Virtual Reality Healthcare Simulation: Economic Evaluation and Return on Investment

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Introduction

The pressures on global healthcare systems are unprecedented, with demands to improve the quality and provision of care with little or no budgetary increase. Focus has therefore fallen on proving efficacy and value for money.

Training, assessment and recruitment of staff is one area where these pressures are in evidence. Simulation - simulated scenarios using mannequins, actors and faculty to allow learners to practice without compromising patient safety - is one technique often used to do this. Simulation is highly effective but extremely costly, and novel methods such as virtual reality (VR) have now been designed to deliver the same simulation learning outcomes in a more efficient and cost effective manner.

This paper outlines the health economics around virtual reality simulation in healthcare, with a focus on promoting efficiency, equity and resource allocation. It then outlines the potential return on investment (ROI) of adopting VR simulation.

Evaluative Framework

An economic evaluation is a comparative analysis of alternative courses of action in terms of both their costs and consequences(1). It therefore requires a comparison between alternative courses of action in terms of both their costs and their benefits.

While this paper outlines a direct comparison between physical simulation and VR simulation, both modalities are multifactorial. Physical simulation varies from standardized patients, to part task training, to a 20-participant in-situ cath lab cardiac arrest. VR simulation is equally diverse - it can focus on any content using a wide range of hardware to deliver it.

For this paper we have compared two defined kinds of simulation: physical 'full-immersion' simulation for clinicians and VR head-mounted display simulation for virtual reality.

Full-immersion physical simulation has been chosen as it is widely used by students, physicians and nurses. 'Fully-immersive' virtual reality has been chosen as it is the most effective method of delivering VR simulation(2).

We have used a cost-utility analysis to question allocative efficiency of delivering simulation using physical or virtual reality methods.

A cost-utility analysis allows the comparison of multiple alternatives (in this case physical and VR simulation) in terms of both their costs and their effectiveness. Costs are measured in monetary terms and utility can be measured as a composite of multiple measures.

In this case, the multiple measures are all the components that create a simulation (whether a physical or VR scenario) and the composite utility measure is a learner leading one simulation scenario.

Cost-utility analysis has been used extensively in healthcare and educational research and is helpful for making decisions when two interventions have demonstrated similar effectiveness. We focus first on the efficacy of simulation and then on the cost of simulation to define cost-utility.

Efficacy of Simulation

Simulation is considered to be the optimal method of training healthcare professionals. It is superior to traditional clinical education for clinical skill acquisition, reduces patient harm and improves quality of care (3, 4).

Simulation is a technique, not a technology. As such the methods for delivering simulation vary. Two broad approaches are physical and virtual reality simulation.

Physical Simulation

The most common method of delivering simulation is physical (or mannequin-based) simulation. This involves simulating a medical emergency with mannequins and actors. This traditional method is what the majority of simulation literature focuses on.

Virtual Reality Simulation

Over recent years there has been an increase in the availability of virtual reality (VR) simulation. Virtual reality has the ability to deliver many of the learning outcomes of physical simulation in a standardized, objective, scalable manner, and so it has the ability to transform the way clinicians train.

However, the term ‘virtual reality’ is poorly defined, making comparison difficult. Screen-based learning has at times been described as VR, as have non-immersive ‘CAVE’ systems. Equally, even in ‘immersive VR’ where the learner is immersed in a virtual world using a head-mounted display (HMD), there are variations in technology and therefore quality of immersion and learning transfer.

For example, a 360-video may be immersive but is not full interactable or dynamic. The need for immersion to embed learning and ensure transfer to practice (5, 6) is lacking with 360-degree video. As such we will only refer to VR as full-immersive computer-generated VR scenarios, as this is the technology with the ability to mirror and deliver the benefits of physical simulation.

Comparative Efficacy of Physical vs VR Simulation

Previous studies suggest virtual simulation as a cost-effective strategy in healthcare education (7). However, due to the emerging nature of VR, few trials have rigorously compared VR and physical simulation efficacy.

One notable exception is Haerling (2018) who compared not only efficacy but cost-utility between VR and physical simulation in a well-designed randomized controlled trial. Eighty-four nursing students completed either VR or physical (mannequin-based) simulation activities. It was found that there were no significant differences in quantitative measures of learning or performance between participants in the mannequin-based and VR simulation groups.

As such, “In the cost-utility analysis, the virtual simulation activity had a more favorable cost-utility ratio versus the mannequin-based simulation activity”(8)

Trials on the OMS VR platform (N=15) have also demonstrated efficacy in changing practice and improving performance. In an independent trial with University College London (Zhou, 2018, in press), OMS VR simulation learners demonstrated significant improvement in time to appropriate fluid resuscitation ($p<0.005$), time to correct antibiotics ($p=0.014$) and improvement in overall score ($p<0.005$).

Note that any comparison between physical simulation assumes the learning objectives (e.g. decision-making, critical thinking or clinical reasoning) are similar between VR and physical simulation. VR should not be considered as a complete replacement for all simulation activities as it may not be the optimal method of reaching some simulation objectives: e.g. in-situ simulation, procedural skills, breaking bad news, etc.

However, assuming learning objectives are appropriate, and based on the papers above, we have proceeded on the understanding that VR simulation is of *equal efficacy* to physical simulation.

Note, however, that the OMS VR system offers benefits beyond what physical simulation can offer. This includes the ability to increase the realism of scenarios, the ability to manage learners centrally, and ability to access learner feedback, performance metrics and analytics. This is in addition to the repeatability, flexibility and standardized nature of VR.

As such, though the assumption is that VR simulation is of equal efficacy to physical simulation, it may be that its additional benefits outweigh that of physical simulation in some areas.

Cost of Simulation

Defining the cost of simulation is complex. Numerous literature surveys have found that cost-effectiveness research in education is “scarce, of poor quality, and fails to inform the public”(9). This is particularly true in medical education and simulation where costs are often difficult to assess and even when attempts are made, are frequently under-reported (10).

Component Costs

To help define costs of simulation we have used work by Zendejas (2013) and Walsh (2013) to create table 1 (below).

The table is indicative of the component costs of simulation rather than an explicit cost analysis. Only costs where there is a direct comparison between physical and VR simulation are made explicit, based on the papers cited. Other simulation cost components can only be calculated on a ‘per-institution’ basis due to the variability between institutions and lack of concordance between estimates.

Category	Item	Item (detail)	Physical sim	Physical sim (detail)	Virtual sim	Virtual sim (detail)
Equipment costs	Fixed hardware costs	Price of mannequin or VR simulator	$102,000	High-fidelity mannequin with accessories and setup	$7,000 (through OMS)	To purchase the OMS VR system of laptop and Oculus Rift
Equipment costs	Variable software or A-V costs cost	Software or training materials	-	Calculated in collaboration with institute	$300 per learner per year	E.g. for a library of 20 scenarios
Equipment costs	Variable repair/ maintenance costs	Repair, upgrades, tech support	$19,000	20% of annual cost	$0	Included in license
Equipment	Variable	Simulation	-	Calculated in	$0	Included in

costs	Consumable costs	equipment and moulage		collaboration with institute		license
Structural costs	Fixed structural costs	Design, construction, A-V installation, furnishings	-	Highly variable depending on needs	$0	No permanent requirement
Structural costs	Variable running costs	Cleaning, electricity, catering	-	Calculated in collaboration with institute	-	Minimal - only when VR being used
Structural costs	Variable rental costs	Room rental	-	Calculated in collaboration with institute	$0	No permanent requirement
Personnel costs	Variable clinical and faculty costs	Staff time to design and prepare simulation	-	Calculated in collaboration with institute	0 staff	-
Personnel costs	Variable admin costs	Staff time to coordinate and schedule simulation	-	Calculated in collaboration with institute	0 staff	-
Personnel costs	Variable clinical and faculty costs	Staff time to run simulation	-	Calculated in collaboration with institute	0 staff	-
Personnel costs	Variable clinical and faculty costs	Staff time to debrief simulation	-	Calculated in collaboration with institute	0-1 staff	Not required but can be beneficial
Personnel costs	Variable actor costs	Actor or clinician time to act as confederate in simulation	-	Calculated in collaboration with institute	0 staff	-
Opportunity costs	Variable opportunity cost of time out of clinical hours	Time that participants spend out of their work day that is when they are not leading a simulation	-	Calculated in collaboration with institute	Reduction relative to physical simulation due to ease of scheduling	-

Table 1: Cost components of physical simulation compared with virtual reality simulation.

The above can be used as a framework for calculating simulation costs per institution. A literature survey to define peer reviewed example costs for the above components reveals three paper: Zendejas (2013), McIntosh (2006) and Iglesias-Vázquez (2007).

Zedejas (2013) notes “A single high-fidelity simulator with its monitoring system and other necessary equipment may cost up to $200,000. In addition, synthetic body fluids, replacement skins, bandages, syringes and other supplies are necessary to simulate the experience of treating real patients in a real hospital."

McIntosh (2006) concludes "Set up cost was $876,485 (renovation of existing facility, equipment). Fixed costs per year totalled $361,425. Variable costs totalled $311 per course hour"

Iglesias-Vázquez (2007) states the "cost of ALS simulation for a four day course is €1,320 [$1455] per passed participant"

Costs of Physical Simulation

From the above, an indicative cost of physical simulation can be calculated. Note that cost calculations assume some fixed costs are sunk (e.g. mannequin and structural costs). Other costs can be calculated as follows:

Mackintosh:
Fixed cost per day (assuming 365 working days) = $990.21 [$361,425/365].
Variable cost per day (assuming an 8 hour day) = $2488.00 [$311x8].
Cost of sim per participant per day (assuming 8 participants in a day) = **$434.78**

Iglesias-Vázquez:
Cost of sim per participant per day = **$363.75** [$1455/4].

Acknowledging wide variations in the practice of simulation, these two approximations are remarkably similar. We have therefore taken a mean ($399.27 rounded down) to estimate the average cost of physical simulation per participant at **$399.**

Costs of Virtual Reality Simulation

As pricing of all VR systems is not widely available, we have focused on the Oxford Medical Simulation VR system with pricing correct as of 2019.

Price for hardware: $7,000 as a fixed cost.
Price for software: $300 for access to twenty scenarios.
Clinical trials demonstrate that users attempt each scenario at least twice - calculating the cost to lead a scenario at **$7.50** [300/(20x2)] or **$15** if learners were only to do every scenario once.

Cost-Utility Analysis

A cost-utility analysis questions the allocative efficiency of the delivery of simulation using physical or virtual reality methods. The 'utility' in question in this case is the delivery of simulation.

Cost-Utility Assumptions

To analyse cost-utility, the following assumptions were made:

- Both physical simulation and VR simulation are available to the given institution.
- Sunk costs (eg. building costs) are non-recoupable and are excluded from the analysis.
- Physical simulation costs $399 per participant.
- Virtual reality simulation is as effective as physical simulation.
- There are 100 learners per institution.
- The institution purchases VR hardware at $7,000 per set. As such this is $70 per learner [7000/100]. Note this cost is only applicable in year 1.
- 20 virtual reality scenarios with unlimited options to repeat are available for $300.
- If the learner was to do all 20 scenarios with scenarios repeated once, the cost is therefore **$9.25** [(300+70)/40] per scenario for the first year, **$7.50** [300/40] per scenario thereafter.

Cost-Utility Calculations

- Assuming an annual training budget of $600 per learner, an institution could deliver **1.50** physical simulation scenarios per learner [600/399].
- With this same budget, the institution could deliver **40.0** [600/300)x20] VR simulation scenarios, assuming learners do every scenario once.
- With this same budget, the institution could deliver **80.0** [(600/300)x40] VR simulation scenarios if each learner does every scenario twice, with this use voluntary use pattern demonstrated in trial data.
- To summarize: **for $399, an institution could run 1 physical simulation scenario or buy licenses providing access to 80 virtual reality scenarios.**

Return on Investment Analysis

Return on investment (ROI) measures the gain generated by an investment (in this case VR simulation) relative to the amount of money invested. ROI is usually expressed as a percentage. It can be calculated as: (Gain from Investment - Cost of Investment) / Cost of Investment (x100 if percentage).

Return on Investment Assumptions

- Both physical simulation and VR simulation are available to the given institution.
- Sunk costs (eg. building costs) are non-recoupable and are excluded from the analysis.
- Physical simulation costs $399 per participant.
- Virtual reality simulation is as effective as physical simulation.
- There are 100 learners per institution.
- The institution purchases VR hardware at $7000 per set. As such this is $70 per learner [7000/100]. Note this cost is only true for the first year.
- 20 virtual reality scenarios with unlimited options to repeat are available for $300.
- If the user was to do all 20 scenarios with one repeat only, the cost is therefore $9.25 [(300+70)/40] per scenario for the first year and $7.50 [300/40] per scenario thereafter.
- The institution already invests in physical simulation and believes it to be cost effective. As physical simulation costs $399 per participant, the institution places the gain from investment in delivering simulation at $399.

Return on Investment Calculations

- If we assume the institution would like to provide students with *20* simulation sessions per year, either using VR or mannequins, the ROI from adopting VR = (((20x399)-300)/300)x100 = **2,560%.** At high numbers of scenarios VR therefore delivers a huge return on investment.
- Even if we now assume the institution would like to provide students with only *two* simulation sessions per year, either using VR or mannequins, the ROI from adopting VR = (((2x399)-300)/300)x100 = **166%.** Therefore, even if a low number of scenarios are being undertaken, VR delivers a clear return on investment.
- Looked at in another way, **if an institution had 20 learners where learners were required to accomplish two simulation sessions per year, they could buy one set of hardware at $7,000 and learners would each need to do *only one VR simulation scenario out of the twenty (and do it only once)* to make a positive return on investment.**
    - ((((20x2)x399)-(7000+(300x20)))/(7000+(300x20)))x100 = **22.8%**

Summary

Physical simulation is effective but costly, involving both fixed and ongoing costs. Virtual reality simulation from OMS demonstrates clear cost utility and return on investment. Where physical simulation averages $399 per learner per simulation, OMS VR simulation can save time, space, and money - reducing the cost for one learner to lead a scenario to $15 if learners do a scenario once, or $7.50 if they repeat the scenario.

- Cost utility
    - For $399 an institution could run **one** physical simulation or buy hardware and licenses to cover **80** virtual reality scenarios.
- Return on investment
    - If learners do 20 VR simulation sessions per year rather than physical simulation the ROI is **2,560%**
    - If learners perform only two simulation sessions per year instead of physical simulation the ROI is **166%**
    - Even if learners perform only one simulation session per year instead of physical simulation the ROI is **22.8%**, making the case for VR simulation, even without large user volumes.

In addition to providing clear return on investment, OMS VR simulation can make scenarios more realistic, standardize quality, collect data and democratize delivery of simulation. It can allow students to take control of their own learning and provide the opportunity to learn collaboratively, ultimately improving performance and optimizing patient care.

In summary, “though the development costs can be high, the expected revenue, in terms of better patient care and prevention of error, provides a decisive argument for investing in such development.”(11)

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