EIM 329: Virtual Reality Orthopaedic Simulator

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Addressing the Lack of Experience and Familiarity of Orthopaedic Residents in Clinicals

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Introduction

This report aims to examine the progress made by our team, focusing mainly on Project Clarification, Concept Design and Prototyping. Some key terms will be defined in Table 1 to facilitate the understanding of our project.

Table 1: Terminology

Terminology	Meaning
Orthopaedic	Field of medicine involved in the surgical treatment of conditions concerning the musculoskeletal system
Resident	Junior Doctor training to be a specialist
Consultant	Senior Doctor that has already completed specialist training
Patient	The Patient with a scheduled appointment with the Doctor
Clinicals	Process where consultants see patients with prior appointment scheduled
Malpractice Claim	The situation where a patient files a lawsuit against the doctor due to an incidence of clinical misdiagnosis

1.1 Problem

Under supervision from the consultant, residents often conduct Clinicals as part of their specialist training. However, the number of doctors in Singapore has been increasing much faster compared to population growth. Thus, resulting in the decrease in the number of patients per doctor. The Doctor to Patient ratio has decreased by 35% from 1:635 in 2006 to 1:410 in 2018 [1]. As such, the number of patients that residents see during Clinicals has decreased, reducing the number of patient interactions and clinical practice they receive during their specialist training. This results in the Orthopedic residents becoming less experienced and familiar in conducting Clinicals. Hence, the problem we will be addressing would be the **lack of familiarity and experience of the Orthopaedic residents in Clinicals.**

1.2 Significance of Problem

Due to the lack of experience and familiarity, the residents tend to take longer time to diagnose patients. Certain diagnostic tests may also be conducted more than once if the resident fails to come to a conclusion the first time [2]. As such, patients have to suffer through a longer clinical session. The lack of experience and familiarity in Clinicals also leads to an increased risk of clinical misdiagnosis [3]. A study showed that Orthopedics was among the top 4 medical specialties that had the highest rate of physicians with a Malpractice Claim annually [3].

1.3 Objective of Our Project

This project aims to increase the familiarity and experience of Orthopedic residents in Clinicals, increasing their speed of diagnosis and reducing patient suffering. The increased experience and familiarity would increase the resident’s accuracy of clinical diagnosis, reducing the risk of the resident receiving a Malpractice Claim.

In the subsequent sections, we will first take you through the breakdown of our Design Statement and value proposition, before detailing the process of our concept generation and the eventual selection of our proposed solution. Next, we then talk about the prototyping progress regarding the different components of our proposed solution along with the insights we have gained. Finally, we will conclude the report with a summary of our progress so far, as well as the challenges we have faced.

Design Statement

2.1 Observation Session of Orthopaedic Clinicals

The lack of experience and familiarity of the residents when conducting Clinicals is a complex and multi-faceted issue. In order to further analyse and breakdown the problem, we conducted primary research by observing an Orthopaedic Clinical session at National University Hospital (NUH). During the session, we observed Dr Eugene Lau (Resident) attending to 3 patients under the supervision of Dr Gabriel Liu (Consultant). Clinicals were primarily conducted by Resident. Only when necessary or in cases whereby errors were made by the Resident, the Consultant would interrupt to provide guidance [2]. (Refer to Appendix A for the session details).

2.2 Value Proposition

After observing the clinical session, it became clear to us that the three stakeholders involved were the consultants, residents and the patient. However, for our project, we decided to focus on the residents and consultants as our key stakeholders as the patient's needs would be directly met upon the resolution of the problem (Refer to Appendix B for personas of key stakeholders). Consultants were chosen as a key stakeholder as the resident's learning progress is strongly dependent on the consultants' monitoring and feedback. From our observations, we identified the needs of our key stakeholders (Table 2) and their respective Point-of-View (POV) statements (Table 3). By considering our stakeholders' needs and POV, we established our design direction in multiple "How might we" (HMW) statements (Table 4), which will guide us in designing our design statement and proposed solutions.

Table 2: Stakeholders' needs

Residents need…	Consultants need…
Familiarity with the clinical procedures (verbal tests and physical examinations)	Pinpoint residents' mistakes promptly and provide immediate feedback
Effective and efficient communication with patients while empathizing with them	Track residents' proficiency level during Clinicals
Greater number of exposures to different medical cases, especially rare cases	Minimise extra patient consultation time due to the training of residents

Table 3: Stakeholder's Point-of-View (POV)

Residents' POV	Consultants' POV
Need more practice in Clinicals to gain more experience, helping them to make faster and more accurate diagnosis of patients	Need to constantly monitor residents to pinpoint their mistakes promptly and provide immediate feedback to enhance their learning
Need more practice in Clinicals to increase their familiarity with clinical procedures, facilitating the conduct of these procedures while attending to the patient's needs	Need a system to keep track of residents' proficiency level in different segments of Clinicals, such as the accuracy of their diagnosis and follow-up plans
Needs more patient interaction opportunities to better communicate and empathize with patients, to help residents quickly understand their medical conditions.	Need a tool to demonstrate the correct clinical procedures to the residents such that patient's consultation time stays within 10 minutes [2]
Need more exposure to different medical cases, especially rare cases, to better prepare them for similar cases in the future	

Table 4: Our design direction

How might we…
1. Create a platform containing a wide variety of patient scenarios for residents to gain experience in clinical assessments to diagnose the patient quickly and accurately
2. Design a realistic simulation tool to increase the number of interactions between the residents and patients to improve their ability to build rapport and empathise with the patients
3. Design an easily accessible simulation tool to make clinical practice more available to residents, helping them gain familiarity with the necessary clinical tests
4. Provide consultants with a fast, user-friendly and portable system to give instant feedback to multiple residents during Clinicals, optimising the learning process of the residents

2.3 Existing Solutions

There are various educational tools in the current medical education market, namely independent learning, classroom-based learning, hospital or clinic-based learning and simulation tools [4]. However, considering the nature of Clinicals whereby human interactions are essential and our HMW statements, only simulation tools are adequate to fulfil these criteria.

Simulation tools allow for the application of important non-technical skills such as teamwork, communication and leadership, which are essential in a clinical context. It offers the most practical way of visualisation for residents to analyse their skills in real-life context. A higher level of cognitive and practical skills is used as they face real-life challenges during clinical simulations. Furthermore, simulation tools satisfy the residents' desire for practice and provide them with a more meaningful training experience. Thus, providing them with a greater motivation to learn.

Using our HMW statements, we constructed an evaluation framework (Table 5) to evaluate the efficacy of the current simulation platforms in relation to the problem we are addressing (Refer to Appendix C for details of current platforms). It is also important to note that all platforms evaluated showed an average of 8 in Technological Readiness Levels. Thus, the Technological Simulation Level (TSL) rubric [5] (Refer to Appendix D for TSL rubric), a scale specifically designed to evaluate and gauge the stage of development of the simulation solutions, was used instead as a better means of comparison between the simulation solutions. As seen in table 6, each current solution has its own limitations, making them inadequate to serve as a simulation tool for Orthopaedic clinicals. Hence, our proposed solutions will circumvent these limitations and address all evaluation criteria.

Table 5: Evaluation criteria for existing solutions

Degree of realism (TSL rubric)	It should provide residents with hands-on and experimental-based learning, involving most senses (sight, smell, touch) to facilitate learning
Long-term sustainability	It should require minimal resources and yield consistent long-term benefits in terms of cost and manpower required to operate the platforms
Scalability of Database	Ease of expanding the database to include more patient scenarios in the area of Orthopaedic Clinicals

Table 6: Evaluation of current simulation platforms

	Degree of realism (TSL Rubric)	**Long term Sustainability**	**Scalability of Database**
Standardised Patients (SPs) [6]	(*Level 3*) Human actors enhance visual realism. However, patient behaviour is scripted.	(-) Most SPs work part time, resulting in limited availability. Takes considerable training time and investments to train.	(-) SPs may forget scripts, negatively affecting residents' learning. Scenarios limited by SPs' acting ability
Oxford Virtual Reality Medical Simulation [7]	(*Level 4*) Less realistic as selection of equipment comes from a drop-down text menu	(+) No additional manpower required to operate the devices	(-) Scenarios are generalized, hence orthopaedic scenarios must be expanded by building them from scratch
SimX Virtual Reality Medical Simulation [8]	(*Level 4*) Realistic visual aspect due to 3D graphic design. Patient behaviour is unscripted and realistic	(-) Requires additional medical professionals to operate the dialog flow externally, increasing the strain on limited resources	(+) It is easy to scale up the database as it has access to thousands of cases from hospitals around the world
Acadicus Virtual Reality Medical Simulation [9]	(*Level 4*) No voice interaction between patient and doctor (only physical)	(-) Considerable training time and investments to train medical professionals at developing scenarios (High adoption cost)	(-) Patient scenarios can only be expanded by building them from scratch

2.4 Market Analysis

In addition, the market for medical simulation tools for education and training purposes is expected to grow, thus presenting opportunities and value for development. The market for medical simulation tools is set to reach USD 400 Billion by 2024, with a compound annual growth rate of 14.2% [10]. The key market drivers include the advantages of simulation over conventional learning, the increased emphasis on patient safety, the potential cost savings medical simulation can bring, as well as the huge demand from academic institutes. [10] As seen from the number of current simulation platforms stated above, there are fewer competitors in the market of clinical simulation, especially in the area of orthopaedic. Hence, directing our design statement and proposed solutions towards simulation tools for training purposes in the area of Orthopaedics Clinicals will ensure business viability and sustainable growth in the long run.

2.5 Design Statement

Overall, simulation is the most effective tool for medical education in the area of Orthopaedic Clinicals. This helped us craft our design statement, which will form the basis of all our proposed solution. Hence, **our project aims to design a realistic, user-friendly and easily accessible simulation tool to help orthopaedic residents gain more experience and familiarity in clinicals, as well as receive real-time feedback from the consultants.**

Proposed Solution

3.1 Design Specification

In addition to our Design Statement to guide us in our ideation process, it is also important that our proposed solution adequately address our stakeholders' demands and potentially their wishes too. Hence, their demands and wishes (Table 7) will form the basis of our concept selection and evaluation of our proposed solution.

Table 7: Demands and wishes of key stakeholders

Demands	
Requirements	**Keywords**
A scenario database that can be expanded by uploading past medical diagnoses and patient conditions	Variability, Exposure
Able to change conversational flow by reacting to the residents' input	Adaptability, Dynamic
Able to accurately depict the nature and location of pain through facial expression and impaired motion	Accurate depiction
Able to realistically reconstruct 3D model of a human patient, with special attention to bone structures and joint movements	3D modelling, Anatomy, Orthopaedic parameters
Enable the consultant to deliver instant feedback and demonstrate correct procedures to residents at the point of error	Instant feedback
Wishes	
Able to provide key metrics of resident's performance to both residents and consultant, identifying areas of improvement and strengths	Grading system
Able to allow multiple users to collaborate while at different locations	Collaboration, Different locations

3.2 Function Analysis

Functional analysis is a process of translating system-level requirements into detailed functional and performance design criteria. Considering the clinical procedures, we identified 3 core functions, patient interaction with the resident, real-time intervention by consultant and grading system. We further break down these 3 core functions into multiple detailed sub-functions (Figure 1), facilitating the ideation process of our proposed solutions.

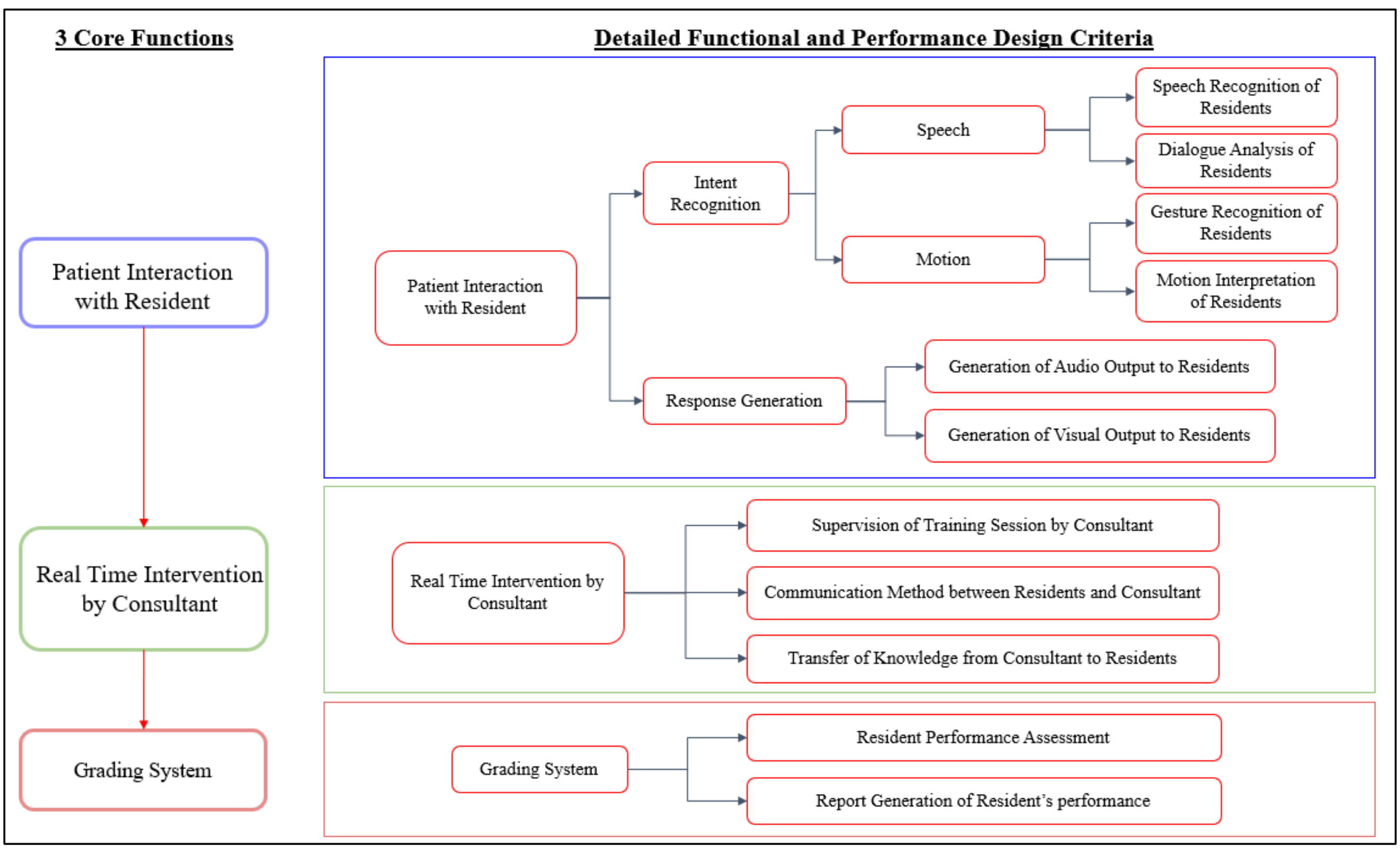

Figure 1: Function analysis

3.3 Proposed Solutions

Considering the sub-functions identified, we generated different concepts (Refer to Appendix E for details of concept generation). Following our design statement and design specifications, we developed 5 different Orthopaedic Clinical simulation platforms that allow residents to interact with a virtual patient controlled by artificial intelligence, or humans (Refer to Appendix F for details of the solutions). These solutions will serve as practice tools to increase residents' familiarity and experience in Clinicals. Thus, these solutions were designed with TSL levels of at least 3, to ensure an adequate degree of realism and effectiveness for clinical practice.

Solution A: Brain Controlled Computer Simulation

This solution involves a computer simulation, where the resident controls a virtual avatar via brain signals using a Brain-Computer Interface [11]. Brain signals from the resident's brain will be translated into motions and speech commands of the avatar as it interacts with the virtual patient. This allows a higher degree of motion control over the avatar compared to a physical controller. Haptic feedback from the interaction between the avatar and virtual patient will be relayed to the resident using vibrotactile feedback [12]. Both features enhance the degree of realism for the resident. The resident's motions are analysed using a deep learning algorithm, while a conversational agent that utilizes Natural Language Processing (NLP) processes resident's speech inputs, allowing the virtual patient to react accordingly. A video recording function for clinical playback enables residents to view the playback of their simulation with detailed feedback inserted throughout the video by the consultant.

Solution B: High Fidelity Virtual Reality Simulation

This solution involves virtual reality (VR) technology, giving the resident an immersive, first-person perspective of the clinical simulation in a virtual environment. The VR headset is in-built with motion tracking cameras, boasting controller-free hand-tracking capabilities [13]. Coupled with the smart wearable textile on the resident, these functions will provide a high degree of motion tracking and interpretation. Aside from motion tracking, an in-built conversational agent will utilise NLP to process the resident's inputs. Thus, these features will aid in triggering appropriate responses by the virtual patient. Furthermore, as this platform supports multiplayer [14], the consultant can enter the same virtual environment as the resident, allowing for interaction between the resident, consultant and virtual patient. This will enhance the resident's learning experience.

Solution C: Holographic Room

This solution is a 3D holographic projection system that allows 3D hologram illusions to be created using projections [15]. The resident will interact with a holographic virtual patient. The specialized room will be equipped with a motion capture system, which captures motions using ultrasound [16]. Using the emission and reflection of ultrasound signals, the system will detect and analyse the resident's movements and body positions. The deep learning algorithm subsequently generates appropriate responses for the holographic virtual patient. The Consultant can enter the simulation room to monitor and provide feedback, allowing interactions between the resident, consultant and patient. Audio responses are generated via a dialogue tree programmed into the system.

Solution D: AR Simulation + Full Body Haptic Suit

Using augmented reality (AR) technology, this solution provides residents with an interactive experience of a real-world environment where the objects and surroundings are enhanced by computer-generated perceptual information [17]. By overlaying 3D graphics onto objects and the surroundings, it mimics a clinical setting. Furthermore, a full-body haptic suit will capture and analyse the resident's motions [18], providing a high degree of motion control. This detected motion will trigger virtual patient motions. Also, the virtual patient is controlled by a conversational agent that utilizes NLP to process residents' speech inputs, to generate appropriate replies.

Solution E: Virtual Standardized Patient for Hire

This solution utilizes Virtual Reality technology, similar to that of Solution B. The difference is that while Solution B involves a virtual patient controlled by a conversational agent, Solution E utilizes the multiplayer capabilities of VR to allow the virtual patient to be controlled by another person. Such human to human interaction through VR allows human interpretation of both motion and speech, boasting the highest degree of realism possible. When the resident starts the simulation, the system will automatically match him with a certified standardized patient actor. Upon a successful match, both parties will enter the virtual environment together by utilizing VR headsets at their own locations. The simulation will then proceed with the certified actor controlling the virtual patient. Furthermore, as the platform supports multiplayer feature, any consultant or certified orthopaedic clinical examiner can be hired to assess the resident in the same virtual environment. This allows for interaction between the resident, consultant and patient, enhancing the resident's learning experience.

3.4 Concept Selection

In order to choose a solution that best fulfills our stakeholder's demands and wishes, we compared the relative strengths and weaknesses of our proposed solutions using a weighted scoring matrix (Refer to Appendix G for justification of the scoring matrix). Hence, we selected Solution B for further development (Table 8).

Table 8: Weighted scoring matrix of our proposed solutions

		Concepts									
		A		B		C (REF)		D		E	
SELECTION CRITERIA	Weight (%)	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Expandable Database	15	5	0.75	4	0.6	3	0.45	2	0.3	1	0.15
Adaptive Conversational Flow	15	4	0.6	4	0.6	3	0.45	4	0.6	5	0.75
Accurate Patient Behaviour	20	1	0.2	4	0.8	3	0.6	4	0.8	5	1
Accurate Anatomical Features	15	2	0.3	2	0.3	3	0.45	3	0.45	3	0.45
Sense of Touch Simulation	10	1	0.1	5	0.5	3	0.3	5	0.5	4	0.4
Immediate Intervention	15	1	0.15	3	0.45	3	0.45	3	0.45	3	0.45
Useful Grading System	10	5	0.5	5	0.5	3	0.3	5	0.5	3	0.3
	Total Score	2.6		3.75		3		3.6		3.5	
	Rank	5		1		4		2		3	
	Continue?	No		Yes		No		No		No	

Proposed Solution

Upon selecting solution B (High Fidelity VR Simulation), we took a modular approach to break down our prototype into 2 key functions, allowing them to be worked on independently. Naming our Virtual Patient as *Bob*, the conversational agent component will act as his "brain" while the motion and facial animation as his "body".

4.1 Component 1: Conversational Agent

The objective of the Conversational Agent is to analyse speech inputs and generate verbal and physical responses for the virtual patient to output. We have chosen to use the infrastructure and tools provided by RASA to create *Bob*, our very own Conversational Agent [19]. Appendix H.2 shows the prototyping process used to create *Bob*.

4.1.1 Conversing with *Bob*

Figure 3 shows a high-level overview of how *Bob* takes in a text input, detects the intent, and outputs a response (Refer to Appendix H.1 for a detailed explanation of *Bob*'s workflow). In this example, *Bob* correctly identifies the "**introducing_yourself**" intent and outputs "**utter_chit_chat_introduction**" as a response.

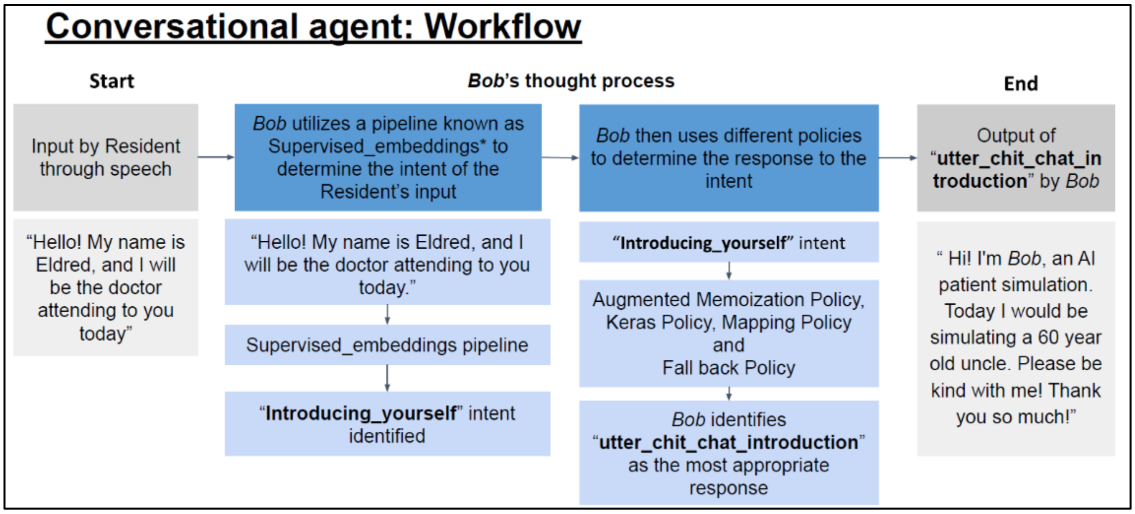

Figure 2: *Bob's* thought process

4.1.2 Results and Testing

Bob was first trained with a small amount of training data to test his functionality. By speaking to *Bob* on RASA-X (Refer to Appendix H.2 for RASA-X deployment process), we noted that he was able to recognize our intent and give the correct reply. Following the successful trial test, we trained him with a larger database in order to prepare for an actual user test case scenario. Note that RASA-X is the interface we use to communicate with *Bob*.

We enlisted the help of Xiao Shiwei, a year 3 NUS medical student who has previously studied orthopaedic clinicals. As such, she is qualified to test out *Bob* and provide feedback on *Bob's* performance (Refer to Appendix H.3 for testing process). *Bob* managed to answer Shiwei in most instances, but there were some cases where *Bob* failed to generate an acceptable response. In those cases, the team had to step in to type in a suitable response to keep the conversation going (Refer to appendix H.3 for examples of where *Bob* succeeded and failed).

4.1.3 Evaluation

From the user testing session of *Bob* with Shiwei, we identified some key insights (Table 9). After analysing user testing results and the feedback obtained from Shiwei, we felt that *Bob* has successfully fulfilled the objectives of a conversational agent, making him suitable for our Virtual Reality simulation tool. However, more work is needed to expand *Bob*'s database to be able to handle the complexity of an actual simulation.

Table 9: Key findings and insights

Key findings identified from the user testing of *Bob* with Shiwei	
Strengths	*Bob* was able to understand most of the questions asked and generate realistic responses accordingly. This gives us validation that *Bob* has achieved what we intended it to do
Limitations (listed according to insightfulness)	• The medical student highlighted that *Bob*'s database needs to be further expanded to respond to inputs related to cancer, weakness and numbness of body, as well as Activities of Daily Living (ADL) independency *(most insightful)* • *Bob* is unable to understand sentences when there are multiple possible answers (e.g. "When do you feel the most pain?" can be answered with the time of the day - morning/night, or when the leg is in a specific position - flexed/extended) • *Bob* is unable to understand user inputs if they are phrased very differently from the training data • *Bob* is unable to understand a user input with multiple intents *(least insightful)* (i.e. "Did the **back pain** and **leg pain** start at the same time?")
Evaluation	*Bob* is a feasible conversational agent that can be incorporated into our Virtual Reality Simulation Tool. However, considerable work has to be done to expand *Bob*'s database and train him to be able to handle the rigour of an actual simulation

4.2 Component 2: Facial and Motion Animation

The objective of animation is to develop *Bob*, into a realistic 3D model that can simulate the actions required during Clinicals. Thus, we explored the concepts of motion and facial animation to investigate the feasibility of building a VR simulation platform supporting an adequate degree of realism essential for Orthopaedics Clinicals.

4.2.1 Animating and Controlling *Bob*

Fundamentally, motion and facial animation involve 3 steps, that is rigging of the model, animation creation and model control. Different software was used to test their feasibility in performing the steps (Table 10) (Refer to Appendix I for more details on the individual steps and the software involved).

Table 10: Software used

Steps involved	Software	Essential features
Rigging	Blender	A free and open-source 3D computer graphics software toolset, which supports the entirety of the 3D pipeline, from modelling to game creation [20]
Animation Creation	Blender	
	Kinect 360	Kinect 360 supports motion-sensing capabilities, allowing the device to perform real-time gesture recognition and detection of up to four people [21]
Model Control	Unity	A cross-platform game engine that supports the assembly of 3D models and animations exported from various sources such as Blender and Kinect 360 [22]

4.2.2 Results and Testing

Through rigging and animation creation, we successfully animated *Bob* to demonstrate a posture of back pain with a sad and painful facial expression. This shows the feasibility of our solution in fulfilling the needs of a realistic simulation (Figure 5). Furthermore, Unity was successfully used to control both *Bob*'s animations that were imported from Blender and Kinect respectively (Figure 6).

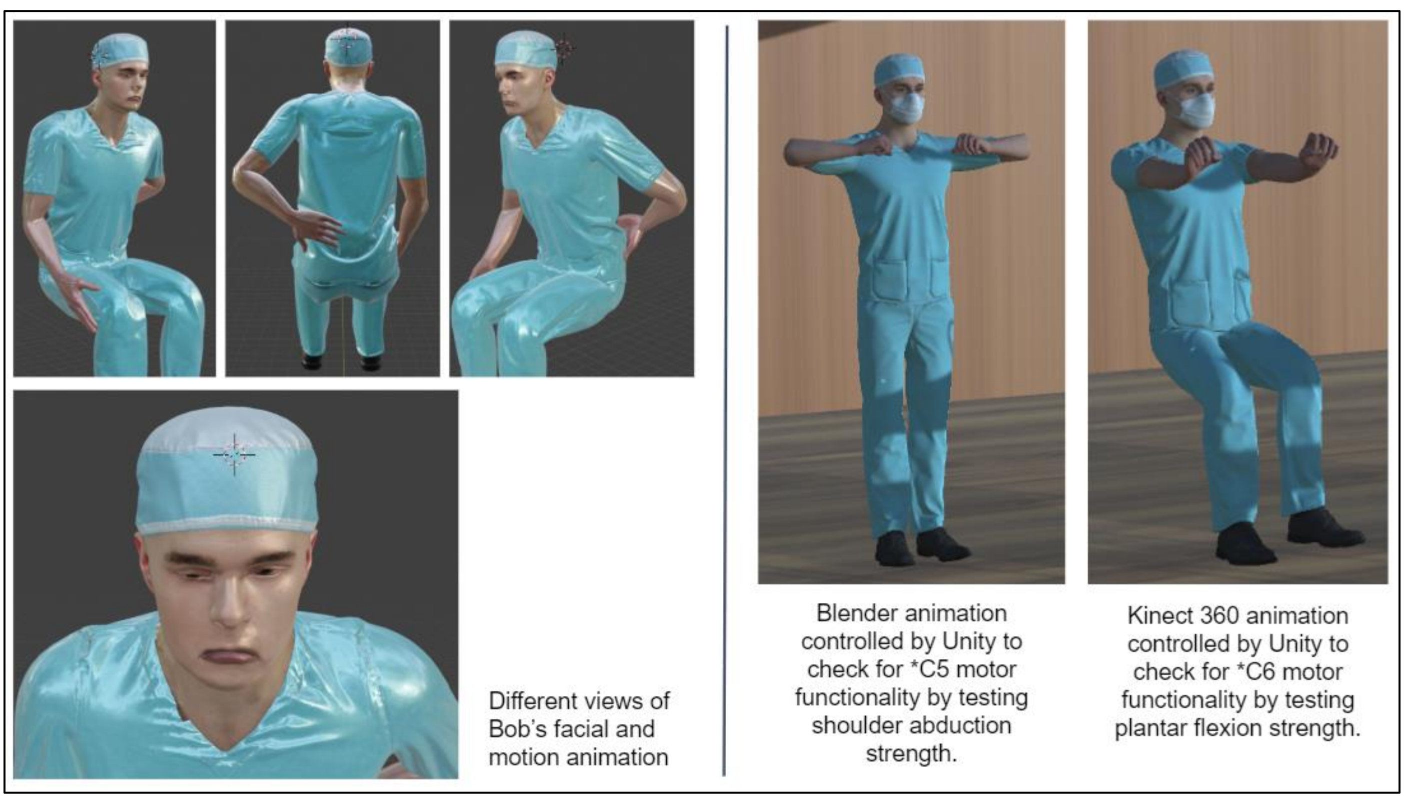

Figure 3: Animation creation and model control of *Bob* (* Refer to Appendix A for spine anatomy [23])

4.2.3 Evaluation

From the testing session of *Bob*, we identified key insights regarding the different software used in each step (Table 11 and 12). We felt that all software can be used simultaneously to ease *Bob*'s animation process, while enhancing the realism of *Bob* in Orthopaedic Clinicals. Overall, *Bob* has successfully fulfilled the objectives of a 3D virtual patient and is a suitable addition to our VR simulation tool. However, more work is needed to expand *Bob*'s database of motion and facial animation to handle the complexity of an actual simulation.

Table 11: Evaluation of animation creation

	Blender (Motion and Facial)	**Xbox Kinect (Motion only)**
Strengths	Allows more precise control over motions.	Able to generate many frames of custom animation at a fast pace (a 20 second video captured at 30fps generates 600 frames).
Limitations	• Very time consuming to individually rotate each bone per frame to make the entire animation. • It lacks the realism of creases in the skin and muscles during facial expression and movements.	• Motion captured may be inaccurate especially when the subject's body part is behind another (e.g. hand behind the leg). • Requires additional hardware to run i.e. Kinect 360 sensor.
Evaluations	This should be used as a post-processing tool to clean up inaccurate motions from Kinect.	This is feasible to create custom animations quickly.

Table 12: Evaluation of model control

	Animation Tab	**Script for Custom Animation**
Strengths	Quicker to animate as it has a graphic user interface (GUI) to drag and drop animations.	Allows for more customizability, and can be extended to speech inputs, rather than just a fixed number of keyboard inputs.
Limitations	Limited in the ability to customize and control our character animations.	It is more time consuming to code for individual animations.
Evaluations	This should be done for quick testing to check if the animation is correctly imported into Unity.	This should be done for our final prototype as it is compatible with more types of user inputs. This will allow better integration with *Bob* when assembling our prototype.

Conclusion

In conclusion, we aim to produce a high-fidelity VR simulation platform that will give Orthopaedic residents a means to practice their clinical skills, helping them become more experienced and familiar in Clinicals. As of now, the team has validated the feasibility of using certain solutions in fulfilling the requirements of the VR simulation platform. We have tested the usefulness of RASA as a conversational agent and trialled 3D gaming and graphics design software like Blender, Unity and Kinect 360 for facial and motion animation.

Throughout the initial conceptualisation and testing phase, we faced certain challenges that impeded our progress. Due to the COVID-19 situation and the activation of DORSCON-ORANGE after our first set of observation in Orthopaedic Clinicals, it became impossible to observe Orthopaedic Clinicals as non-medical personnel were not allowed in hospitals. Furthermore, the team was faced with steep learning curves when attempting to prototype the different components of our solution due to the complexity of the software. Moving on, we hope to further improve both components of our solution by considering the limitations and insights surfaced during the prototyping phase. From there, we will be integrating both the conversational agent as well as facial and motion animation to develop a fully functional VR simulation platform for Orthopaedic Clinicals.

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Appendix

Appendix A: Documentation of the Orthopaedic Clinicals Observation Session

Table 1: Details of observation session

Date	7 February 2020
Time	1700 - 1900
Location	National University Hospital (NUH)
Attending	Chia Ji Hong, Augustine; Eldred Sng Hui Yeong
Supervisor	Dr Khoo Eng Tat
Purpose	• To observe the conducting of Orthopaedic Clinicals (verbal and physical examination) by Dr Eugene Lau (Resident) on 3 patients under the supervision of Dr Gabriel Liu (Consultant) • To gain deeper insights on the problems faced by the residents and consultants during Clinicals

Table 2: Background of patients observed during the observation session

	Background and Medical Conditions
Patient 1	Middle aged IT worker, headache around the left and right side of temple, occasionally across the temple. Had a surgery prior to his headaches.
Patient 2	Elderly female patient complaining primarily of leg pain and difficulty walking
Patient 3	Caucasian male coming in for a routine check-up

Table 3: Summary of insights gained

<table>
<tr><th>Residents</th><th>Consultants</th></tr>
<tr><td>The ability to observe and be sensitive to minute details to detect unspoken symptoms</td><td>The ability to monitor Resident’s actions and interactions to assess their learning process</td></tr>
<tr><td>The ability to identify external factors and their impacts on the final diagnosis</td><td>The ability to intervene in a timely manner if errors were made by Resident</td></tr>
<tr><td>The ability to recall specific details of clinical assessments (verbal and physical)</td><td>The ability to efficiently impart situation-specific clinical skills and knowledge to Resident</td></tr>
<tr><td>The ability to empathize and build trust between himself, the patient and their family members</td><td></td></tr>
<tr><td>The ability to communicate effectively to minimise misunderstandings and obtain all necessary patient information required</td><td></td></tr>
<tr><th colspan="2">General</th></tr>
<tr><td colspan="2">Orthopedic Spine Clinicals are typically conducted in two phases, the history taking phase and the physical examination phase. Based on our observations from clinicals conducted at NUH Orthopedic Spine Clinic:
• The history taking phase involves the resident rapidly asking a set of questions to the patient to narrow down their condition
• The physical examination phase involves the resident testing the sensory and motor functionality of the spinal nerves shown in the diagram (Figure 1)</td></tr>
</table>

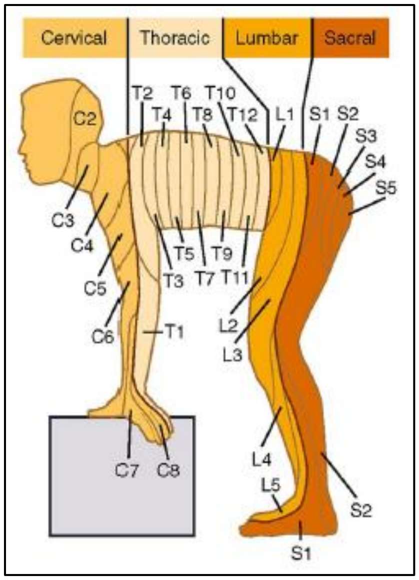


Figure 1: Representation of spine anatomy

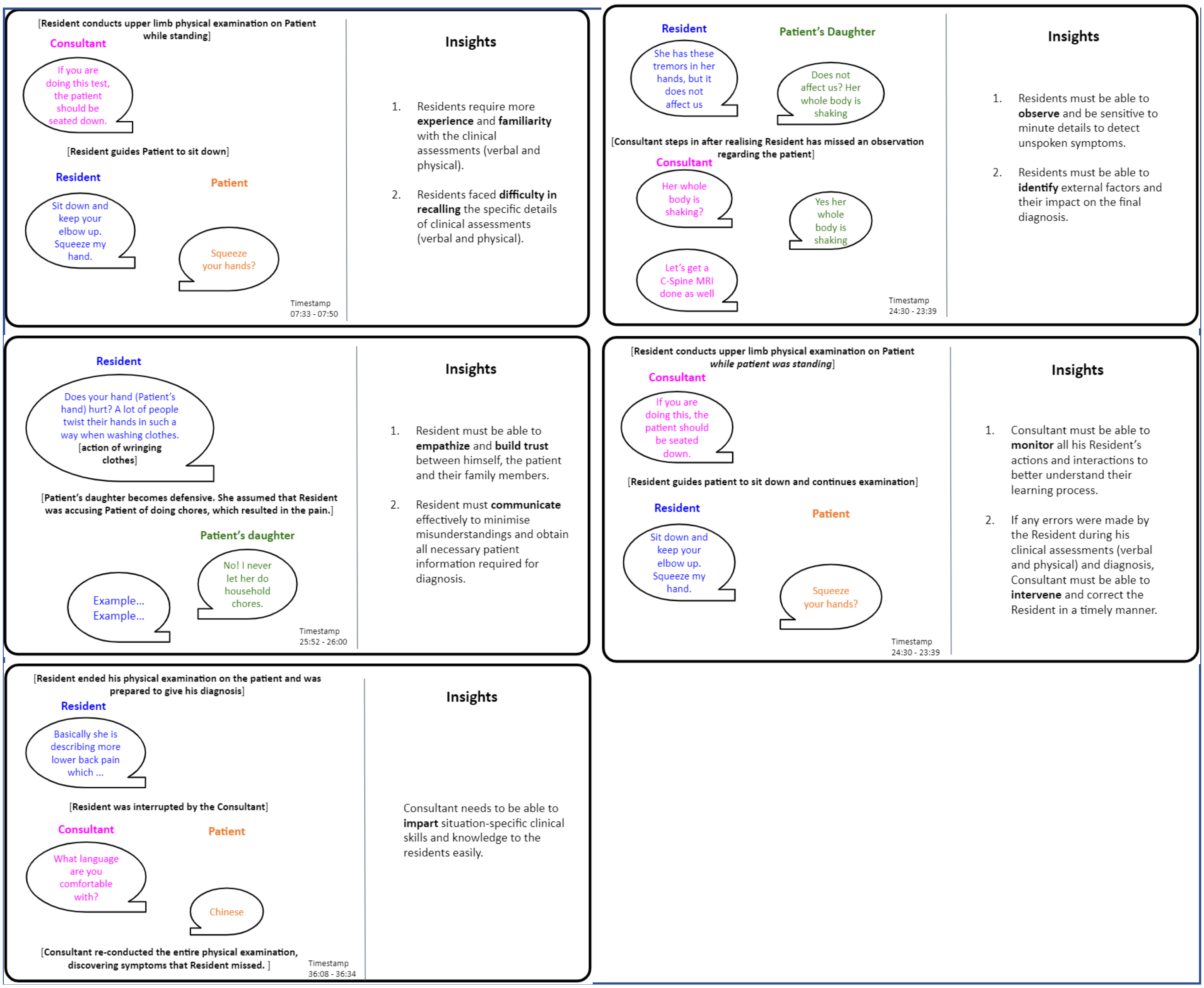


Figure 2: Observation and insights gained

Appendix B: Personas of Key Stakeholders

Persona of Resident

Name: Dr Eugene Lau
Occupation: NUH Orthopedic **Resident**

Key Characteristics:
- Has a very **busy** schedule
- **Limited opportunities** to practice clinicals under guidance from consultant.

Good day in Dr Lau's life:
- Smooth day at the clinic with **minor incidents and mistakes**, easy to figure out patient's mistakes and diagnose them.
- Able to benefit from the short time spent at clinicals and apply his medical knowledge into various scenarios.

Bad Day in Dr Lau's life:
- Difficult to find out patient's problems, **unable to recall** certain medical concepts and getting scolded by the consultant.
- **Misdiagnosing** the patient and getting reprimanded by the consultant.

Figure 3: Persona of Resident

Persona of consultant

Name: Dr Gabriel Liu

Occupation (Academic Appointment): Associate Professor, Department of Orthopedic Surgery

Clinical Appointments:
- Head & Senior **Consultant**
  University Spine Centre
  University Orthopaedics, Hand & Reconstructive Microsurgery Cluster
  National University Health System, Singapore
- Core Faculty
  NUHS Residency Programme
  University Orthopaedics, Hand & Reconstructive Microsurgery Cluster
  National University Health System, Singapore

Persona of consultant

Key Characteristics:
- Always **busy**, moving between 2 clinical rooms and occasionally outside to settle certain management procedures with hospital staff.
- **Confident** in communicating with the patient, due to experience.
- **Familiar** with clinicals to know what mistakes the residents are making.
- **Responsible** for the patients as they are directly under him (not the residents)

Good Day:
- able to **observe** the residents diagnosing their patients one by one, guide them accordingly and intervene **immediately** when they make mistakes.

Bad Day:
- busy with management procedures, and has **no time to supervise** the residents.
- unable to correct the resident's mistakes in time, hindering the learning progress of the residents as well as potentially dangering the patient.

Figure 4: Persona of Consultant

Appendix C: Details of Current Simulation Platforms

Table 4: Details of Standardised Patient

Standardised Patient
Description: A Standardized Patient (SP) is a person carefully recruited and trained to take on the characteristics of a real patient thereby affording the student an opportunity to learn and to be evaluated on learned skills in a simulated clinical environment. They promote patient-centered learning for the residents.
Patent Details: -NIL-

Table 5: Details of Oxford Medical Simulation

Oxford Medical Simulation
Description: Oxford Medical Simulation (OMS) is a virtual reality platform that delivers quality, evidence-based and highly realistic simulation. It assists in efficiently and effectively training healthcare professionals in world-class patient management practices to improve patient care, and without the possibility of risking real human lives. • Users are able to communicate with a patient in a virtual world to give diagnosis and treatment • Allows the doctors to be familiar with diagnosis and treatment of a realistic patient (patient will be visibly pale if left alone untreated) • Gives user an analysis of what was done right or wrong in the process, providing valuable feedback to enhance the resident's learning
Patent Details: -NIL-

Table 6: Details of SimX Medical Simulation

SimX Medical Simulation
Description: SimX Medical Simulation is a wireless, multiplayer, virtual reality medical simulator to increase the familiarity of residents to real diagnosis treatments • Replaces physical simulation mannequins with a customizable, high-definition, 3D virtual patient that can be projected anywhere • Allows residents to diagnose and treat patients who are customised according to their needs • Allows multiple residents to work around the same virtual patient completely wirelessly • Able to provide haptic feedback that increases the realism of the simulation, boosting the resident's learning experience
Patent Details: Title: Augmented and Virtual Reality Simulator for Professional and Educational Training Abstract: Patent for medical training through virtual avatars, and using real life objects projected in virtual space Patent number and link: 20170213473 (http://appft1.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PG01&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&s1=20170213473)

Table 7: Details of Acadicus VRMedical Simulation

Acadicus VR Medical Simulation
Description: Acadicus VR Medical Simulation is a virtual medical learning platform that allows anyone to teach and learn in VR by providing everything needed to access, create and share content created by consultants. • Consultants can capture or access a library of 3D recordings of demonstrations, enabling residents to follow along with as many times as needed anytime and anywhere • Allows users to rehearse training steps in surgical and clinical setting • Live VR sessions enable multiple consultants and/or residents to be together in VR, interacting with assets and participating remotely, allowing for interaction between residents and the consultant for effective communication and real time feedback • Able to create customized patient scenarios that cater to the learning need of the residents.
Patent Details: -NIL-

Appendix D: Technological Simulation Level Rubrics

Table 1. Proposed typology of simulation methodologies split in 6 levels and with there respective characteristic. Each can either be student or trainer-led.

Technological simulation levels	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Simulation technique	Written simulations includes pen and paper simulations or "Patient Management Problems" and latent images	3-D models which can be a basic mannequin, low fidelity simulation models, or part-task simulators	Screen-based simulators Computer simulation, Simulation software, videos, DVDs, or Virtual Reality (VR) and surgical simulators	Standardized patients Real or simulated patients (trained actors), Role play	Intermediate fidelity patient simulators Computer controlled, programmable full body size patient simulators not fully interactive	Interactive patient simulators or Computer controlled model driven patient simulators, also known as high-fidelity simulation platforms
Mode of delivery	Usually student led	Student or trainer led	Student or trainer led	Student or trainer led	Preferably trainer led	Preferably student led
Type	Passive		Interactive		Partly interactive	Interactive
Skills addressed	Cognitive	Psychomotor	Cognitive	Psychomotor, cognitive, and interpersonal	Psychomotor, cognitive, and interpersonal	Psychomotor, cognitive, and interpersonal
Facility required	Classroom	Clinical skills room or classroom	Multimedia/Computer laboratory or classroom	Depends on the scenario requirements	Clinical skills room or simulation centre realistic setting (simulated theatre, ICU, A&E or ward)	Simulation centre with realistic setting (simulated theatre, ICU, A&E or ward) usually set up with audio and video recording equipment
Typical use	Patient management problems Diagnosis Mainly for assessment	Demonstration and practice of skills	Cognitive skills Clinical management Sometimes interpersonal skills (software allowing for a team to interact over networked computers)	Same as Level 2 plus patient physical assessment, diagnostic, or management problems Interpersonal skills	Same as Level 3 plus procedural skills Full-scale simulation training Sometimes used for demonstrations	Same as Level 4
Disadvantages	Unrealistic Feedback cannot be given instantaneously after the exercise	Limited range of training functions No or little interactivity	Unrealistic setting Students and trainers have to be familiar with the software/ equipment Software has to be kept up to date with the relevant medical regulations/procedures VR sometimes requires very high computational power	For small groups of students only Patients have to be trained and briefed Inconvenient if the exercise has to be repeated many times Not valid for any invasive practice unless used in conjunction with a part-task trainer	May require programming of scenarios Several trainers required for a relatively small group of students Trainers have to be familiar with the equipment Requires an emulated patient monitor for most parameters	Cost (mannequin and facility) Several trainers required for a relatively small group of students Trainers have to be familiar with the equipment Not very portable
Advantages	Low cost (no special equipment required in most cases) One academic may be sufficient for a large number of students	Equipment relatively mobile and always available One academic may be sufficient for a class of students working on the same skill Spares patient discomfort	Relatively low cost, except for VR One academic may be sufficient for a large number of students Students can use it on their own (self learning) Software often provides feedback on performance	Can be very realistic A must for communication skills and patient history taking Allows for truly multiprofesional training	Provides a fairly realistic experience Can be used to apply a broad range of skills Students' performance sometimes recorded Allows for truly multiprofesional training Usually portable	Provides a realistic experience Can be used to apply a broad range of skills Students' performance recorded for debriefing Allows for truly multiprofesional training Can be used with real clinical monitoring equipment

Figure 5: Technological Simulation Level Rubrics

Appendix E: Concept Generation

Table 8: Function and solution principles for concept generation

Function	Solution Principles			
Speech Recognition of Residents	Dialog selection	Translation of neural signals into speech	Speech to text software	Human interpretation assisted by speech to text software
Dialogue Analysis of Residents	Natural Language Processing	Dialogue tree	Analysis of transcripts for context and keywords	Human interpretation assisted by Natural Language Processing
Gesture Recognition of Residents	Motion capture system	Emission and reflection of ultrasound signals to detect movements and body position	Physical controller input	Translation of neural signals into motion
Motion Interpretation of Residents	Smart wearable textiles with electromyography sensors to interpret muscle signals	Manual selection of motion	Deep learning algorithm to predict Resident's intents for various motions	Interpretation by real Human
Generation of Audio Output to Residents	Text to speech software	Voice skinning using generative adversarial deep neural networks (GAN) to recreate different voices and languages	Hire voice actors to pre-record audio clips that can be played back	Human voice
Generation of Visual Output to Residents	Use professional actors to pre-record video clips that can be played back	Recreating virtual 3D avatar from multiple photographic images (Photogrammetry)	3D graphic design software	
Supervision of Training Session by Consultant	Live human observation	Video streaming	Holographic projection of the clinical session	
Communication Method between Residents and Consultant	Using audio enabled smart cameras with 2-way audio feature	2-way push-to-talk device	Push-button notification system	
Transfer of Knowledge from Consultant to Residents	Holographic projection of Consultant that is capable of mimicking his actions in real time	Live video conferencing	Virtual Consultant avatar guiding the Residents	
Resident Performance Assessment	System marking based on model answers	Real-time grading by specialists	Entire simulation is videoed down and saved to portal where a pool of qualified Consultants can mark the simulation	
Report Generation of Resident's performance	Online form builders that will use template and populate variable fields	Metrics, comments and visualizations will be presented in the clinical playback to help the Resident visualize his performance	System to view individual and peer learning progression, ie leadership board	

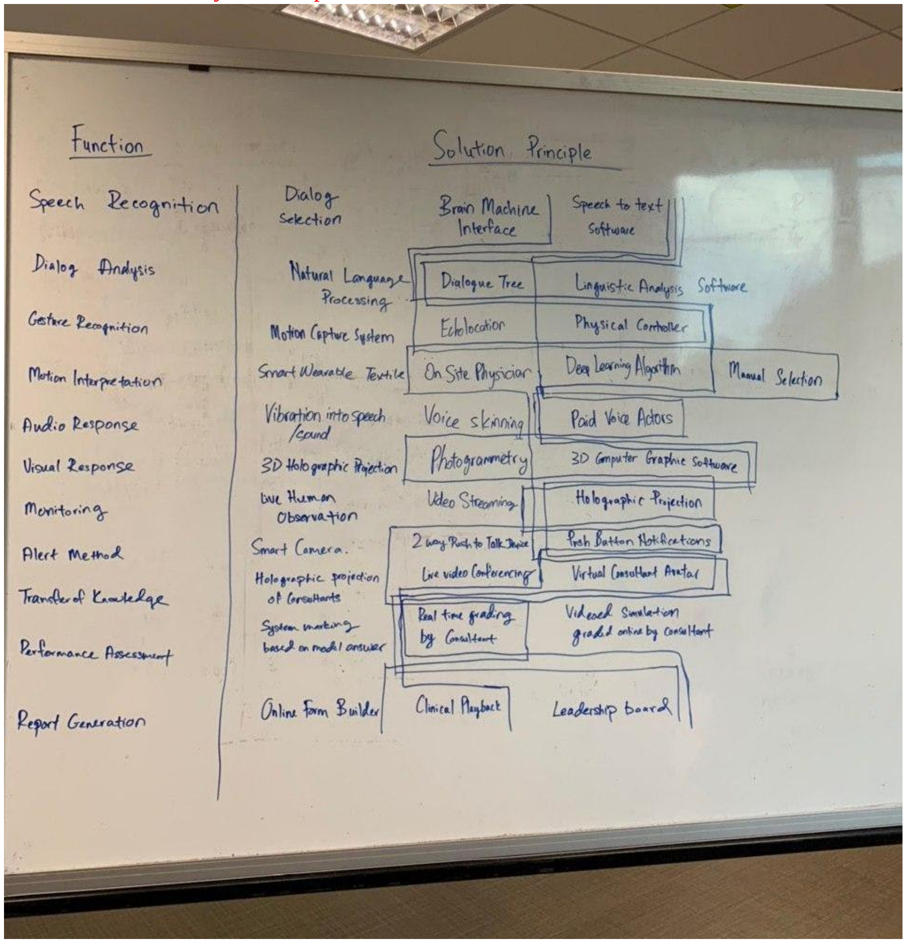


Figure 6: Concept Generation by integrating different solution principles

Appendix F: Details of Proposed Solutions A to E

Table 9: Summary of solution principles for each proposed solution

Functions	A: 2D Brain Controlled Computer Simulation	B: High Fidelity VR Simulation	C: Holographic Room	D: AR + Full Body Haptic Bodysuit	E: Virtual Standardized Patient for Hire
Speech Recognition of Residents	Translation of neural signals into speech	Speech to text software	Speech to text software	Speech to text software	Human assisted by speech to text
Dialogue Analysis of Residents	Natural Language Processing	Natural Language Processing	Dialogue Tree	Natural Language Processing	Human assisted by Natural Language Processing
Gesture Recognition of Residents	Translation of neural signals into motion	Motion capture system	Emission and reflection of ultrasound signals to detect movements and body position	Motion capture system	Motion capture system
Motion Interpretation of Residents	Deep learning algorithm	Smart Wearable Textile	Deep learning algorithm	Smart Wearable Textile	Human interpretation
Generation of Audio Output to Residents	Voice skinning	Text to speech software	Paid voice actors	Voice skinning	Human Voice
Generation of Visual Output to Residents	3D computer graphics software	3D computer graphic software	3D photogrammetry	3D photogrammetry	3D photogrammetry
Supervision of Training Session by Consultant	Video streaming	Video streaming	Holographic Projection	Video streaming	Video streaming
Communication Method between Residents and Consultant	Audio enabled smart cameras with 2-way audio feature	Audio enabled smart cameras with 2-way audio feature	2 way push to talk device	2 way push to talk device	Audio enabled smart cameras with 2-way audio feature
Transfer of Knowledge from Consultant to Residents	Live video conferencing	Virtual Consultant Avatar	Holographic projection of Consultants	Virtual Consultant Avatar	Virtual Consultant Avatar
Resident Performance Assessment	System marking based on model answer	System marking based on model answer	Real time grading by Consultant	System marking based on model answer	Real time grading by certified patient and external grader
Report Generation of Resident's performance	Clinical Playback	Leaderboard system	Online form builder	Leaderboard system	Online form builder

F.1: Solution A – Brain Controlled Computer Simulation

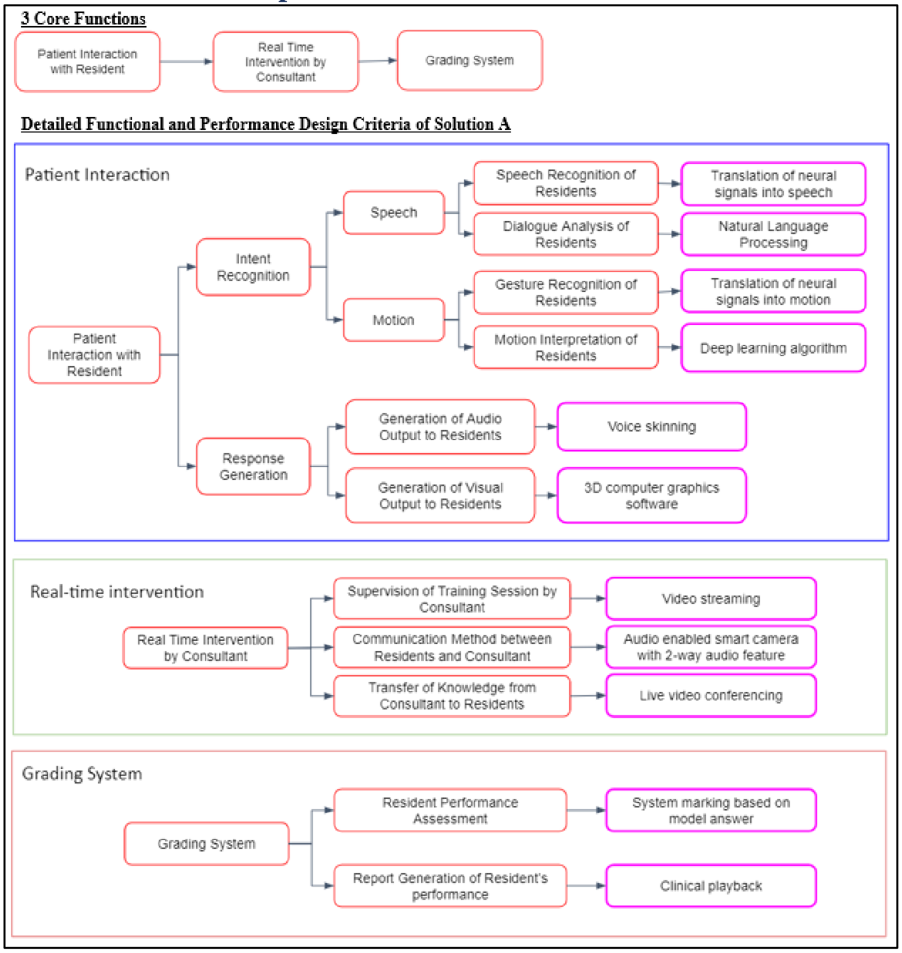


Figure 7: System architecture of solution A

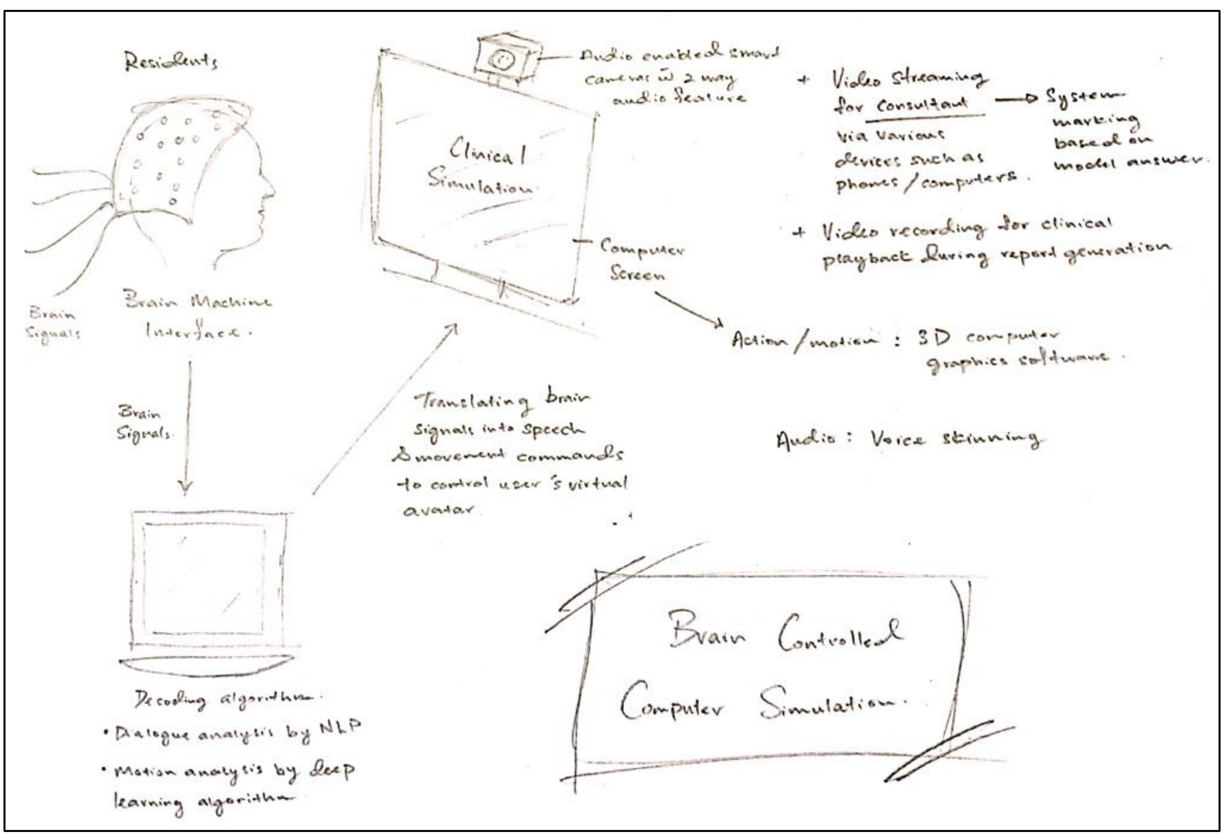


Figure 8: System design of solution A

F.2: Solution B – High Fidelity VR Simulation

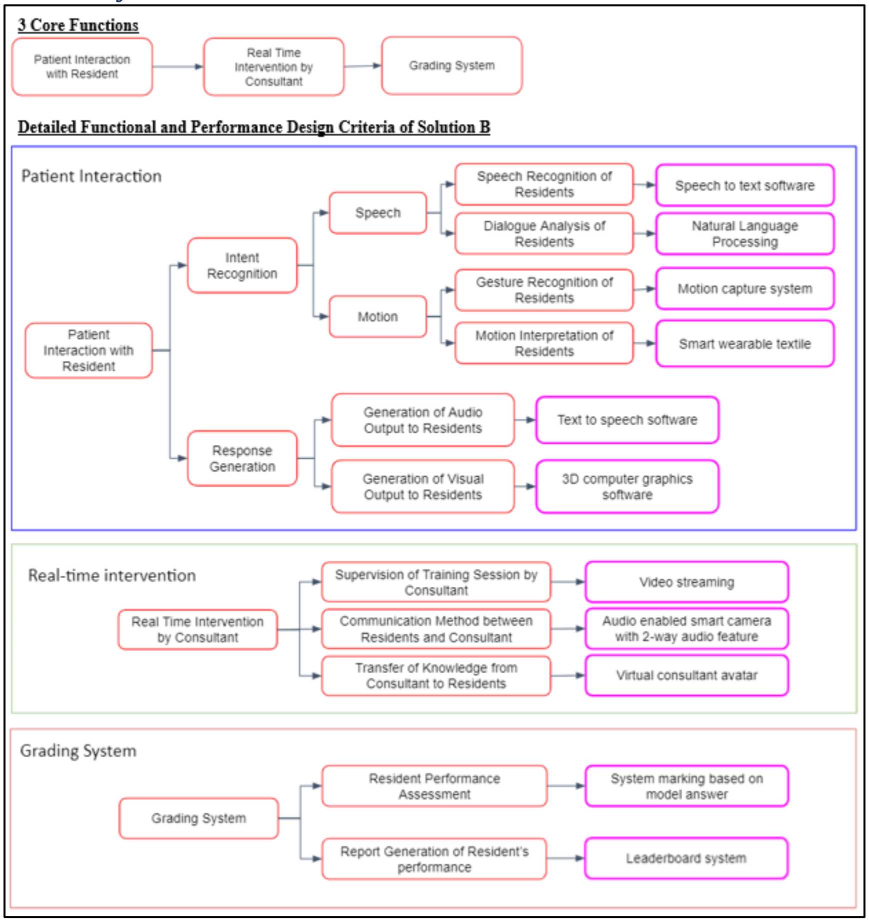


Figure 9: System architecture of solution B

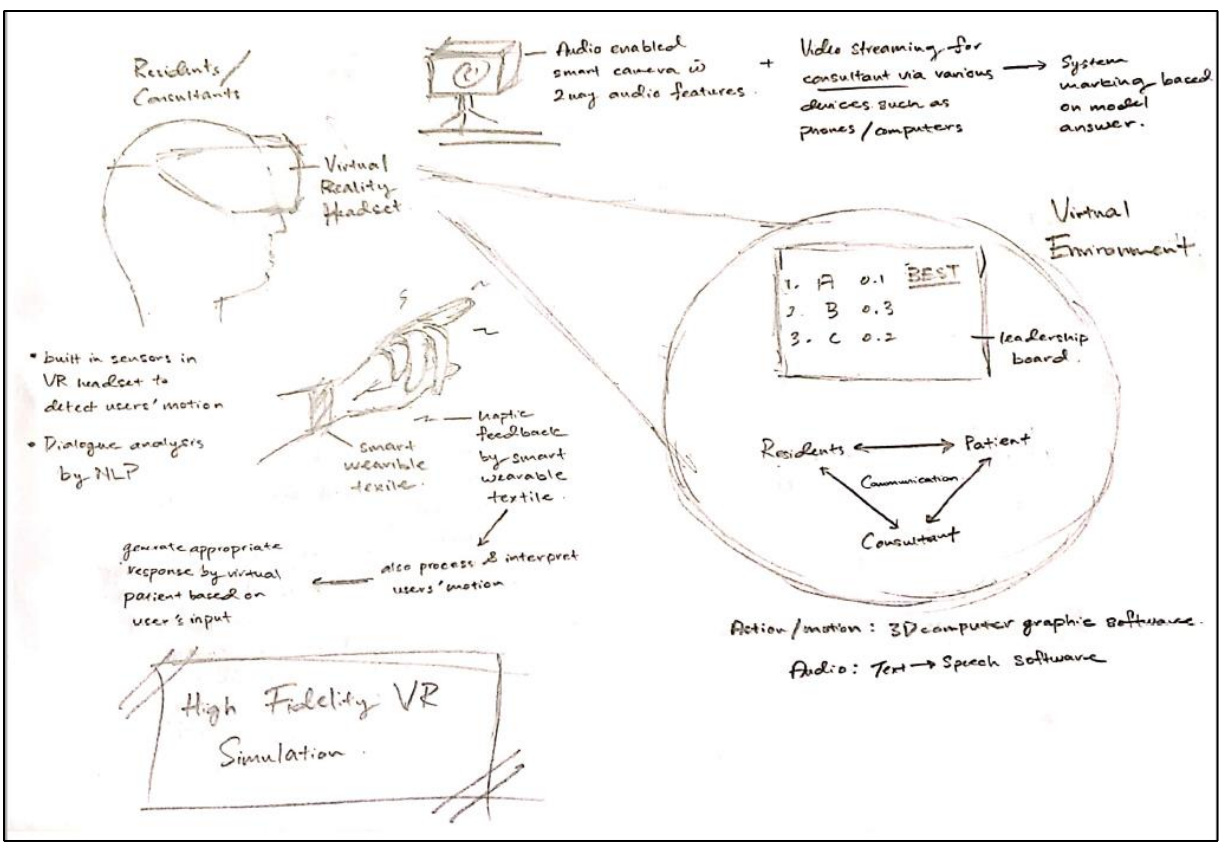


Figure 10: System design of solution B

F.3: Solution C – Holographic Room

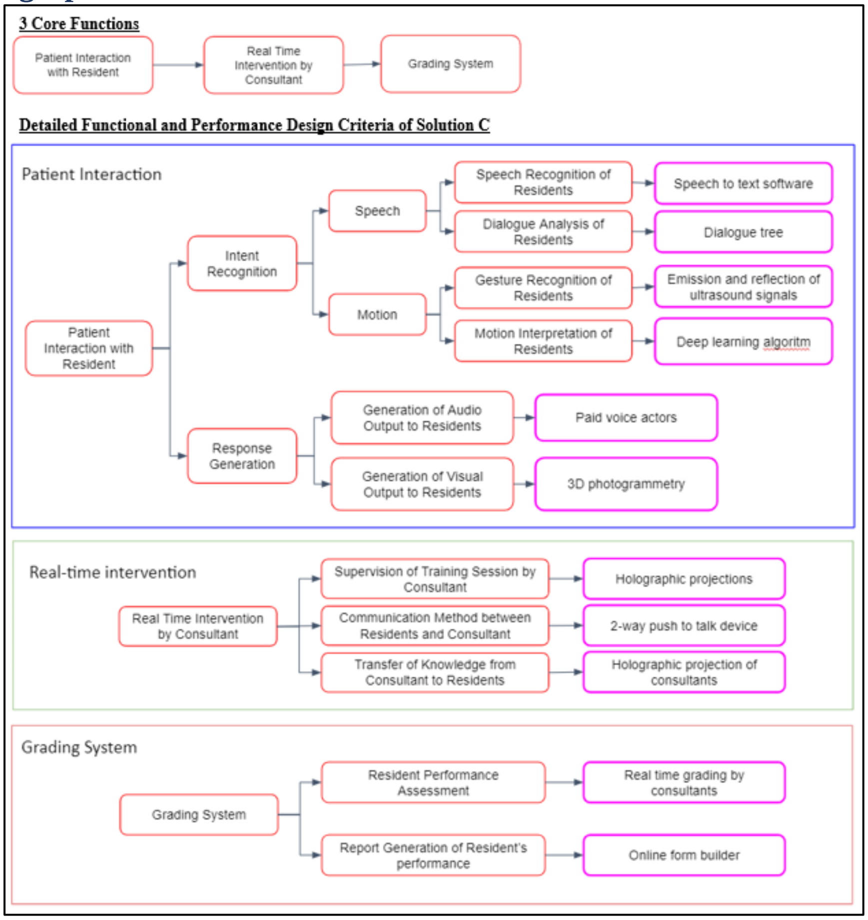


Figure 11: System architecture of solution C

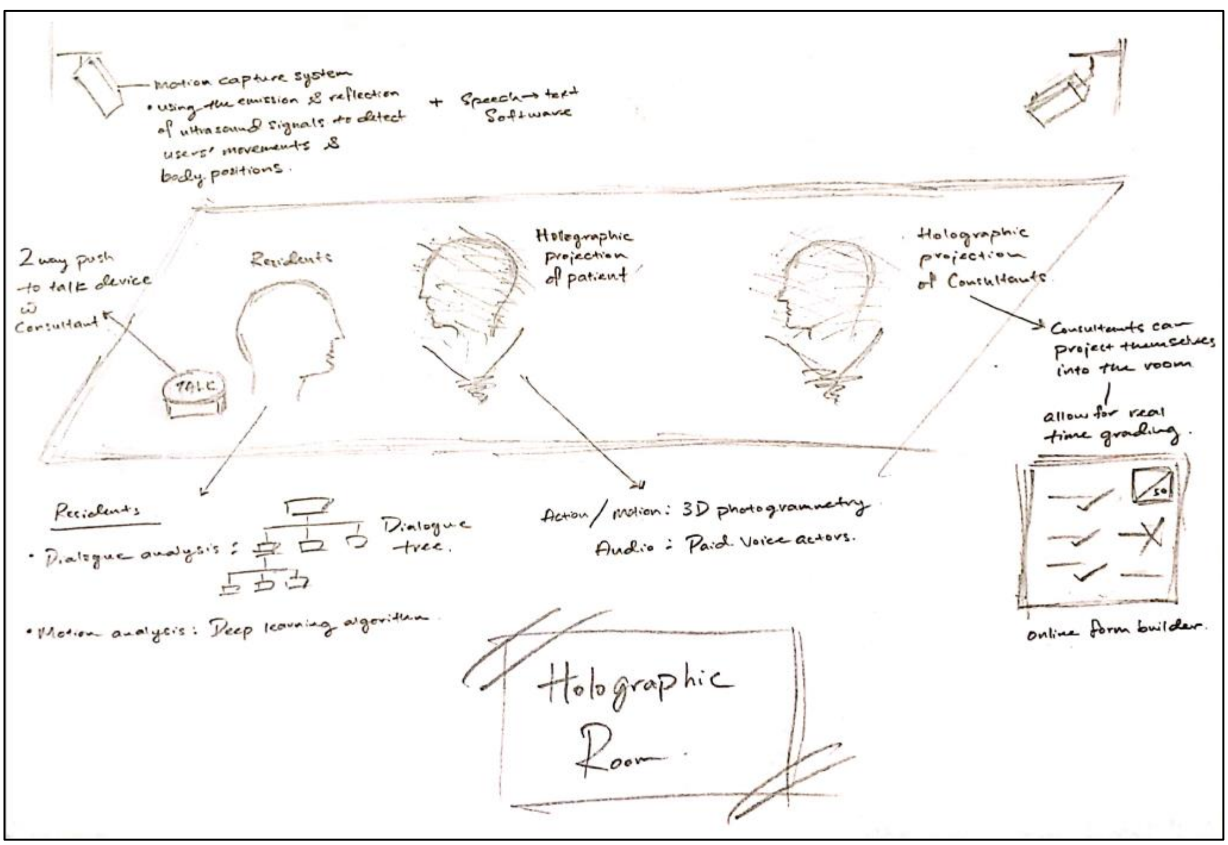


Figure 12: System design of solution C

F.4: Solution D – AR Simulation + Full Body Haptic Suit

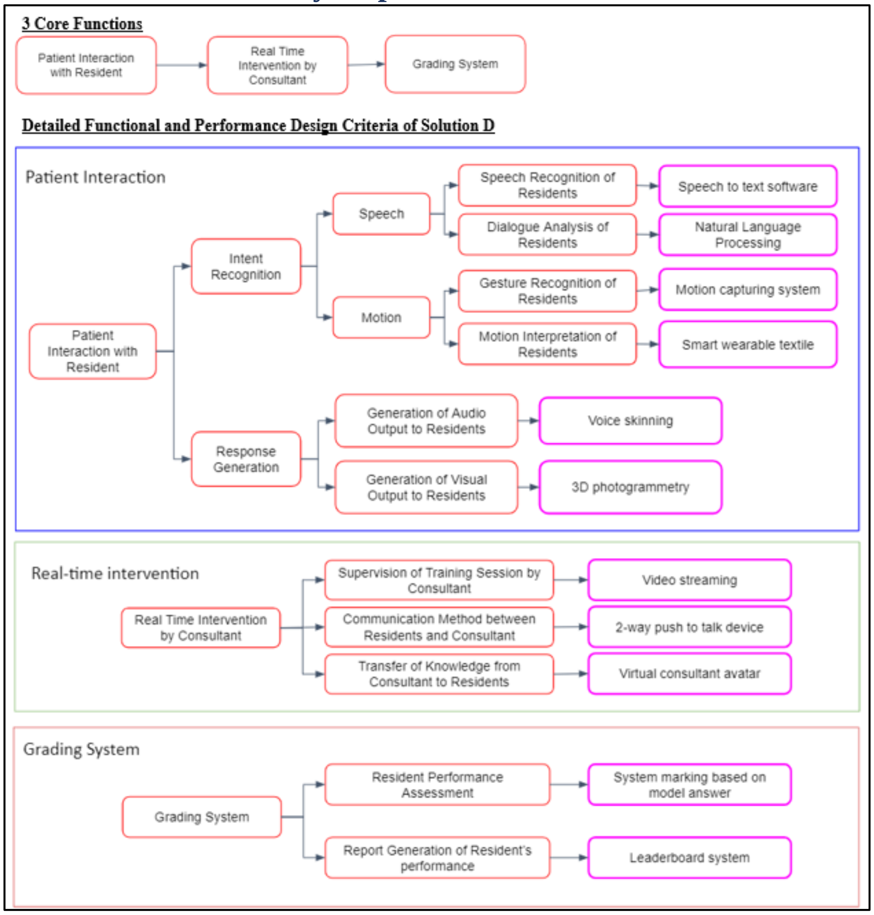


Figure 13: System architecture of solution D

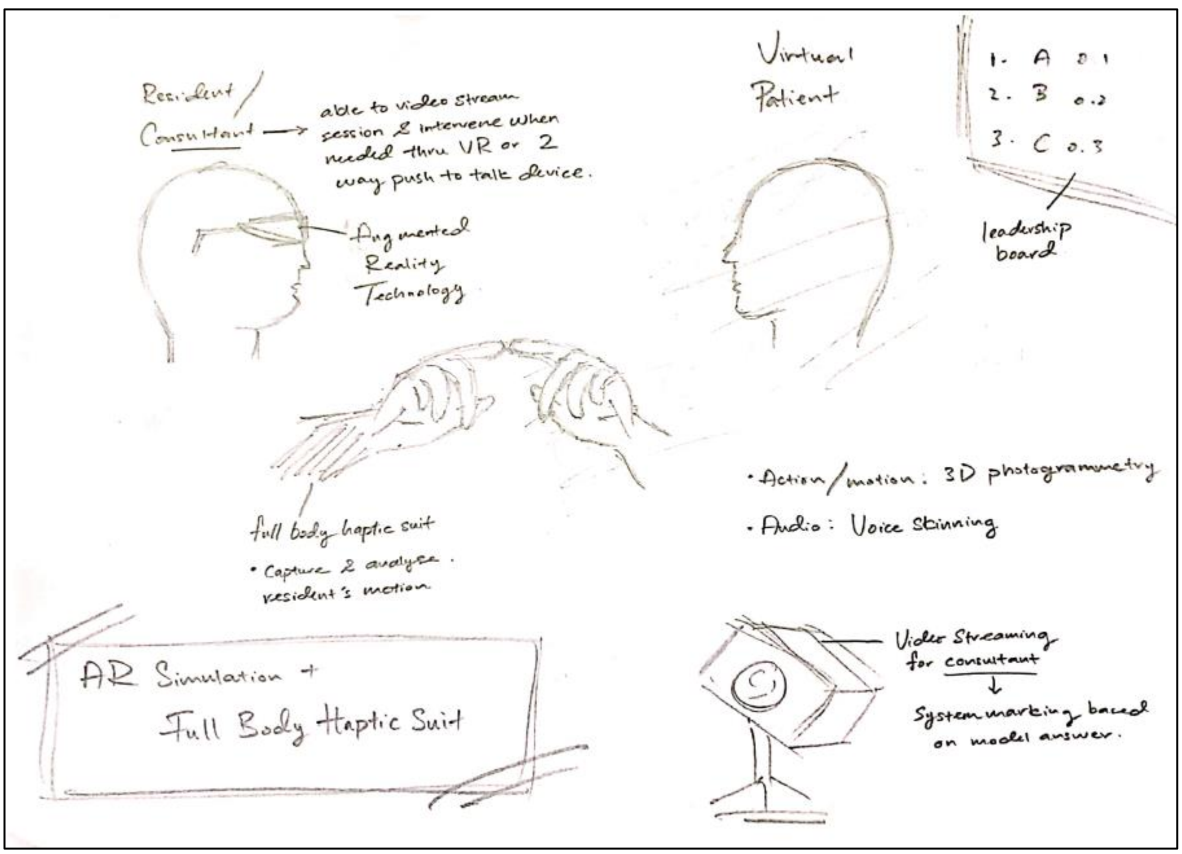


Figure 14: System design of solution D

F.4: Solution E – Virtual Standardised Patient for Hire

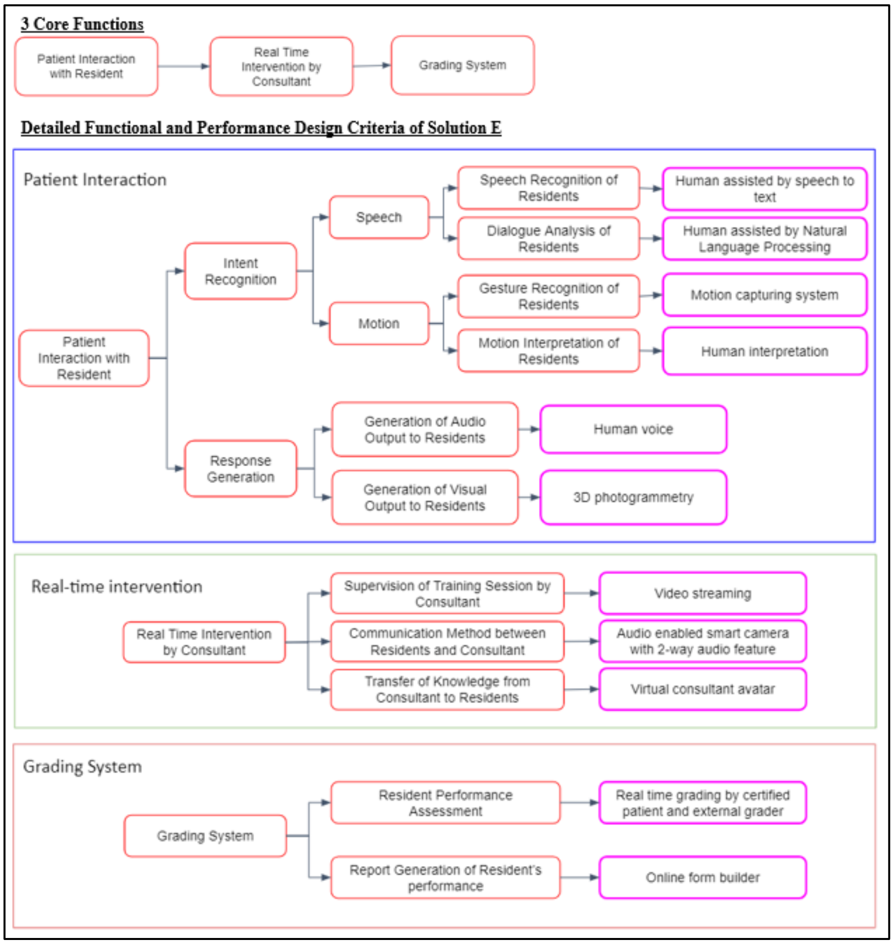


Figure 15: System architecture of solution E

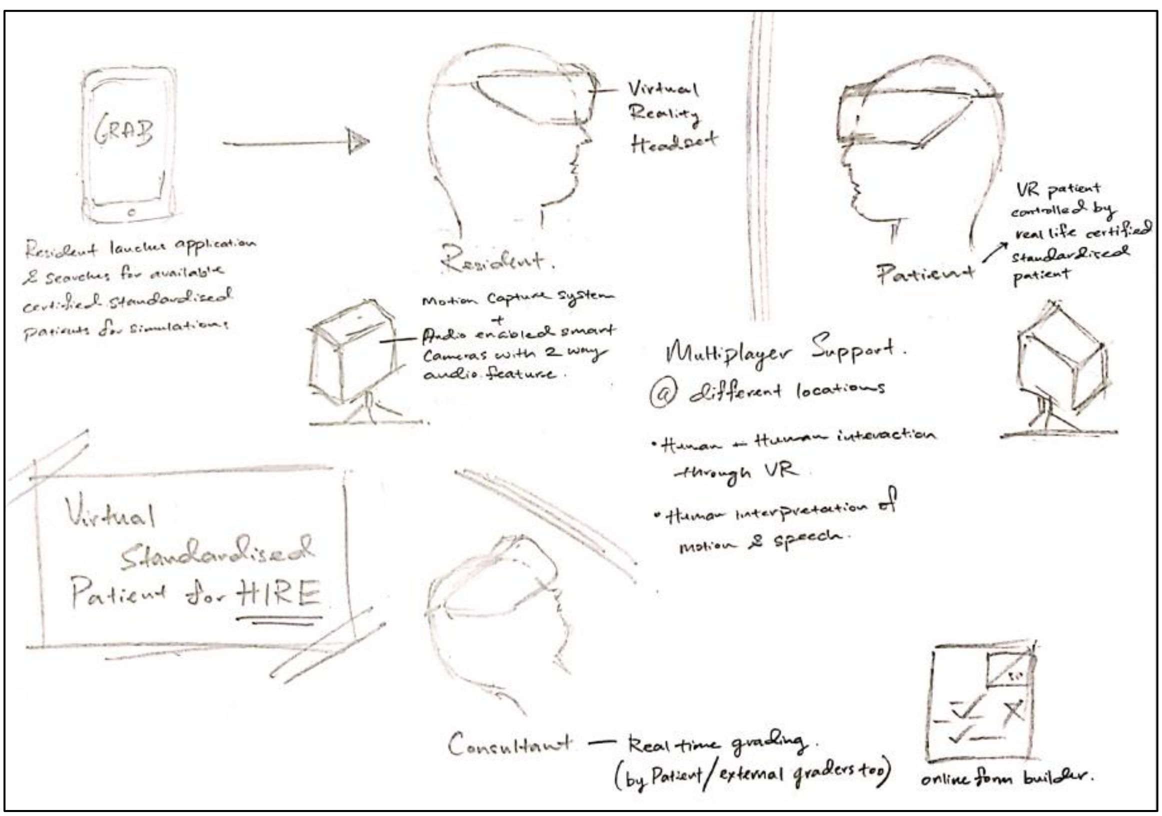


Figure 16: System design of solution E

Appendix G: Concept Selection

Table 10: Reasonings for weighted scores during concept selection of proposed solutions

		Explanation of Concepts Ratings									
		A		B		C (REF)		D		E	
SELECTION CRITERIA	Weight (%)	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Expandable Scenario Database	10	5	Database for computer games are easily updated and expanded. 3D graphic software will be better to create new scenarios, compared to 3D photogrammetry , which requires mulitple real life photos	4	3D graphic software will be better to create new scenarios, compared to 3D photogrammetry , which requires mulitple real life photos	3	3D graphic software will be better to create new scenarios, compared to 3D photogrammetry , which requires multiple real life photos	2	AR requires actual rooms and objects to overlay with 3D graphics. 3D graphic software will be better to create new scenarios, compared to 3D photogrammetry , which requires mulitple real life photos	1	This will be heavily based on the ability of the hired standardised patient to carry out the scenarios. 3D graphic software will be better to create new scenarios, compared to 3D photogrammetry , which requires mulitple real life photos
Adaptive Conversational Flow	15	4	NLP allows the generation of more natural and realistic responses according to the conversation history	4	NLP allows the generation of more natural and realistic responses according to the conversation history.	3	Dialogue tree is a set of predetermined responses.	4	NLP allows the generation of more natural and realistic responses according to the conversation history	5	Actual human conversation is the more natural. Human-human interactions are also more realistic.
Accurate Patient Behaviour	20	1	As it is a computer game, simulation is not fully immersive	4	It is fully immersive due to the recreation of the entire simulation environment	3	It is semi-immersive as the simulation environment is not recreated. Furthermore, the generation of audio output is via pre-recorded audio files	4	It is fully immersive due to the recreation of the entire simulation environment	5	Human-human interactions are also more realistic.
Accurate Anatomical Features	15	2	Generation of anatomical features using graphic software is not as accurate and reaslistic as 3D model reconstruction from photos	2	Generation of anatomical features using graphic software is not as accurate and reaslistic as 3D model reconstruction from	3	Generation of anatomical features using graphic software is not as accurate and reaslistic as 3D model reconstruction from photos	3	Generation of anatomical features using graphic software is not as accurate and reaslistic as 3D model reconstruction from photos	3	Generation of anatomical features using graphic software is not as accurate and reaslistic as 3D model reconstruction from photos
Sense of Touch Simulation	5	1	Low quality visual haptic feedback as it is a 2D computer simulation	5	High visual and audio feedbackas users is immersed in the virtual environment. Smart wearible textile can simulate the sense of touch and force feedback	3	Medium quiality visual haptic feedback as it is semi-immersive smulation	5	High visual and audio feedbackas users is immersed in the virtual environment. Smart wearible textile can simulate the sense of touch and force feedback	4	High visual and audio feedback as users is immersed in the virtual environment
Immediate Intervention	15	1	Live video conferencing only allows audio explanation. Consultants are unable to demostrate proper techniques in computer games	3	Virtual consultant avatar allows consultants to interact and demostrate proper techniques on the virtual patient within the simulation	3	Virtual consultant avatar allows consultants to interact and demostrate proper techniques on the virtual patient within the simulation	3	Virtual consultant avatar allows consultants to interact and demostrate proper techniques on the virtual patient within the simulation	3	Virtual consultant avatar allows consultants to interact and demostrate proper techniques on the virtual patient within the simulation
Useful Grading System	10	5	Standardised marking system with no biasness.	5	Standardised marking system with no biasness.	3	Real-time marking may results in errors and missing details. Performance biasness may be present due to human biasness	5	Standardised marking system with no biasness.	3	Real-time marking may results in errors and missing details. Performance biasness may be present due to human biasness

Appendix H: Conversational Agent

H.1: Rasa Component Analysis

Table 11: Rasa Pipelines

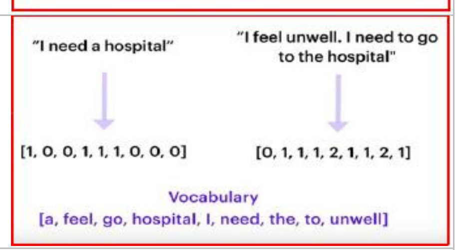
<table>
<tr><th colspan="3">Pipelines</th></tr>
<tr><td colspan="3">Description: Pipelines are a sequence of processing steps which are used to extract specific text features and train certain components which allows the model to understand patterns.</td></tr>
<tr><td colspan="3">The Supervised embeddings pipeline consists of a few key components listed below:</td></tr>
<tr><td>Whitespace Tokenizer</td><td>Looks for a white space and creates a division</td><td>
</td></tr>
<tr><td>Count Vectors Featurizer</td><td>Breaks each text input into an array of words and counts how many times each word appears in each text input</td><td>
</td></tr>
<tr><td>Embedding Intent Classifier</td><td colspan="2">Takes array output from Count Vectors Featurizer and uses it to determine most probable intent based on training data</td></tr>
</table>

Table 12: Rasa Policies

Policies	
Description: Policies are the components responsible for training a dialogue model to decide how the assistant should respond next. Each policy in the configuration makes its own prediction about the next best action. The policy that predicts the next action with the highest confidence level determines the assistant's next action.	
Augmented Memorization Policy:	The conversational agent tries to match the current conversation flow to training stories provided in the data file. If current conversation matches existing training data exactly, it predicts output with a probability of 1. If there is no match, output is predicted with probability 0. Needs to be used in conjunction with other policies
Mapping Policy:	The conversational agent maps an intent to a specific action. Useful in the scenario where you are certain that the intent should always be followed by a certain response, regardless of conversation history
Keras Policy:	Utilizes machine learning to predict the next action. The conversational agent will learn from training data, and uses past conversation histories to try and determine the correct output
Fallback Policy:	This is activated when the conversational agent cannot predict an intent or action with a probability above a certain threshold. Default action is triggered in this case

H.2: RASA Prototyping Process

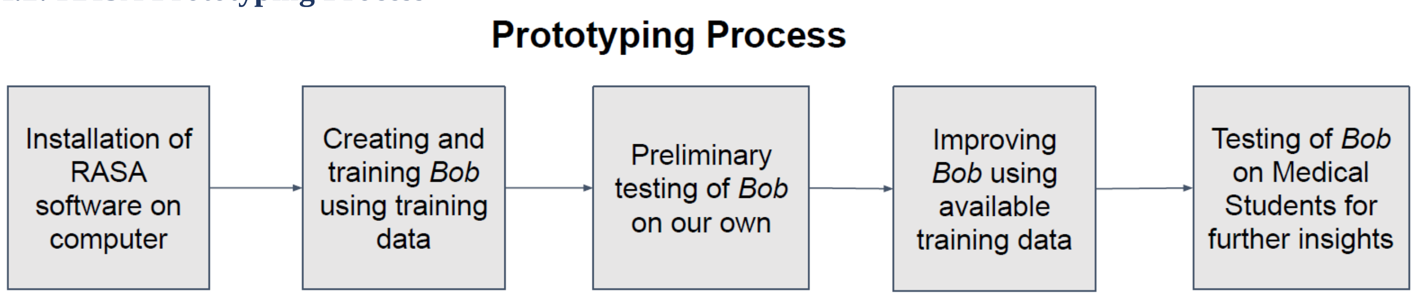


Figure 17: RASA prototyping process

H.3: RASA-X Deployment Process

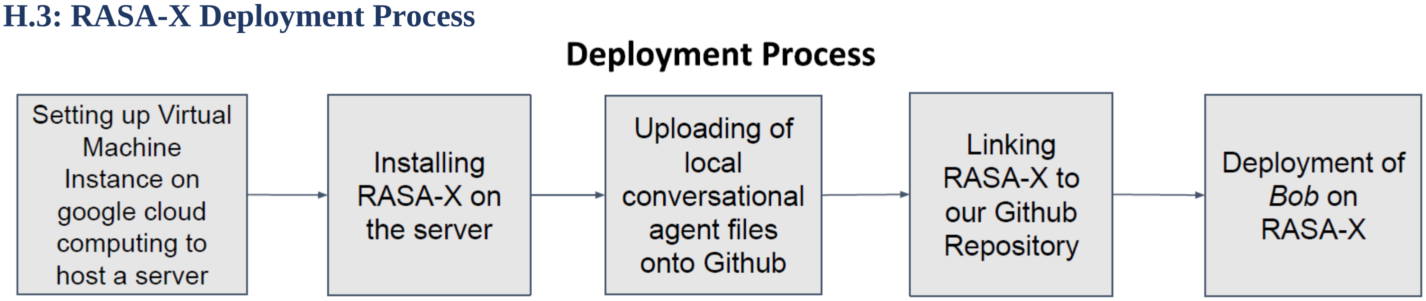


Figure 18: Deployment process of *Bob* onto RASA-X

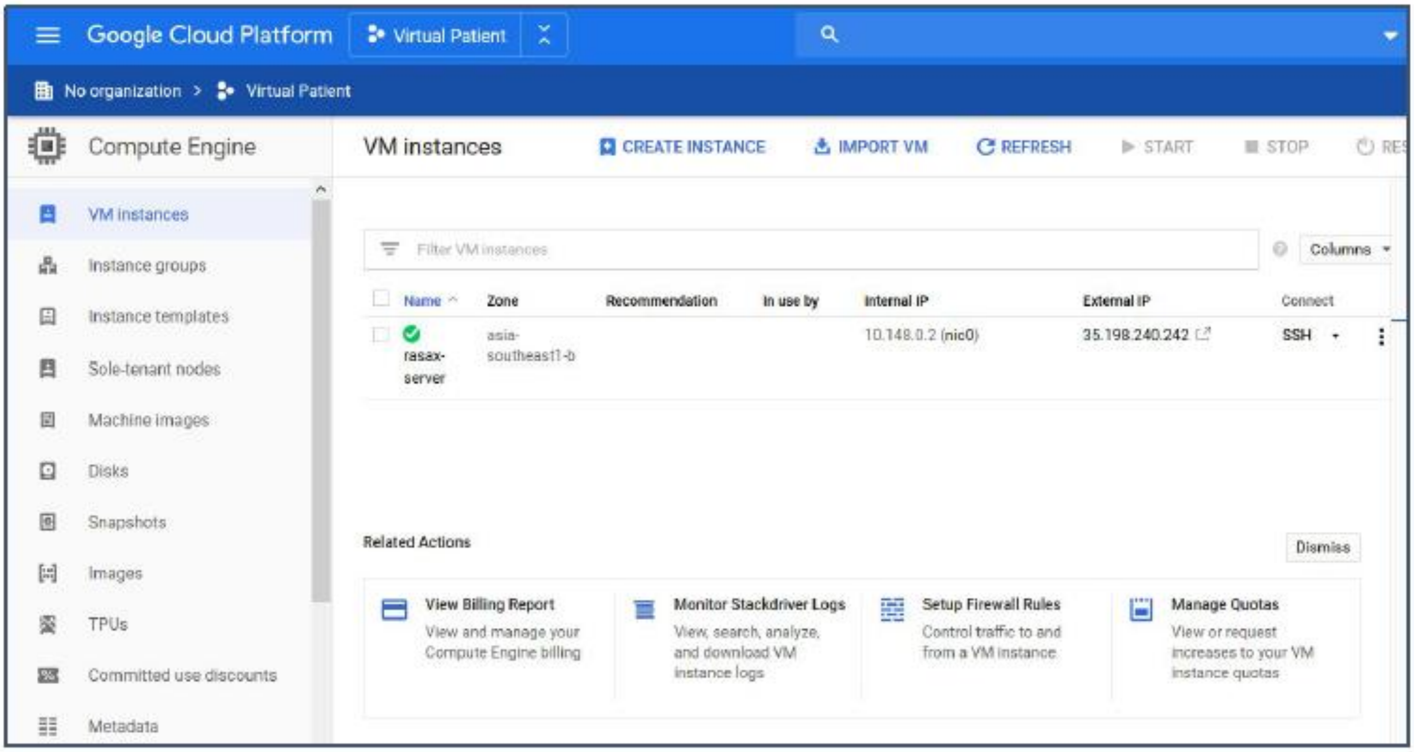


Figure 19: Google cloud interface used to create and control Virtual machine instance hosting the RASA-X server

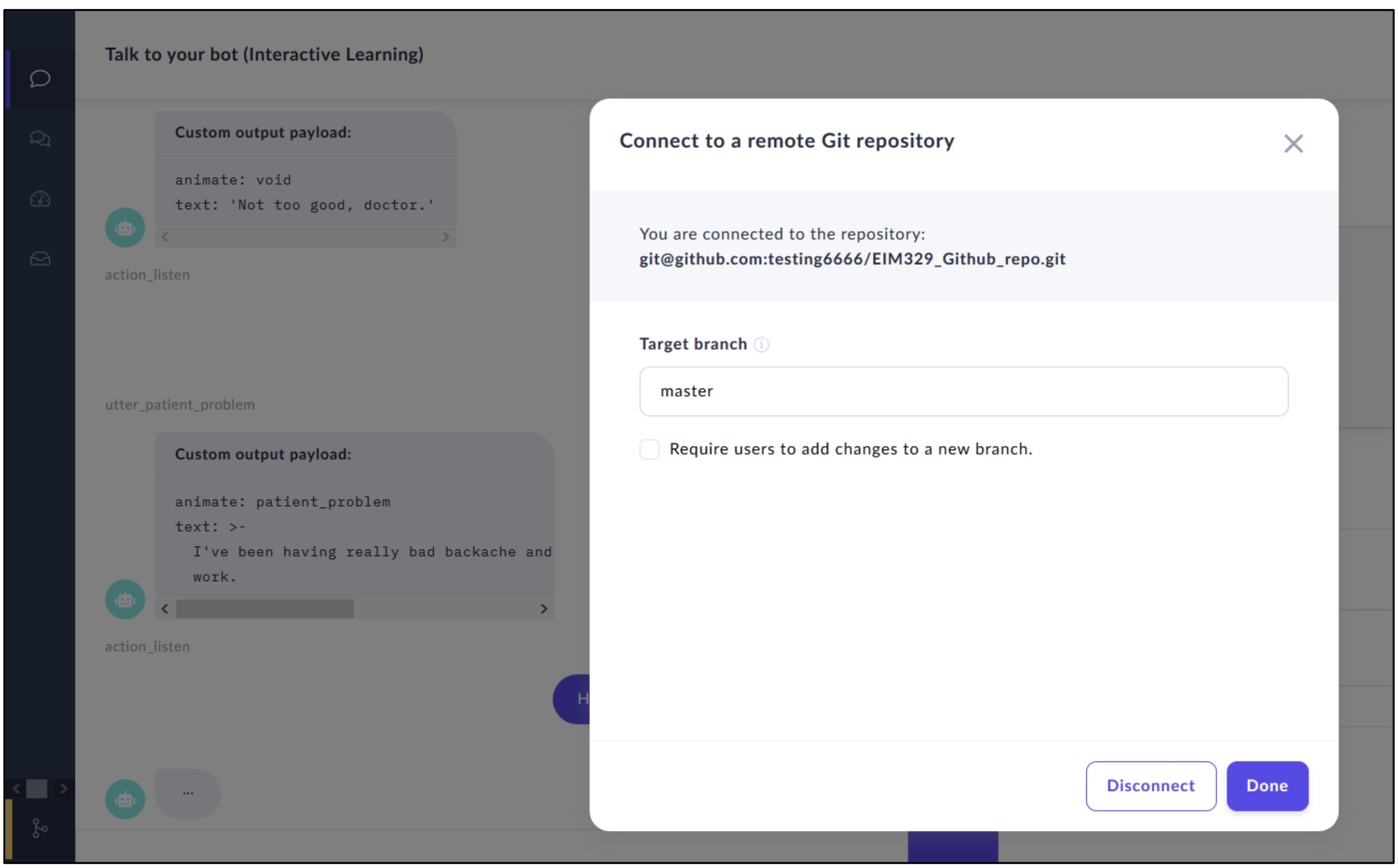


Figure 20: Linking of RASA-X to remote GitHub repository containing conversational agent files

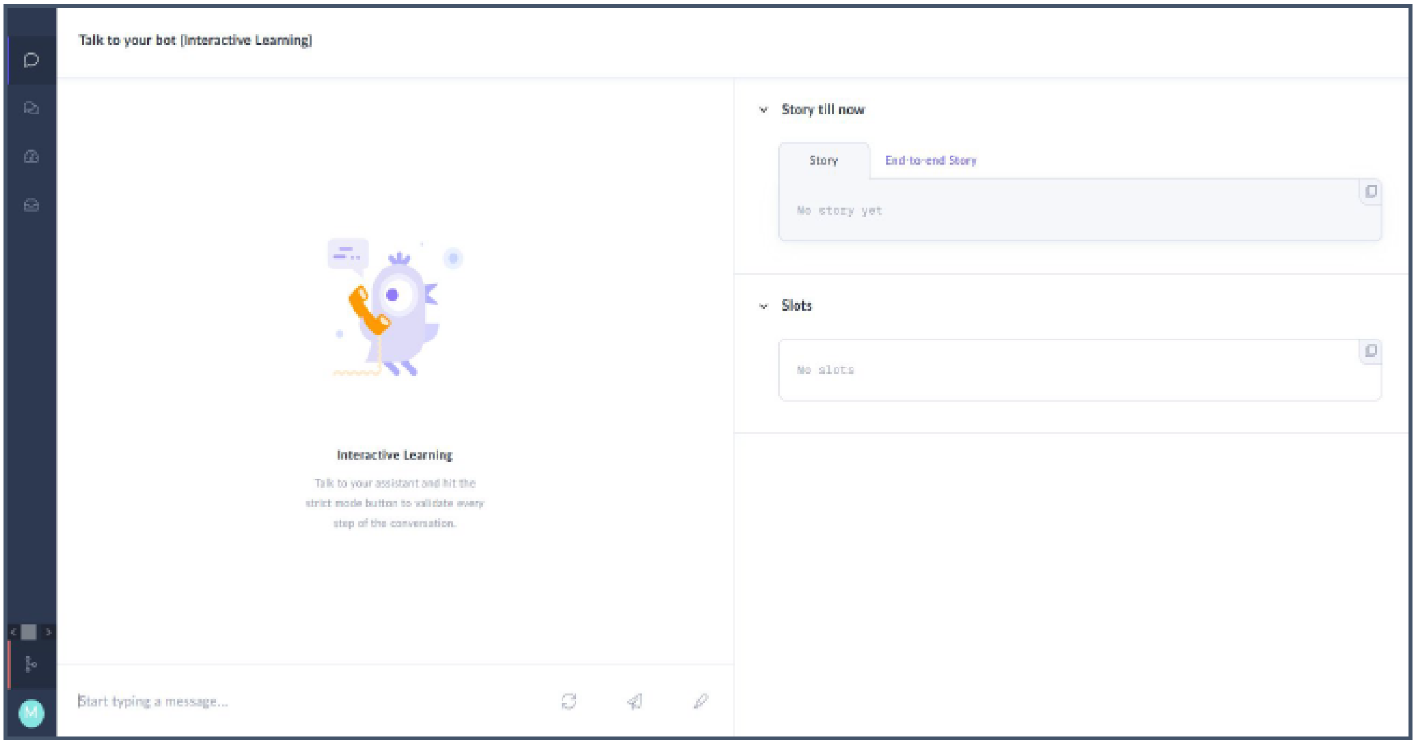


Figure 21: RASA-X interface where we communicate with *Bob*

H.4: Testing of *Bob* with Shiwei

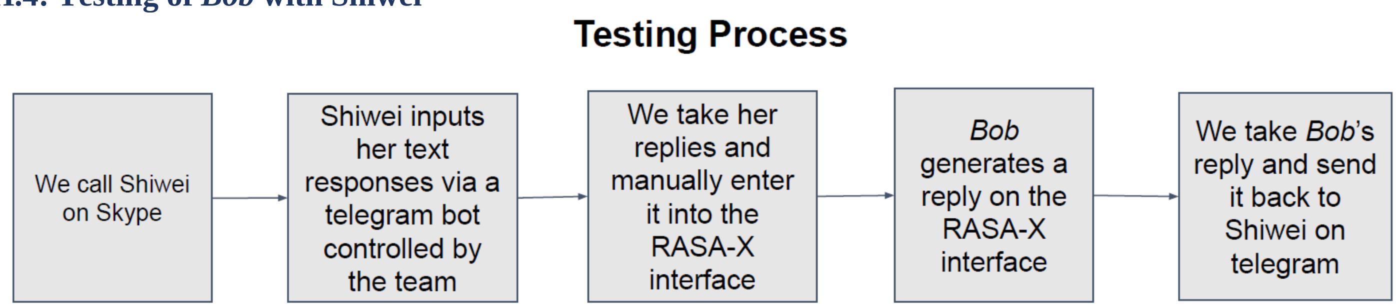


Figure 22: Testing Process with Shiwei

Figure 23: Picture of Shiwei

Figure 24: Interaction of Shiwei with *Bob*

Figure 25: Red boxes are instances where *Bob* failed and we had to type in our own responses to Shiwei. Black boxes are where *Bob* successfully generates a suitable response.

Appendix I: Facial and Motion Animation

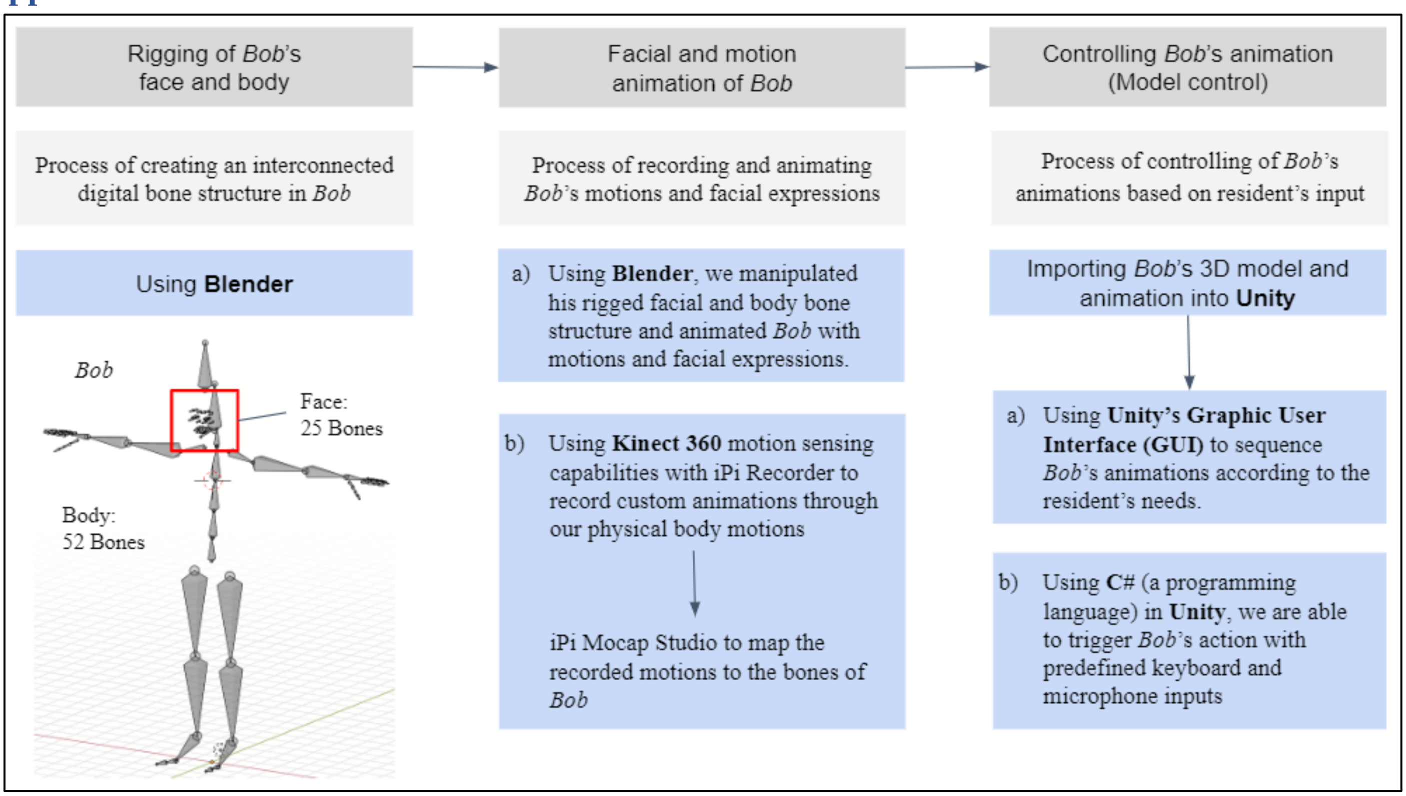


Figure 26: Facial and motion animation process

I.1: Rigging Process of *Bob*

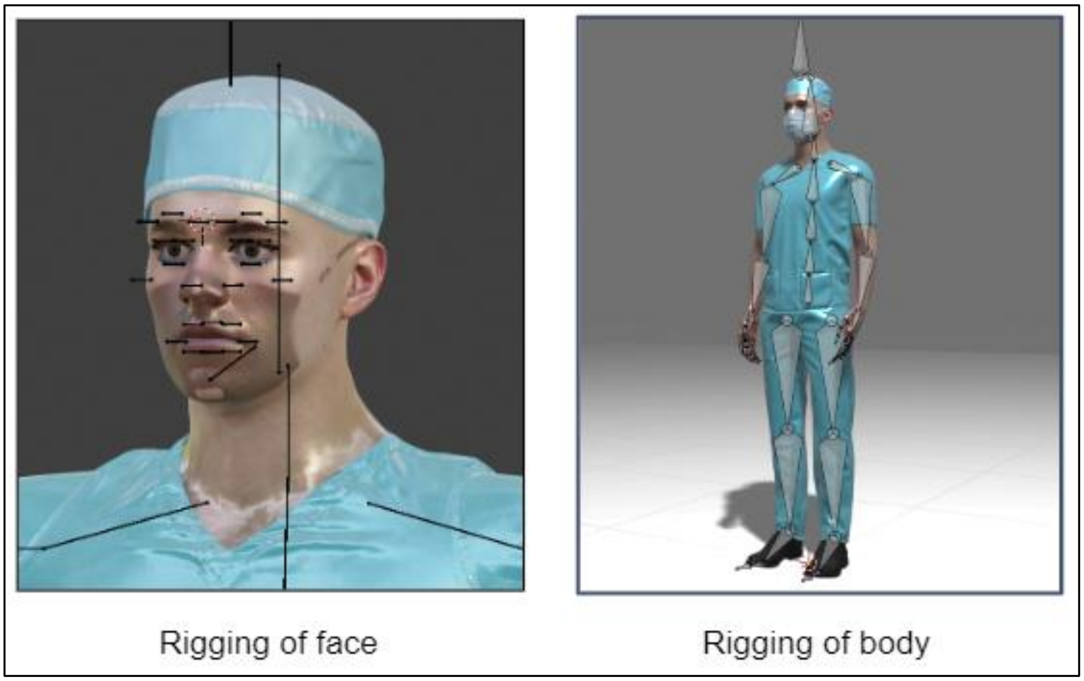


Figure 27: Rigging of *Bob*'s face and body using Blender

I.2: Animation Creation of *Bob*

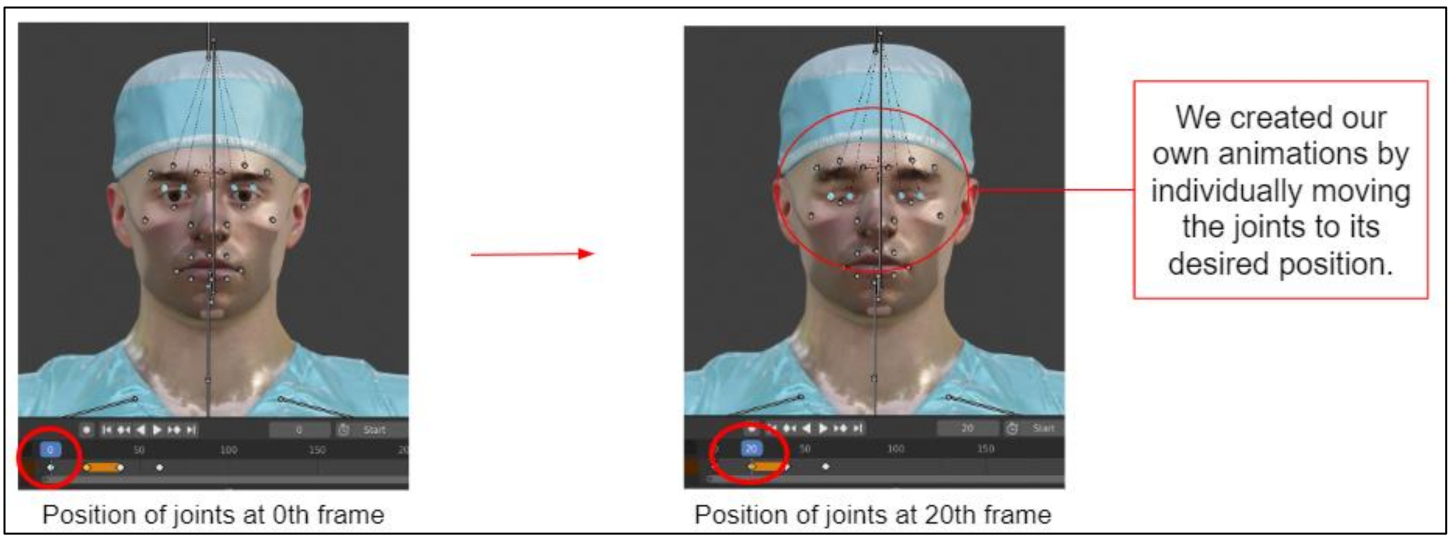


Figure 28: Facial animation of *Bob*'s face using Blender

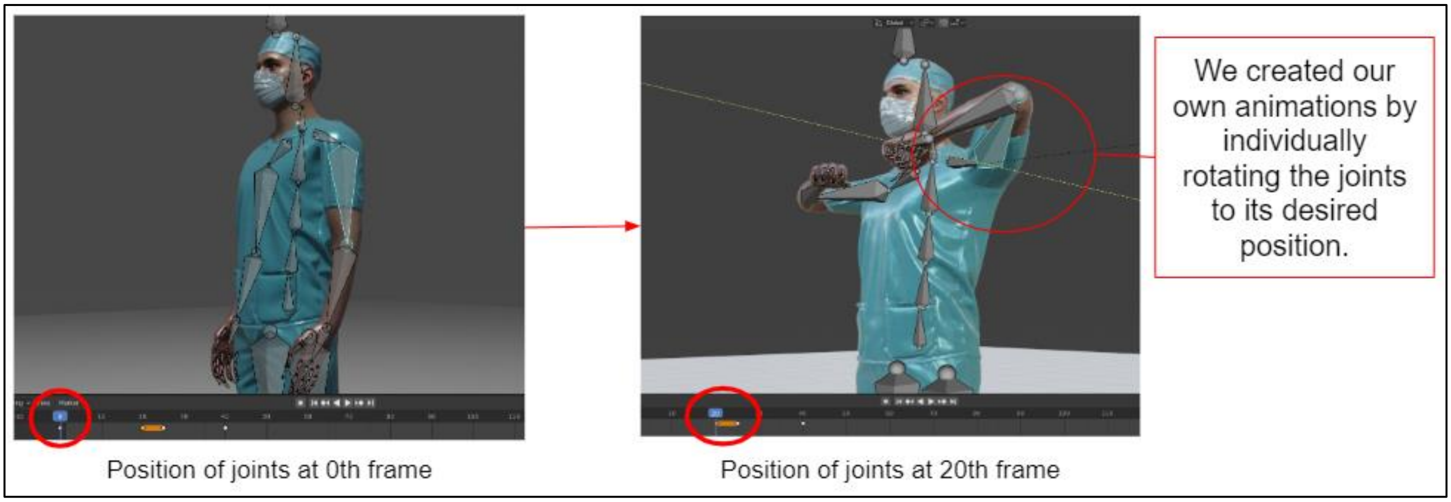


Figure 29: Motion animation of *Bob*'s body using Blender

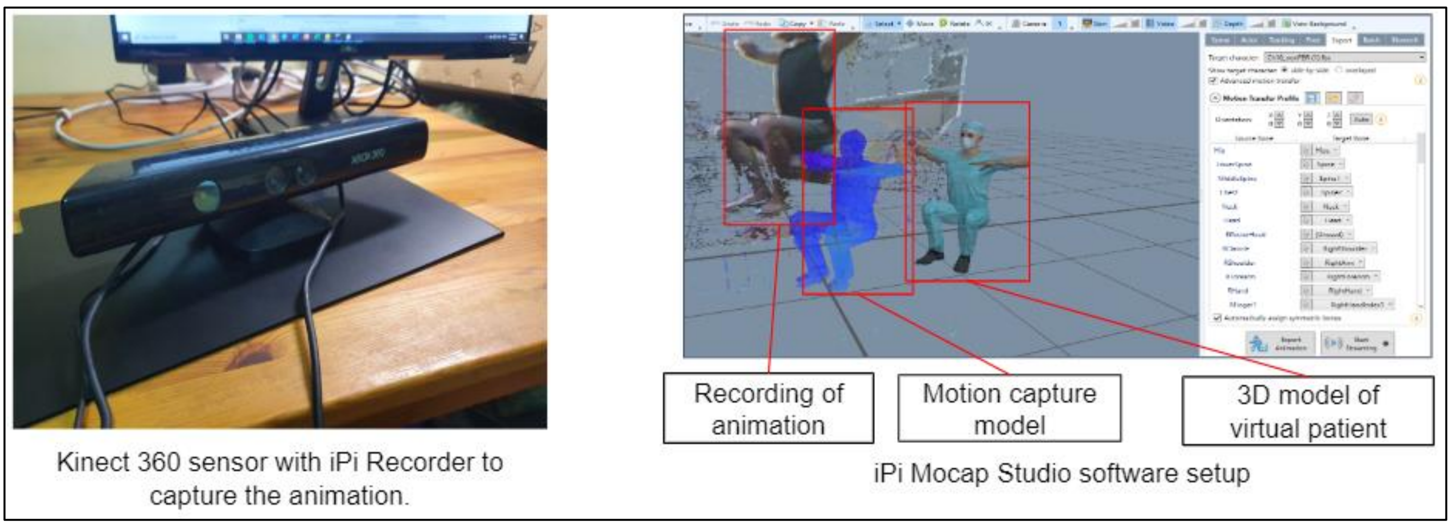


Figure 30: Motion animation of *Bob*'s body using Kinect 360

I.3: Control of *Bob*'s Animation

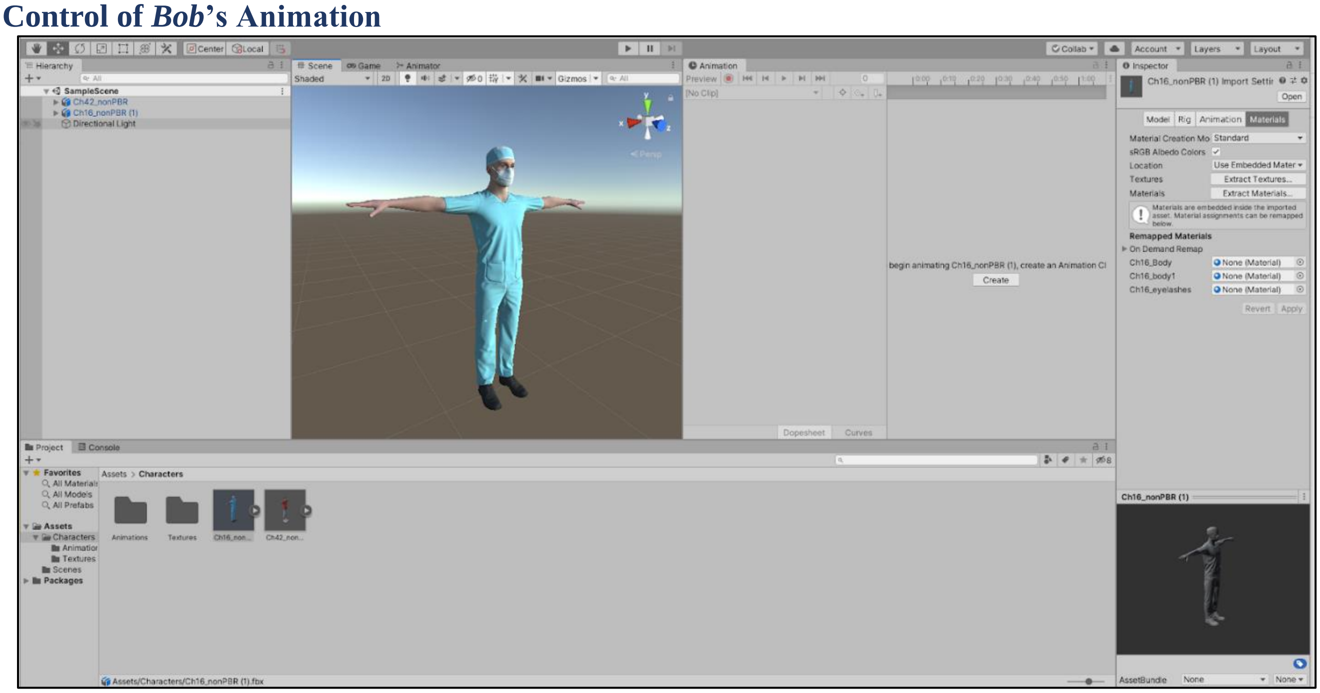


Figure 31: Default layout in Unity with our character mode

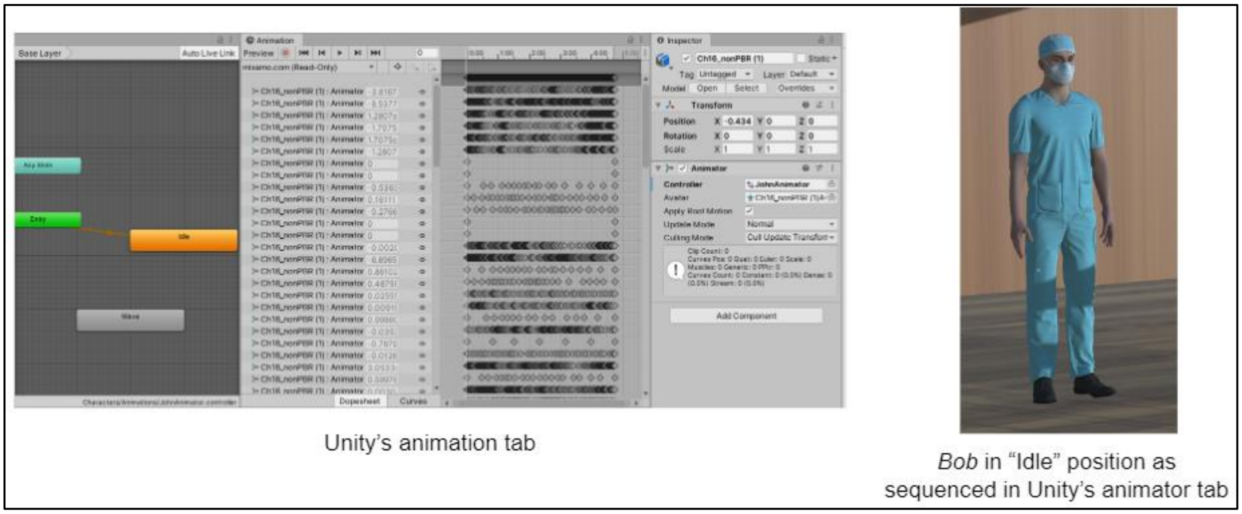


Figure 32: Controlling *Bob* using Unity's animation tab

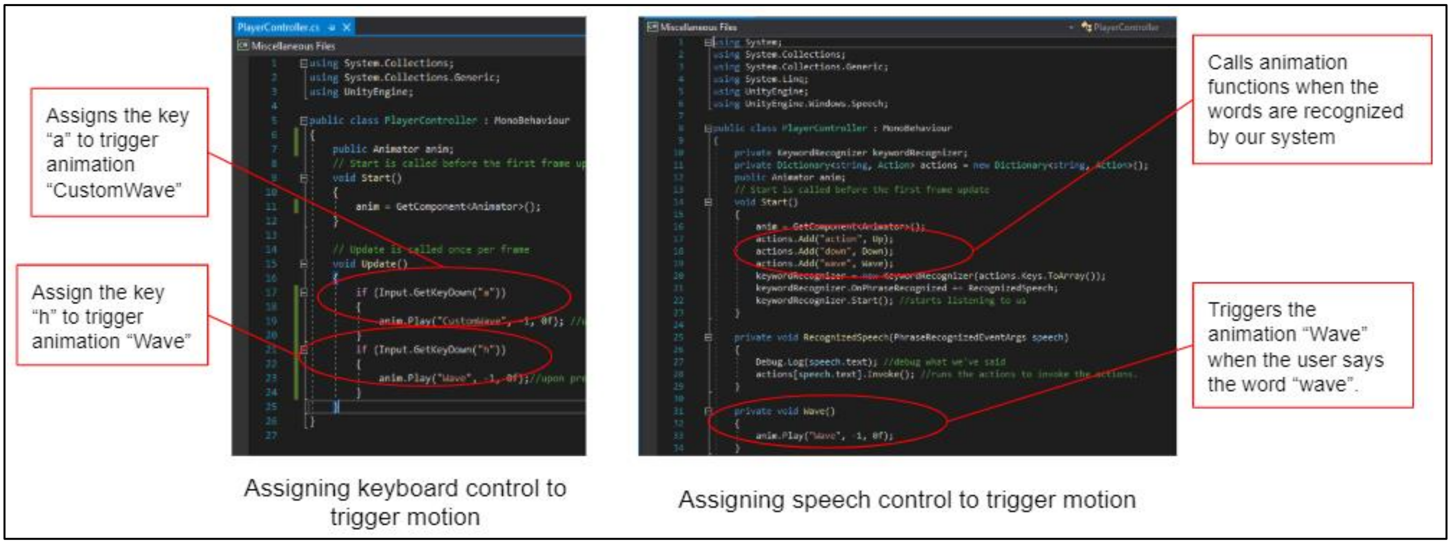


Figure 33: Controlling *Bob* using Unity's scripting function (C#)