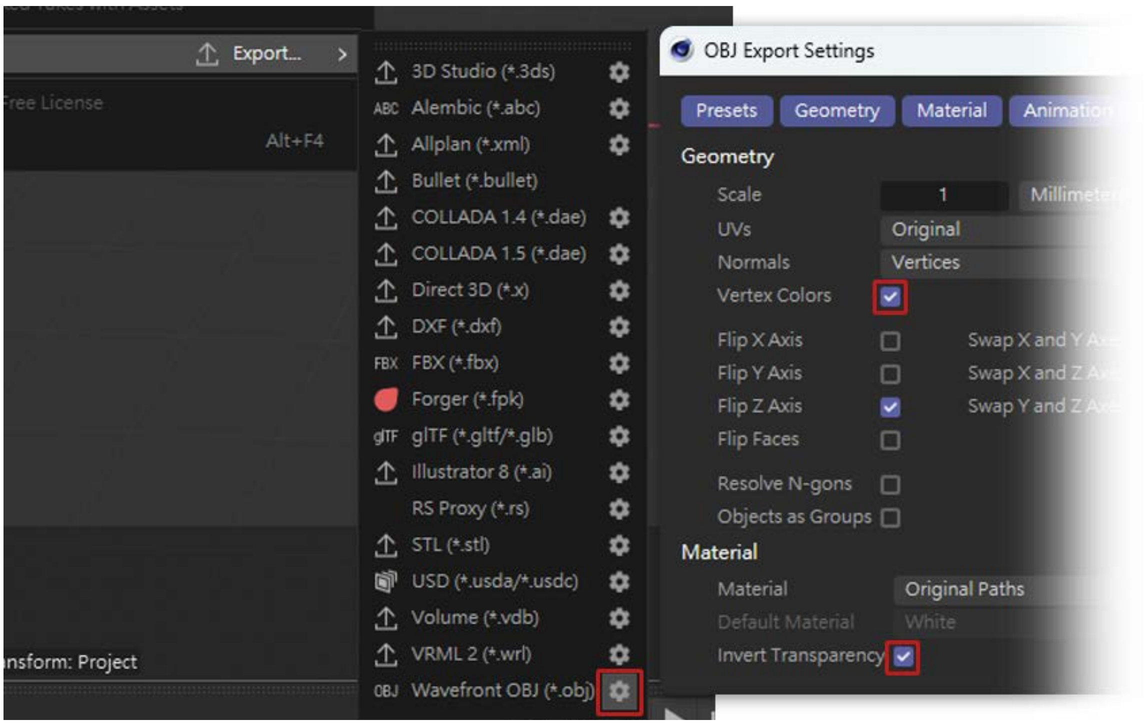

Figure 8. How to change model export settings in Maxon Cinema 4D.

Building Online Practice Interactive in Unity and WordPress

The concept was after providing students with an opportunity to engage in a tactile exercise using our 3D-printed models during class, they would have access to an online virtual module that reflects what they've just learned in class, allowing them to revisit and reinforce their knowledge at their convenience. We made an online module enabling students to practice extracting instruments from a CVC kit and categorizing them into the appropriate groups based on the sequence of procedure.

To simulate the effect of users pulling instruments out of the CVC kit tray, we employed a technique that combines the *Sprite Swap* Button Transition with *DraggableItem* script (**Appendix 4**). This approach allowed for an interactive and intuitive learning experience, closely mimicking the hands-on practice they received in class.

Each instrument was made into a "button" with the Transition mode set to *Sprite Swap* instead of the default *Color Tint*. (**Figure 9a**) The natural state of the Button (Source Image) was assigned to a Sprite (2D and UI) that was only an empty PNG (**Figure 9b**). This means the Button remains invisible when not interacted with or hovered over, and only displays a standalone PNG of the instrument when the button is clicked and dragged away.

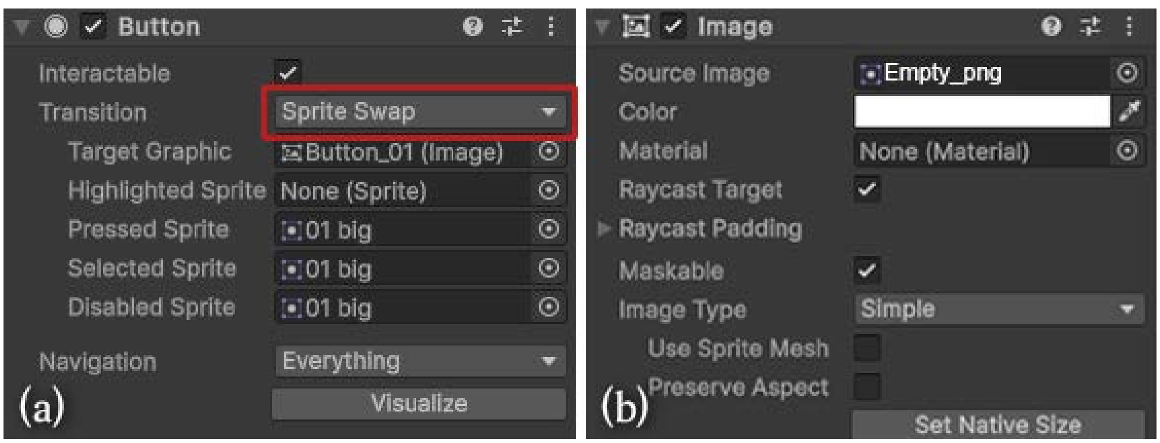

Figure 9. (a) For buttons to change form in Unity, use Sprite Swap instead of the default Color Tint. (b) Source image of the instrument Button was assigned to a transparent empty PNG to make the button invisible initially.

The rationale behind this approach was to account for the dynamic shadows cast on the instruments as their spatial relationship with the tray changes. Simply placing the instrument Button on top of an empty tray image without these considerations would result in a lack of natural shadows on the instruments, making them appear less realistic.

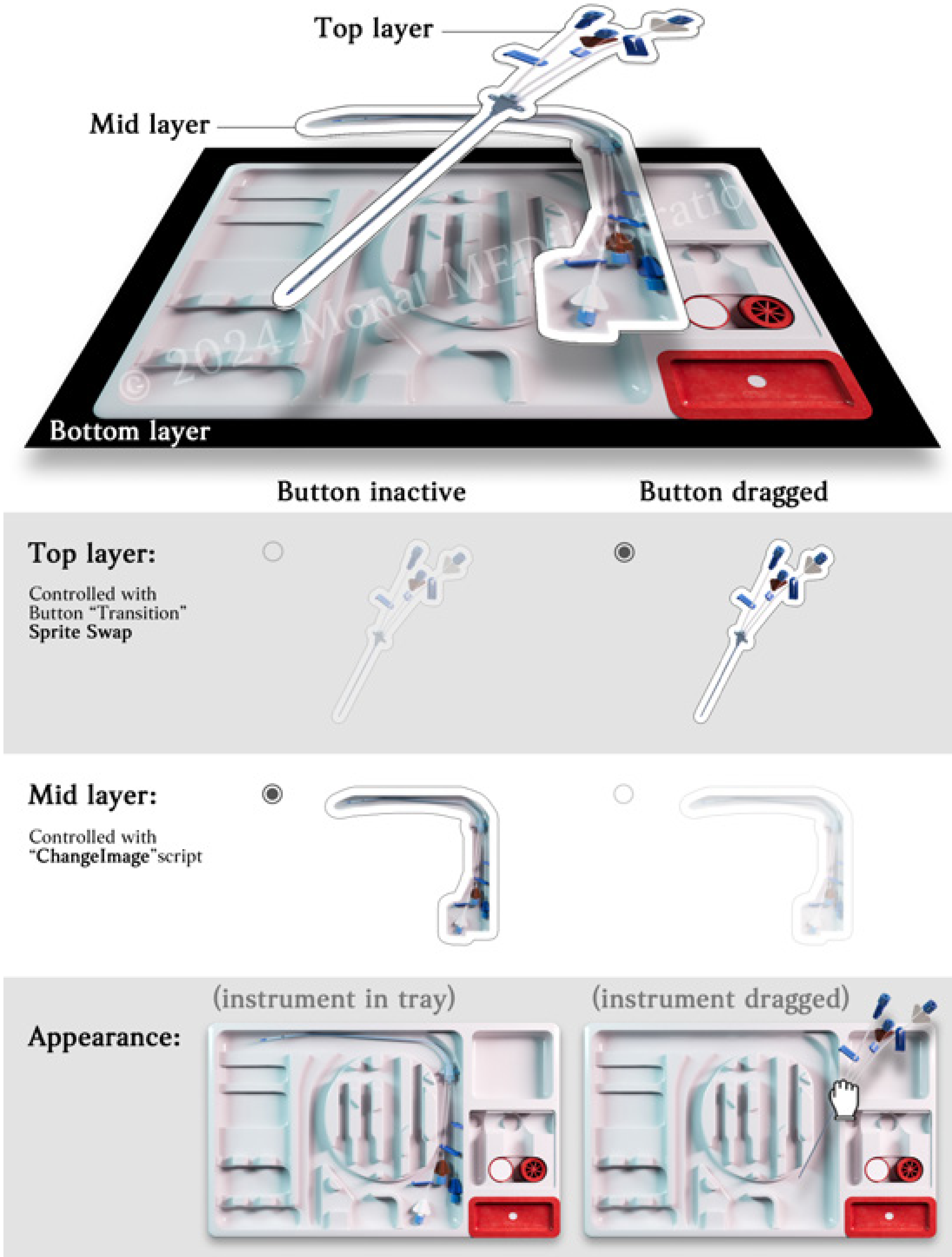

Figure 10. To create the illusion of an empty spot in the tray after removing an instrument, we layered a spot image of the instrument over an empty tray image, beneath the draggable Button image. (Top layer) The draggable instrument Button. (Mid layer) A spot image of the instrument, accurately placed in the tray, complete with the correct shadows. (Bottom layer) A background image of an empty tray is positioned at the lowest layer.

As the instrument Button remained invisible when inactive, we placed an image in its spot that displayed all the shadows, designed to become invisible once the Button was activated and dragged away. (**Figure 10**) This created the illusion of an empty spot in the tray, signifying that the instrument had been removed. The effect was achieved by concealing an Image Object beneath the instrument Button. We applied a *ChangeImage* script (**Appendix 5**) to the instrument Button, instructing it to disable the Image Object underneath as soon as the Button was engaged.

To manage the behavior of draggable instrument Buttons within the online module, we employed the *IBeginDragHandler*, *IDragHandler*, and *IEndDragHandler* interfaces. These ensured that all draggable instruments were confined to float only within the designated module area. Additionally, to visually indicate that an instrument is being dragged, the opacity of the draggable instrument Buttons was reduced to half (**Appendix 4**). Moreover, to avoid the Buttons reverting to their invisible state after being picked up from the tray, they were permanently disabled once clicked or dragged with the *DisableButton* script (**Appendix 6**).

Students' proficiency within this online module was primarily assessed based on their accuracy in categorizing an instrument after removing it from the tray. To facilitate this evaluation, each instrument Button was assigned a specific Tag, which was then linked to an item slot next to the tray using the *ItemSlot* script (**Appendix 7**). There are a total of five item slots that correlated to the five step buckets: **Sterilization** (Step 1), **Local anesthesia** (Step 2), **Puncture** (Step 3), **Insertion** (Step 4), **Secure** (Step 5). All instrument Buttons and item slots were equipped with an activated *Box / Polygon Collider 2D* component. This setup allows the system to detect when an instrument Button and an item slot overlap, facilitating accurate recognition of correct placements within the module. For every instrument correctly placed and categorized, students earned a point towards their final score. The final score would sum up in the next scene once they hit SUBMIT.

When users submit their categorizations and transition to another scene, the *UIManager* script (**Appendix 8**) captures not just the final scores but also a final screenshot of their categorization efforts. This screenshot is then carried over to the next scene, allowing users to review their work and compare it to the correct answer. (**Figure 11**)

To enhance the accuracy of the scoring system and prevent an item from being counted twice if it was placed in the correct slot, removed, and placed back again, we implemented a *GameManager* script (**Appendix 9**). This script works with the *UIManager* and *DraggableItem* scripts, differentiating each instrument Button with a unique item ID.

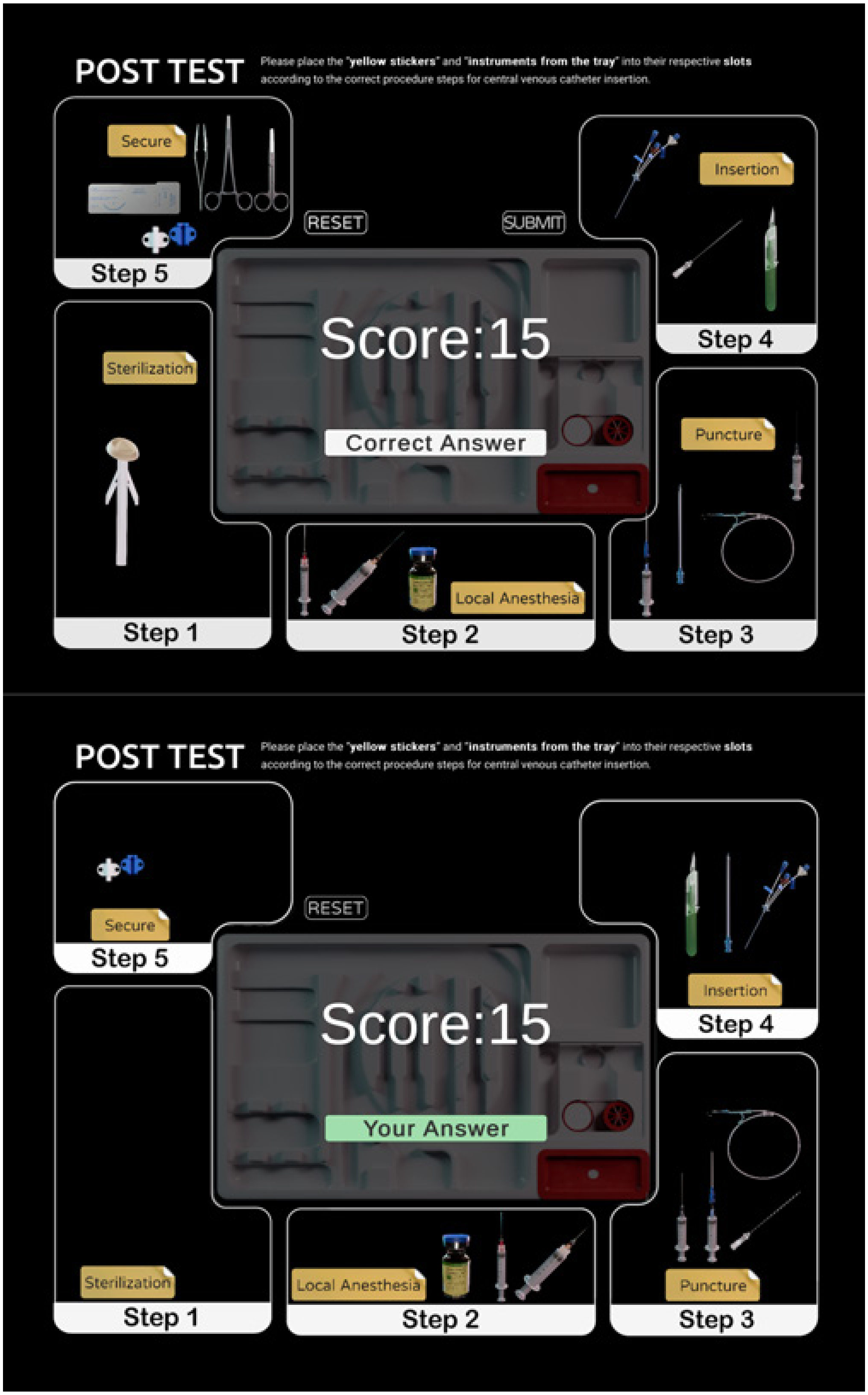

Figure 11. Users were able to compare their responses with the correct answers to identify errors and facilitate improvement. Not all text intended to be read.

The module also includes a RESET button that enables users to quickly return all the instruments to their original positions, reset the scoring, and start the exercise anew. This functionality is facilitated by a simple script named *RestartButton*, streamlining the process for users who wish to practice multiple times or correct their initial attempts.

```
using UnityEngine;
using UnityEngine.UI;
using UnityEngine.SceneManagement;

public class RestartButton : MonoBehaviour

{
    private Button restartButton;
    void Start()
    {
        restartButton = GetComponent<Button>();
        if (restartButton != null)
        {
            restartButton.onClick.AddListener(RestartScene);
        }
    }

    void RestartScene()
    {
       GameManager.Instance.ResetScore();
        Scene currentScene = SceneManager.GetActiveScene();
        SceneManager.LoadScene(currentScene.name);
    }
}
```

While viewing the answers, users have the option to click around and explore the explainers provided for each category. This interactive feature enables learners to delve deeper into the rationale behind each categorization, fostering a more comprehensive understanding of the subject matter. (**Figure 12**)

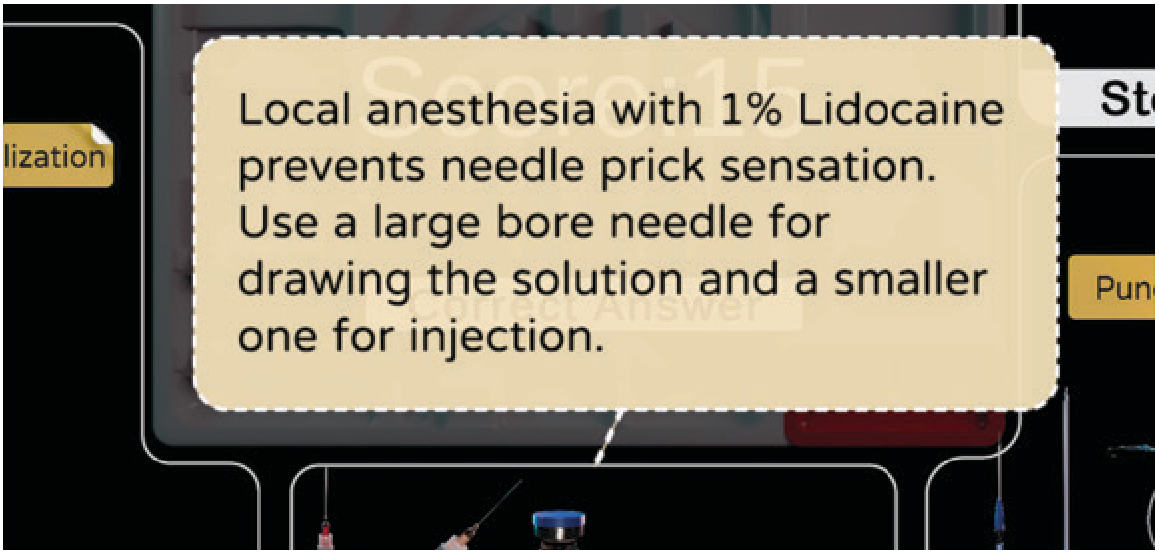

Figure 12. Upon submitting their answers, users receive explainers detailing the reasoning behind the correct responses, enhancing their understanding and learning.

The **Practice** WebGL application was uploaded to *simmer.io* and embedded into the bottom of our landing webpage, complemented by a html bookmark for easy navigation after class.

Phase III

The experts were invited back for a preliminary usability test aimed at further refining the teaching module. During this phase, they explored the online interactive components and engaged with the 3D-printed models, while responding to a series of guided questions, designed to evaluate the module's educational efficacy. (**Appendix 10**)

Results

We recruited 5 experts over a six-week period from February to March 2024, including 1 anesthesiologist, 2 nurse anesthetists and 2 anesthesiology and pediatric critical care fellows. (**Table 1**) Our survey revealed that experts favor the internal jugular vein for access over the subclavian and femoral veins, reporting an average procedural time of approximately 37.5 minutes. One in six experts reported having encountered complications during catheter placement. All participating experts were right-handed. (**Table 2**) Each session spanned roughly one and a half hours.

Characteristics	Experts; n=5 n (%)
Age	
Mean	38
Median	33
Range	33, 47
Sex	
Male	3 (60)
Ethnicity	
White	4 (80)
Black or African American	1 (20)
Asian	0 (0)
Job title	
Fellow	2 (40)
MD/DO	1 (20)
CRNA	2 (40)
Affiliation	
Anesthesia	3
CBID*	0
PICU	1
School of Nursing	1

Table 1. Demographic of experts.

Total CVC placements performed	
Jugular	7
Subclavian	0
Femoral	5
Time spent per CVC placement (minutes)	37.5
Preferred CVC placement site	Jugular
Complication encounters	33%
Handedness	
Right	100%
Left	0%

Table 2. Survey on experts' daily practice in central venous catheter (CVC) placement.

The same experts, along with a Master's student from the Johns Hopkins Center for Bioengineering Innovation & Design, were invited for a user test of our serious game teaching module (**Table 3**). Feedback on the online interactives, including the Instrument List and Practice modules, was very positive. The primary critique was that the Practice module did not closely mimic a real-life setting, though it was still praised as an effective self-learning tool for categorizing instruments by function.

Usability Test Questionnaire		On a scale of 1-5*
Instrument List	**Q1**: How helpful is the Instrument List as preliminary material?	4.5
	Q2: How easy is it to read the text and explainers?	5
3D-printed models		(Miniature replica / Semi-3D cards)
	Q3: How easy is it to make the connection between the 3D-printed models to the real kit?	4.8 / 3.8
	Q4: How durable do you think the models are?	3 / 4.8
	Q5: How likely will you use the models as part of your teaching/learning tools in real life?	4.3 / 3
	Q6: How cost-effective do you think they are, compared to the real kit?	4 / 2.7
	Q7: Which set of models do you think is more effective?	Miniature replica
Practice	**Q8**: How intuitive do you think it is to drag the items around?	4.5
	Q9: How helpful is it to show the scoring?	4.8
	Q10: How helpful is the Practice section, as an adjunct to the teaching process?	4.8
	Q11: How much does the Practice section resemble real-life experience?	3.3
	Q12: Would you recommend this whole teaching module before the real kits?	Yes (100%) No (0%)

Table 3. Results from the usability tests conducted with experts on the online interactive modules and 3D-printed models. [= except for Q7 and Q12]*

Two participants suggested that the Instrument List could be enhanced by explaining how each instrument functions, rather than just its purpose. Additionally, another participant found the animations in the Instrument List slightly distracting and recommended limiting animation to the beginning for a more focused reading experience.

All users expressed a preference for the 3D-printed miniature replica models over the semi-3D cards, citing a diminished sense of realism and color in the semi-3D versions despite their greater durability. One user suggested that the 3D-printed models would better complement the Practice online module if they could be utilized in a similar manner. Responding to this feedback, we subsequently created a physical version of the step buckets out of fabric, which was incorporated alongside the miniature replicas. (**Figure 13**)

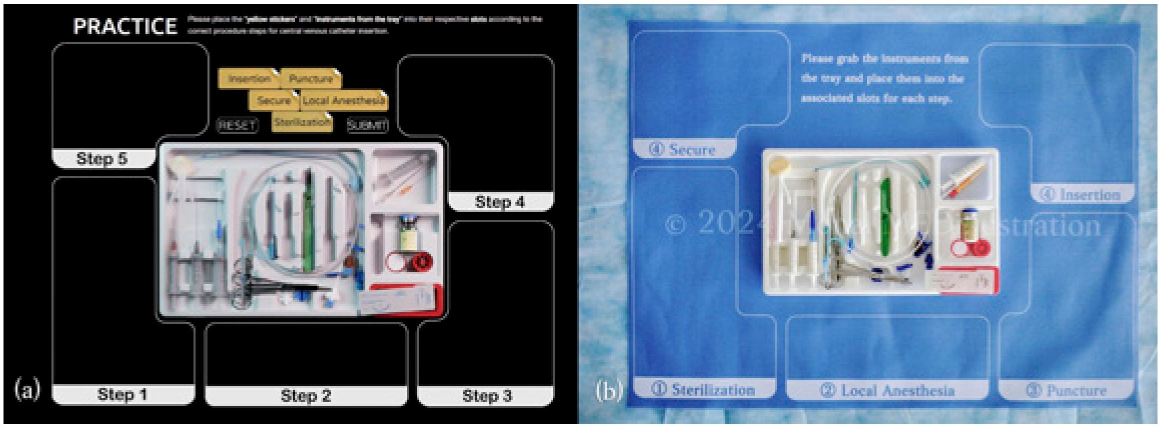

Figure 13. Considering the feedback from the usability tests, we enhanced the connection between the (a) online Practice module and (b) 3D-printed models by incorporating step buckets that are printed on fabric into the 3D-printed model set as well. Not all text intended to be read.

Overall, all users were firmly in favor of introducing trainees to this serious game prior to working with the actual kits.

Access to Assets

Access to the serious game teaching module resulting from this thesis can be viewed at: https://monalmed.com/interactives/ or by contacting the author at monal@email.com. The author may also be reached through *Johns Hopkins Department of Art as Applied to Medicine* via: https://medicalart.johnshopkins.edu/

Discussion

Deterding et. al defined gamification as “the use of game design elements in non-game contexts” (Deterding et al., 2011) In meaningful gamification, users are intrinsically motivated to remain actively engaged in the game. This concept is closely tied to the *Self-Determination Theory* (Deci & Ryan, 2004). To achieve this, game design should offer users *autonomy*, *competence*, and *relatedness*, fostering enduring connections and long-term engagement. (Fransen et al., 2018; Karimi & Sotoodeh, 2020; Li et al., 2024) In our serious game, we aimed to offer users with tools that are not only safe, enjoyable, and visually engaging but also sufficiently realistic, enabling practice at any time and space indefinitely. This approach ensures accessibility to education even when a simulation center or real sterile kits are unavailable.

During the observation of the experts, it became evident that physicians from diverse departments adopt markedly different strategies for instrument arrangement. This variation largely stems from the distinct environmental constraints and spatial limitations inherent to their respective working areas. Notably, practitioners operating within the confines of an operating room, such as anesthesiologists, demonstrate a heightened efficiency in spatial utilization due to significant space restrictions for procedure setups encountered in operating rooms. Consequently, they often arrange instruments strategically within the tray or, in some instances, directly on the patient, ensuring that all necessary tools are within arm’s reach for rapid access. This underscores the importance of teaching trainees not just to assign instruments to fixed locations, but to group them by function and adapt their organization to any environment they may encounter.

In our quest to craft the most effective Practice module design, we explored numerous prototypes. Initial versions were more straightforward, asking users to reorder all instruments within a time limit (**Figure 14**). This approach didn't account for the flexibility required in procedural steps, such as whether to first pick up a vial or a syringe for Lidocaine extraction. To address this, later prototypes introduced procedural *step buckets*, requiring users to categorize instruments by purpose. Yet, this modification introduced an unintended cognitive burden, as the step buckets weren't sequentially organized (**Figure 15**). To alleviate this issue, we replaced numerical order with step name stickers, simplifying the task to arranging step sequences before grouping related instruments (**Figure 16**). The final design further refined this concept by positioning step buckets around the tray similar to real-world scenarios (**Figure 11**).

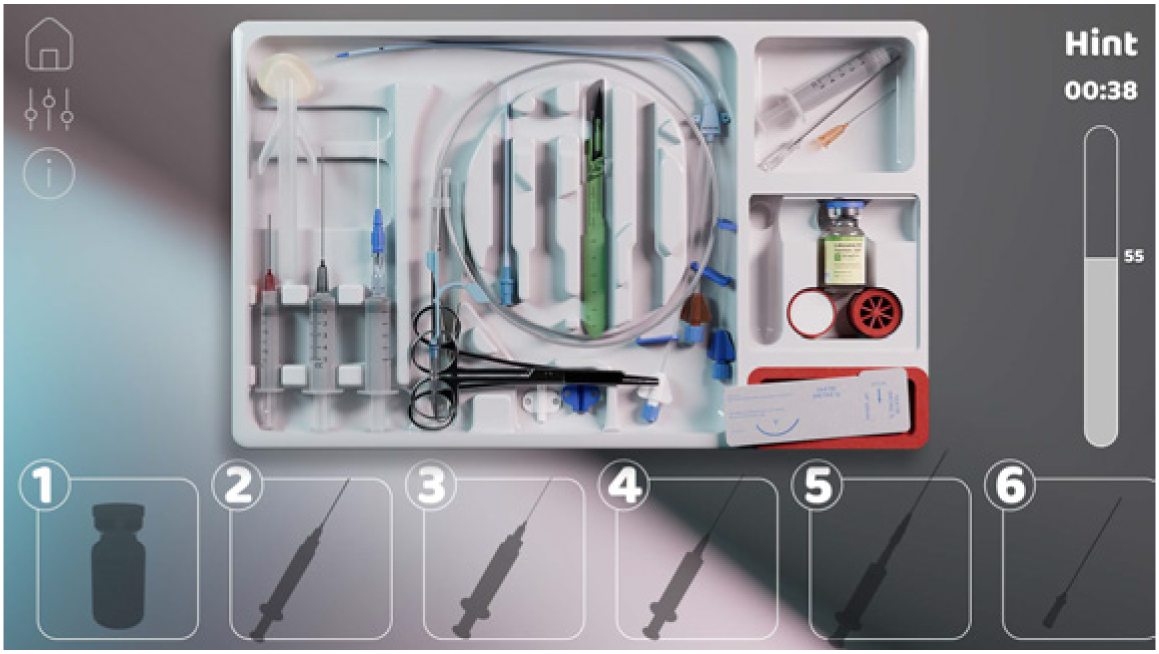

Figure 14. The initial prototype of the online Practice module challenges users to arrange instruments in the correct order within a specified time limit.

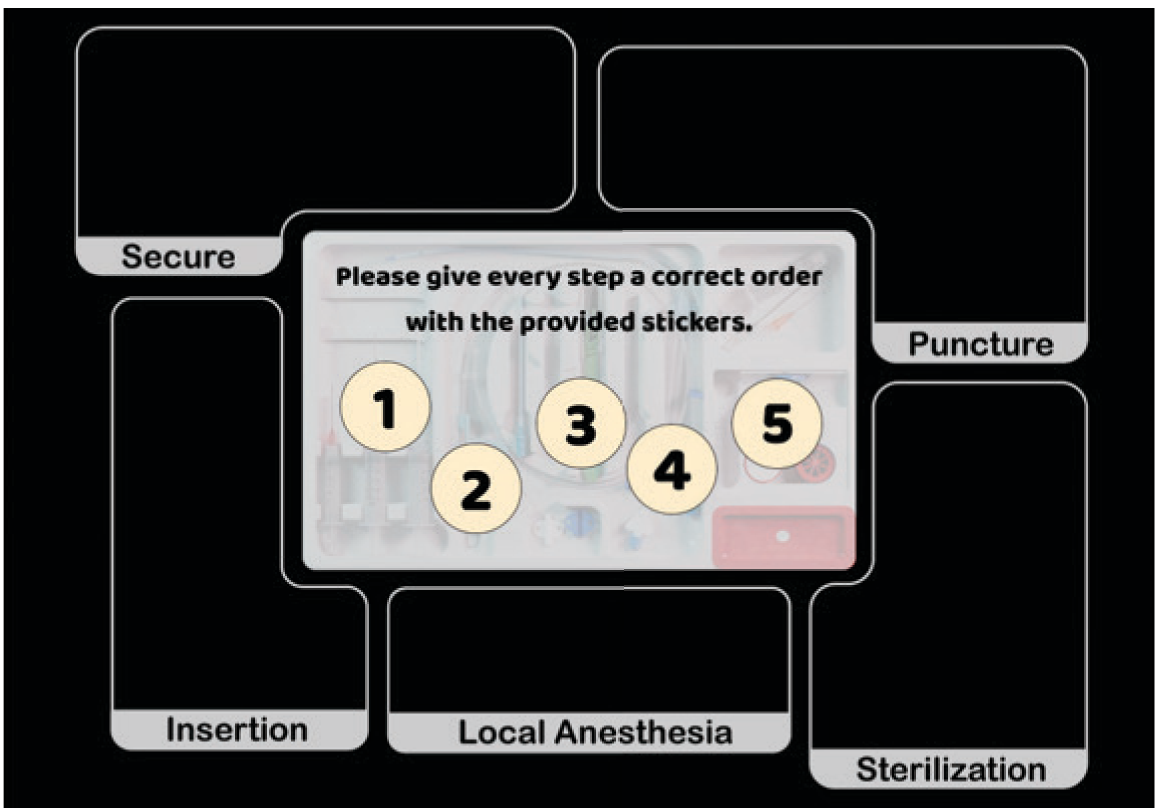

Figure 15. Subsequent iterations of the online Practice module prototypes required users to first sequence the procedural steps, then place the necessary instruments into these categorized step buckets.

Our study team primarily comprised healthcare professionals. None of the authors possessed expert coding skills at the onset of developing this interactive teaching module. Nevertheless, the project was successfully realized with the assistance of the online AI service ChatGPT 4.0, provided the queries were framed appropriately. This experience underscores the transformative potential of integrating AI into the development of medical educational contents.

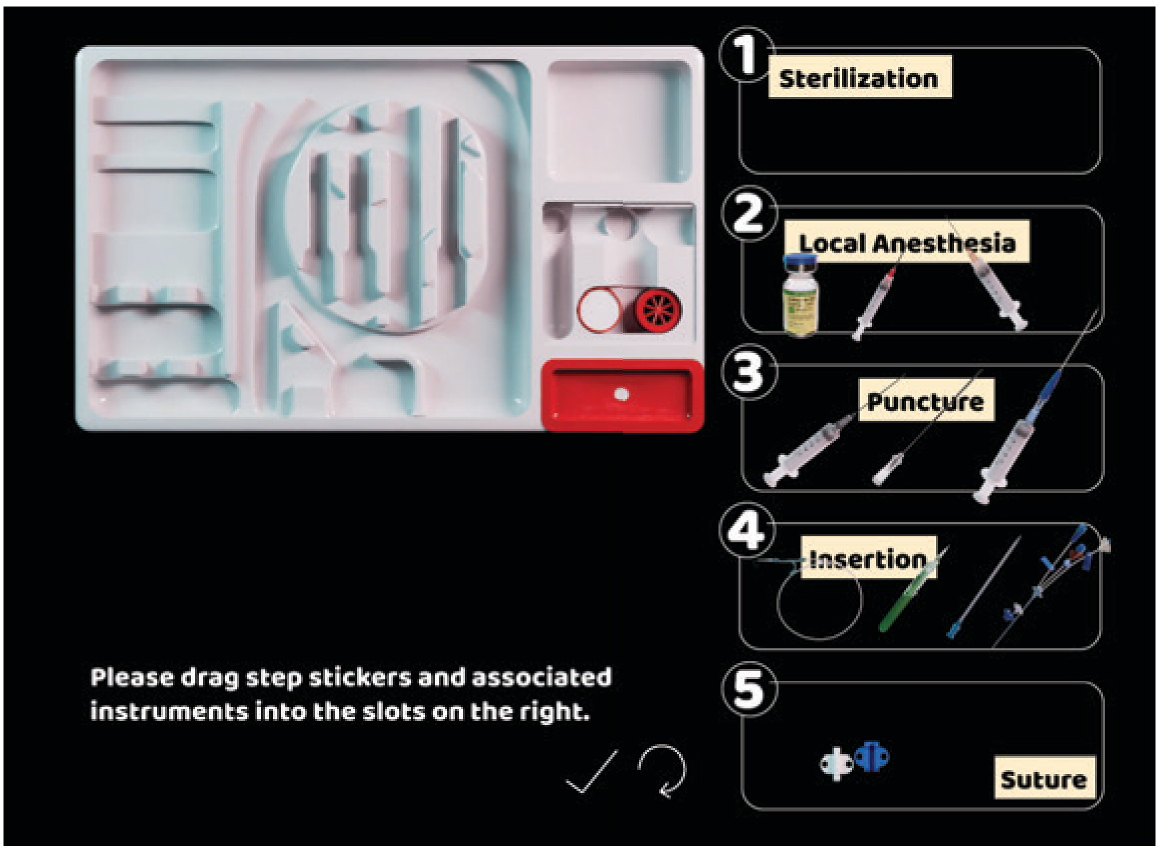

Figure 16. Refined prototypes of the online Practice module prompted users to order the names of procedural steps, rather than the sequence itself, and then allocate the requisite instruments into these categorically defined step buckets.

Conclusion

The insights derived from this project will assist medical educators and practitioners in determining the most effective methods for arranging sterile instruments in preparation for CVC placement. We combined the power of 3D modeling, 3D printing, animation, programming, web design and AI, integrating these varied skills into a cohesive educational tool that enable learners to engage in repetitive, deliberate practice without relying on costly procedure kits. This approach allows learners to explore and identify effective equipment organization strategies for a given procedure and environment, potentially improving efficiency and effectiveness. Our experience would serve as the cornerstone for future developments in serious games for various other medical procedures.

Appendix

Appendix 1

Study Consent

- You are invited to participate in a research study about central venous catheter (CVC) placement. This research study aims to develop an optimal strategy for teaching CVC placement.

- Participation in this study is entirely voluntary. If you choose to take part, after completing this demographic survey, you will be invited to visit the Blalock 7 Simulation Center in-person for a demonstration of CVC placement. During the in person session, we will ask you to wear an eye tracking device and make audio recordings of the session. You may quit the survey or demonstration at any time. Your decision to participate will not affect your employment, education, or training at Johns Hopkins.

- Submitting this survey will serve as your consent to be in the study.

Study Team

• Study Principal Investigator (JHM IRB #: IRB00414349): Geoffrey T. Miller, PH.D.(c), EMT-P, FSSH, Department of Emergency Medicine/Simulation Center (gmille71@jhmi.edu)

• Monal Chang, M.D., M.A. candidate, Department of Art as Applied to Medicine (ychang96@jh.edu)

• Michael A. Rosen, Ph.D., M.A., Department of Anesthesiology and Critical Care Medicine

For questions or concerns about the study, please contact Monal Chang at ychang96@jh.edu, or the Johns Hopkins Medicine Institutional Review Board help desk at jhmeirb@jhmi.edu.

Q1/12

What is your gender?

□ Male

□ Female

□ Other

Q2/12

What is your age?

Q3/12

How would you describe yourself? Please select all that apply.

□ White

□ Black or African American

□ American Indian or Alaska Native

□ Asian

□ Native Hawaiian or Pacific Islander

□ Other

Q4/12

What is your current job title?

□ Resident

□ Fellow

□ MD/DO

□ CRNA

□ NP

□ PA

□ Other -

Q5/12

What year are you in?

Q6/12

Which department are you currently affiliated with?

Q7/12

In the past year, approximately how many central venous catheter placements did you perform?

________ Jugular

________ Subclavian

________ Femoral

Q8/12

How much time do you generally spend to perform the procedure each time? (minutes)

Q9/12

What is your preferred site for CVC insertion?

□ Jugular

□ Subclavian

□ Femoral

Q10/12

Have you encountered any complications related to CVC placement?

□ Yes

□ No

Q11/12

Do you wear glasses (include contact

lenses)?

☐ Yes

☐ No

Q12/12

Are you right- or left-handed?

☐ Right-handed

☐ Left-handed

Q1/12

What is your gender?

☐ Male

☐ Female

☐ Other

Q2/12

What is your age?

Q3/12

How would you describe yourself? Please select all that apply.

☐ White

☐ Black or African American

☐ American Indian or Alaska Native

☐ Asian

☐ Native Hawaiian or Pacific Islander

☐ Other

Q4/12

What is your current job title?

☐ Resident

☐ Fellow

☐ MD/DO

☐ CRNA

☐ NP

☐ PA

☐ Other -

Q5/12

What year are you in?

Q6/12

Which department are you currently affiliated with?

Q7/12

In the past year, approximately how many central venous catheter placements did you perform?

_______ Jugular

_______ Subclavian

_______ Femoral

Q8/12

How much time do you generally spend to perform the procedure each time? (minutes)

Q9/12

What is your preferred site for CVC insertion?

☐ Jugular

☐ Subclavian

☐ Femoral

Q10/12

Have you encountered any complications related to CVC placement?

☐ Yes

☐ No

Q11/12

Do you wear glasses (include contact lenses)?

☐ Yes

☐ No

Q12/12

Are you right- or left-handed?

☐ Right-handed

☐ Left-handed

Appendix 2

Part I Table Arrangements:

- This project aims to develop an optimal way of teaching CVC placement through observation of expert performance.
- The first part of the activity today involves you arranging the instruments in our designated area on the table as if you're preparing for the procedure.
- We will not interrupt you, but your arrangements on the table and eye movements will be recorded on camera and an eye-tracking device.
- We need your eye prescriptions to calibrate the eye-tracking device, but your face and other identifying information will not be recorded. This is a completely anonymized study.
- You will be asked to respond to several questions during a pause in the activity to elicit further details regarding decision-making during the activity. We will be audio recording your answers to ensure the accuracy of your narrative responses. It is only for our reference and will be deleted immediately after extracting viable information.
- Please perform the procedure as if for a non-emergent routine patient without an assistant.
- Please notify us as soon as you finish your preparation on the table.

Help the participant put on the eye-tracking device.

Give the real kit to the participant.

Start recording once the participant is ready.

- Before we move on to the second and last part of this activity, let's discuss a little about the reasonings behind your arrangement on the table.

- Can you describe how you decided to group the instruments this way?

- What devices did you choose to put closer to yourself?

Part II Catheter Insertion:

- Now please start inserting the catheter using the manikin. This time, you will be timed.

Start timer.

Make sure the eye-tracking device is still working.

- After inserting the catheter, is there anything you would probably change with your pre-procedural arrangement on the table?

- That is all for today. Thank you very much for your participation today.

Appendix 3

```
using UnityEngine;

using UnityEngine.SceneManagement;

using UnityEngine.UI;

using System.Collections;


public class SceneTransition : MonoBehaviour

{

    public string sceneToLoad; // The name of the scene to load

    public Button yourButton; // The button that triggers the scene change

    public AudioSource audioSource; // The AudioSource for playing the sound effect

    public CanvasGroup fadePanel; // The CanvasGroup attached to the fade panel

    public float fadeDuration = 1f; // Duration of the fade effect


    void Start()

    {

        yourButton.onClick.AddListener(StartSceneTransition);

    }


    void StartSceneTransition()

    {

        if (audioSource != null)

        {

            audioSource.Play();

        }

        StartCoroutine(FadeAndLoadScene());

    }


    IEnumerator FadeAndLoadScene()
```

```
    {
        // Fade to black
        float time = 0f;
        while (time < fadeDuration)
        {
            time += Time.deltaTime;
            fadePanel.alpha = time / fadeDuration;
            yield return null;
        }
        SceneManager.LoadScene(sceneToLoad);
    }
}
```

Appendix 4

```
using System.Collections.Generic;

using UnityEngine;

using UnityEngine.EventSystems;

using System.Collections;


public class DraggableItem : MonoBehaviour, IBeginDragHandler, IDragHandler, IEndDragHandler

{

    public int itemId;

    [SerializeField] private Canvas canvas;

    private RectTransform rectTransform;

    private CanvasGroup canvasGroup;

    private Transform parentAfterDrag;

    private ItemSlot currentSlot;


    private float canvasHalfWidth;

    private float canvasHalfHeight;


    private void Awake()

    {

        rectTransform = GetComponent<RectTransform>();

        canvasGroup = GetComponent<CanvasGroup>();


        CalculateCanvasBoundaries();


    }

    private void CalculateCanvasBoundaries()

    {

        RectTransform canvasRect = canvas.GetComponent<RectTransform>();
```

```
    canvasHalfWidth = canvasRect.sizeDelta.x * 0.5f;

    canvasHalfHeight = canvasRect.sizeDelta.y * 0.5f;

}

public void OnBeginDrag(PointerEventData eventData)

{

    Debug.Log("Begin Drag");

    CursorManager.Instance.SetCursor(CursorManager.Instance.dragCursor);

    parentAfterDrag = transform.parent;

    transform.SetParent(transform.root);

    transform.SetAsLastSibling();

    canvasGroup.alpha = .7f;

    canvasGroup.blocksRaycasts = false;


}

public void OnDrag(PointerEventData eventData)

{

    Debug.Log("Dragging");


    Vector2 newPosition = rectTransform.anchoredPosition + eventData.delta / canvas.scaleFactor;

    newPosition.x = Mathf.Clamp(newPosition.x, -canvasHalfWidth, canvasHalfWidth);

    newPosition.y = Mathf.Clamp(newPosition.y, -canvasHalfHeight, canvasHalfHeight);


    rectTransform.anchoredPosition = newPosition;

}

public void OnEndDrag(PointerEventData eventData)

{


    Debug.Log("End Drag");

    CursorManager.Instance.SetCursor(CursorManager.Instance.defaultCursor);
```

```
        transform.SetParent(parentAfterDrag);

        canvasGroup.alpha = 1f;

        canvasGroup.blocksRaycasts = true;

    }

}
```

Appendix 5

```
using System.Collections;

using System.Collections.Generic;

using UnityEngine;

using UnityEngine.UI;

using UnityEngine.EventSystems;


public class ChangeImage : MonoBehaviour, IPointerDownHandler, IPointerUpHandler

{

    public Image image;

    public Sprite newSprite;

    public Sprite oldSprite;

    public void OnPointerDown(PointerEventData eventData)

    {

        image.sprite = newSprite;

    }

        public void OnPointerUp(PointerEventData eventData)

    {

        image.sprite = oldSprite;

    }

}
```

Appendix 6

```
using UnityEngine;
using UnityEngine.UI;
using UnityEngine.EventSystems;

public class DisableButton : MonoBehaviour, IBeginDragHandler
{
    private Button myButton;
    private bool isButtonClicked = false;
    private bool isButtonDragged = false;

    void Start()
    {
        myButton = GetComponent<Button>();

        if (myButton != null)
        {
            myButton.onClick.AddListener(OnButtonClick);
        }
    }

    public void OnBeginDrag(PointerEventData eventData)
    {
        if (!isButtonDragged)
        {
            myButton.interactable = false;
            isButtonDragged = true;
        }
    }
    void OnButtonClick()
```

```
    {
        if (!isButtonClicked)
        {
            myButton.interactable = false;
            isButtonClicked = true;
        }     }
}
```

Appendix 7

```
using UnityEngine;

using UnityEngine.EventSystems;

using TMPro;


public class ItemSlot : MonoBehaviour, IDropHandler

{

    public string correctItemTag;

    public TextMeshProUGUI countText;


    public void OnDrop(PointerEventData eventData)

    {

        DraggableItem item = eventData.pointerDrag.GetComponent<DraggableItem>();

        if (item != null && item.CompareTag(correctItemTag))

        {

            GameManager.Instance.AddCorrectItem(item.itemId);

            UpdateCountText();

        }

    }


    private void UpdateCountText()

    {

        if (countText != null)

        {

            countText.text = “” + GameManager.Instance.TotalCorrectCount;

        }

    }

}
```

Appendix 8

```
using UnityEngine;

using System.Collections;

using UnityEngine.SceneManagement;

using TMPro;


public class UIManager : MonoBehaviour

{

    public TextMeshProUGUI countText;

    public string sceneName;


    public void OnSubmitClicked()

    {

        StartCoroutine(CaptureScreenshot());


        DataManager.Instance.CorrectItemCount = GameManager.Instance.TotalCorrectCount;

        SceneManager.LoadScene(sceneName);

    }

    private IEnumerator CaptureScreenshot()

{

    yield return new WaitForEndOfFrame();

    Texture2D screenshot = new Texture2D(Screen.width, Screen.height, TextureFormat.RGB24, false);

    screenshot.ReadPixels(new Rect(0, 0, Screen.width, Screen.height), 0, 0);

    screenshot.Apply();

    byte[] screenshotBytes = screenshot.EncodeToPNG();

    DataManager.Instance.ScreenshotData = screenshotBytes;

    Destroy(screenshot);

  }

}
```

Appendix 9

```
using UnityEngine.SceneManagement;

using System.Collections.Generic;

using UnityEngine;


public class GameManager : MonoBehaviour

{

    public static GameManager Instance;

    private HashSet<int> placedItemIds = new HashSet<int>();

    public int TotalCorrectCount => placedItemIds.Count;

    private void Awake()

    {

        if (Instance == null)

        {            Instance = this;

            DontDestroyOnLoad(gameObject);

        }

        else

        {            Destroy(gameObject);

        }

    }

    public void AddCorrectItem(int itemId)

    {        placedItemIds.Add(itemId);

    }

    public void ResetScore()

    {

        placedItemIds.Clear();

    }

}
```

Appendix 10

On a scale of 1-5…

--Instrument List--

Q1: How helpful is the Instrument List as preliminary material?

Q2: How easy is it to read the text and explainers?

--3D Models-- (give an answer for the miniature replica and semi-3D cards respectively)

Q3: How easy is it to make the connection between the 3D-printed models to the real kit?

Q4: How durable do you think the models are?

Q5: How likely will you use the models as part of your teaching/learning tools in real life?

Q6: How cost-effective do you think they are, compared to the real kit?

(Provide the numbers: Real kit: $300/use; Miniature replica: $147; Semi-3D cards: $312)

Q7: Which set of models do you think is more effective?

--Practice --

Q8: How intuitive do you think it is to drag the items around?

Q9: How helpful is it to show the scoring?

Q10: How helpful is the Practice section, as an adjunct to the teaching process?

Q11: How much does the Practice section resemble real-life experience?

--

Q12: Would you recommend this whole teaching module before the real kits? Yes / No

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Vita

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