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# Medical Sound SimuVest

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Final Design Report for the Medical Sound SimuVest and Dr. McAllister of the College of Nursing at the University of Tennessee, Knoxville

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Table of Contents

## Executive Summary

This report details the final design of the Medical Sound SimuVest, created by Medical Training Simulations (MTS). The SimuVest is a wearable, simulated auscultation training device intended to effectively train healthcare professionals-in-training how to identify normal and abnormal biological sounds. Dr. Marcia McAllister at the University of Tennessee College of Nursing found that many nursing programs in the US and across the world did not have the resources to purchase state of the art simulation equipment—many of the products currently on the market range from $5,000 to in excess of $70,000. In order to bring auscultation simulation training to these underserved programs, MTS was tasked with developing a more affordable device, the Medical Sound SimuVest.

The device needed to be able to produce high fidelity sounds associated with the cardiovascular, respiratory, and gastrointestinal regions while also being comfortable to wear and have an unintrusive, low-profile fit. Additionally, the wearer's natural body sounds should not be heard and all equipment should be easily sanitized with an alcohol-based cleaner.

MTS considered numerous conceptual designs for the SimuVest, including a vest with internal speakers or embedded RFID sensors. Ultimately, the team used barcode technology to map the biologically relevant locations onto the vest—each location of interest has a corresponding barcode printed on that region of the vest. A "smart stethoscope" with an internal barcode scanner was created to read the barcodes and send those data to a program which controls audio playback. Additionally, an instructor can choose whether they want a normal or abnormal sound to play at each location using a graphical user interface (GUI).

Survey results indicate that the conceptual design has value in a nursing classroom. The SimuVest system responds appropriately to the stethoscope's position on the vest, playing sounds appropriate to that region. It has the capability to play a set of normal and abnormal sounds for each location of interest. Furthermore, the vest itself is unobtrusive and comfortable to wear for extended periods of time. With an estimated mass-production retail cost of only $200 per device, the SimuVest could make effective auscultation simulation much more accessible to the world over.

## Background

*Scope*

Dr. Marcia McAllister presented Medical Training Simulations (MTS) with a problem she had found while practicing medicine. She stated that in the ever-changing field of healthcare, adaptive and immersive training techniques are essential in preparing future workers. These nursing students need to be equipped with the skills necessary to diagnose and treat the patients that they see while serving in their positions at the hospital. Simulations and other experiences have been proven to account for up to 50% of the learned skills that healthcare professionals need for the job. Recent studies have shown that only 23% of students entering the workforce do not meet the entry level competency expectations. This is especially prevalent in countries or areas with lower incomes ranges and a decreased access to resources for adequate training techniques. These low-income areas not only lack the resources for advanced training techniques, but they are incredibly understaffed too. Many of these necessary training options are simulated devices that can simulate a variety of scenarios. However, many of the simulation systems are very expensive and can range to upwards of $70,000 making it difficult to give medical students effective training for what they will encounter on the job. This places students in programs with less funding at a disadvantage when they enter the industry. With a projected 100,000+ available jobs by the year 2022 and each year after that, it is a rapidly growing industry and will require the current students in school prepared to fill those positions. Therefore, it is noticeably clear there is a need for a cost-effective simulation apparatus to train and equip students with the skills they need to be successful on the job. The primary focus of our team is to serve the healthcare workers of the future by providing the tools they need to be successful in the industry worldwide.

*Previous Solutions*

There have been many efforts to tackle this problem to properly train healthcare workers. After researching some of the products presently on the market, MTS was able to determine there are three categories of devices that simulate the auscultations desired. We chose to specifically focus on the lower end of the financial spectrum to be more comparable to the price of our expected device. We determined that there were three classifications of devices: speaker-embedded manikins, “smart” stethoscopes, and speaker-embedded wearables.

Speaker-embedded manikins are some of the most common auscultation training devices. A representative example of this technology is the Auscultation Simulator (R10001) manufactured by Erler-Zimmer. This product retails for $5,500 and can simulate 20 heart sounds at 4 positions and 10 respiratory sounds at three positions. The most significant disadvantage to this design is the highly unrealistic learning environment. The student cannot communicate or interact with the patient which does not allow them to develop bedside skills that are becoming ever more important in the healthcare industry.

"Smart" stethoscopes are a group of auscultation training devices wherein sensors pair the stethoscope location to a point on the torso that emulates a sound through the stethoscope itself. One competitor example that stood out was the SimShirt System developed by Cardionics. This system in particular has advantages over other "smart" stethoscopes in that it functions in conjunction with their SimShirt product. The system as a whole sells for $8,500 and has software package add-ons for over 100 sounds. The SimShirt system utilizes RFID tags woven into the shirt and picked up by sensors in the diaphragm of the stethoscope. Additionally, a tablet is provided to allow for live alterations of the patient scenarios. Although, some disadvantages to the SimShirt System are the cost and the need for both the shirt and scope to work simultaneously for the system to function.

Speaker-embedded wearables are simulation devices that users can wear for nursing students to practice auscultation. Typically, speakers are embedded into the shirt or vest, and emit a sound chosen by the user. Students can then use their stethoscope to listen to the sound and make a diagnosis. The Bionic Hybrid Simulator by Cardionics is one specific competitor that stood out. Strengths of this design are that it has a large sound library for simulations and the sounds are emitted in anatomically correct regions. The software is easy for users, and the tablet that controls the shirt comes with its own WiFi hotspot to connect to all devices including the blood pressure simulation reader, the shirt, and the stethoscope used for simulations. The weakness of this design is that it is expensive. It costs $12,500 for the system.

*Needs*

After meeting with our stakeholder, we determined that there were a handful of key needs we needed to meet with our device. The first and most important need is the device we produce is able to emit high fidelity sounds at the anatomically accurate position. It is essential that this need is met because our device will be a pivotal part for the training of future healthcare workers. Secondly, the device needs to be affordable and accessible for programs everywhere. We want to ensure all students have access to quality training programs that adequately equip them for the industry. Our device needs to also be comfortable, flexible, form fitting, and adjustable for any standardized patient that is used. This is necessary because not every patient is the same and the vest needs to simulate the feeling of a normal examination. The normal body sounds of the patient also need to be blocked out because this reduces the quality of the simulations. It is also essential that our design is intuitively created for the ease of instructional use. Instructors need to be able to select the desired simulation and the *SimuVest* accurately performs what is programmed. Sanitation and cleanliness are necessary for this device to be used in the healthcare setting. Therefore, the materials that make up the device need to be durable and easily cleaned with an alcohol-based disinfectant. Palpitations within our device were also a desired component of our device, however upon further analyzing our design and through conversations with our stakeholder, MTS determined that this would not be feasible.

## Problem Definition

The goal of this project is to produce an affordable option for training nursing students in auscultation. The product can be used on any standardized patient, allowing nursing students to practice identifying the correct anatomical locations for auscultation and identifying the pathology associated with the sounds in each location, both normal and abnormal. The intention of these goals is to provide a more effective training option for nursing students that can also be affordable for underfunded nursing programs.

The team identified three principal needs from which the functions and requirements list was derived: the need to (1) produce high quality sounds in cardiovascular, respiratory, and gastrointestinal regions of the body, (2) be comfortable, adjustable, flexible, and form fitting for a variety of standardized patients, and (3) be easily sanitized between uses.

*Need 1: Produce High Quality Sounds*

The first need, producing high quality sounds in cardiovascular, respiratory, and gastrointestinal regions of the body, requires a user interface from which the nursing instructor can select a sound corresponding to different anatomical regions and a backend code that retrieves the sound from a sound library. There are many low-level functions associated with the need for an intuitive graphical user interface (GUI). The GUI must be simple for both instructors and students, allowing them to select the sounds they intend to have played in different areas. It must be able to send the correct information to the computer where the backend code is running. The code must then identify the correct MP3 file selected using the GUI and play it through the headphones when the corresponding barcode is scanned.

The requirements of the design associated with Need 1 include sounds synthesized with high fidelity. The sounds must be recreated reliably without electrical abnormalities, and be played at a consistent volume, allowing them to be easily identifiable by students and instructors. For this, the power supply to the smart stethoscope must be constant and reliable.

High fidelity sounds will contribute to the cost of the product. In the effort of keeping the product affordable, the team has chosen to utilize common materials most nursing students will already have on their person including headphones and a stethoscope.

This requirement can be validated through surveying nursing students on the quality of sounds produced. Survey results are indicated in Section VI. Design

Evaluation. Nursing students can compare the sounds heard through the smart stethoscope to sounds heard through a normal stethoscope and compare in terms of fidelity, volume, and sound.

*Need 2: Comfortable, Flexible, and Adjustable to the Standardized Patient*

The vest is intended for use on a variety of standardized patients. For this reason, it must be adjustable, dynamically fit moving and breathing users, and remain low profile. The adjustable components include buckles, straps, and zippers. It should be simple and comfortable for the user to put on, adjust, and remove the vest. A requirement associated with this function is that the entire process of wearing the vest is comfortable for the standardized patient, and standardized patients of any body type can use this product. Not only must it be simple to adjust on one's body, but the materials must be comfortable to wear for long periods of time and hypoallergenic. It must remain comfortable for the user when standing, sitting, and lying down, and it must be comfortable and low profile enough to fit over the standardized patient's normal clothes. Low profile is considered less than half an inch off of the patient's body.

Comfort can be measured using a survey. MTS intends to have different people wear the vest and adjust it to their own body type and confirm on a numeric scale how difficult it was to adjust and how comfortable it is to wear.

*Need 3: Vest is Easily Sanitized Between Uses*

To maintain a clean, safe environment for the students and standardized patients, the vest must be simple to clean and the smart stethoscope component as well as the vest must be thoroughly sanitized quickly between uses. The user should be able to apply an alcohol-based cleaner to all parts of the system and quickly sanitize the pieces between uses. For this function to be met, the surface of the vest should be smooth and easy to clean all areas of the surface, especially the surfaces touching skin of the standardized patients, namely the collar. The electrical components of the smart stethoscope must be contained in a housing that is not affected by an alcohol-based cleaner. All components should be able to withstand multiple sanitation cycles without deteriorating or breaking. The vest should also be washable without any of the seams loosening or the adjustable components breaking off.

This process can be validated by applying an alcohol based cleanser to both a test strip of vest material and a piece of plastic filament, the material the smart stethoscope housing is made from. After application, the team will confirm that there is no damage or visible effect on the barcodes, t-shirt, or plastic filament. Following prototype construction, the team will sanitize the smart stethoscope and confirm that the electronics housed inside the chestpiece are unaffected by the sanitization process. The vest prototype will also undergo cycles through a standard washing machine and dryer on low heat and the team will confirm that the barcodes and adjustable components are unaffected.

## Concept Development

*Embedded Speakers*

Our initial design was the most intuitive solution, consisting of a vest containing internal speakers that produce biological sounds controlled by a small microcontroller. The microcontroller would contain an SD card loaded with all of the required sounds and would send electrical signals to the speakers so that the sounds would play. An instructor would have either a remote control or graphical user interface (GUI) to control which sounds are played on which speakers. To ensure that the student being trained only hears the sounds emitted from the internal speakers, the vest would contain an insulative material that would block the wearer's natural body sounds. The student would simply use a traditional stethoscope to listen to the sounds produced from the vest and make an appropriate diagnosis.

While developing this design, the team noticed numerous limitations and difficulties with this design. One limitation was the inherent bulkiness of the design given the physical dimensions of off-the-shelf speakers and the required thick insulative material. This bulkiness was difficult to reconcile with our stakeholder's need for the vest to be slim and low-profile, mimicking the form and feel of a real torso. We also believe that such a design would require high quality speakers to be able to produce high-fidelity audio at volumes appropriate for a stethoscope to pick up. Additionally, we concluded that the vest would have a high cost of production given the many components required (microcontroller, one speaker for each area of interest) and the amount of labor needed for assembly. This already difficult assembly process was amplified by the fact that the design team has very little collective experience working with circuits and manufacturing.

*RFID Sensors*

Secondly, the team developed alternative methods that operate around identifying where the stethoscope is with some location system, and a corresponding sound playing through wired earbuds for that anatomical marker. One source of inspiration for this type of design was the SimShirt® system. This design used a "smart stethoscope" with RFID technology to determine where the student was looking on the shirt. When the stethoscope head was placed over an area that corresponded with a sound, the computer played the sound into the stethoscope earpiece. This design allows for the shirt to be very thin and to maximize audio production quality since there is only one sound generation device.

The most difficult aspect of this type of design was to accurately and reliably be able to detect where the student is looking for sounds on the vest. This problem is trivial with the internal speaker design because sounds are produced at the location that they naturally occur. With an external speaker design, a positioning system would be necessary to know which sound is appropriate to play based on when the student has placed the stethoscope head.

Each location that corresponds to an auscultation sound would have an embedded RFID tag, which are very cheap and come in machine washable varieties. For this system, the antenna would be contained within the stethoscope head, mimicking the process of using a real stethoscope. When in use, the software on the computer would continuously read the data that the reader and antenna pick up. When the antenna recognizes a tag, the computer would find all corresponding sound files. Depending on the instructor's preselected settings, the computer would then play the normal or abnormal sound to the attached headphones. This entire process would ideally take place with minimal latency. Potential limitations to this design are the high cost of RFID readers, the possibility that adjacent tags could accidentally read, and the complexity required to develop RFID software.

*Barcode System*

Another discrete positioning system utilizes barcodes, perhaps one of the most simple identification technologies. This system has a similar structure to the RFID design above: each anatomical location of interest would have a corresponding barcode printed onto the vest. To identify each barcode, the stethoscope body would have an embedded scanner that would continuously scan for information. When the student moves the stethoscope over one of the barcodes, the computer would recognize the code and determine which audio files are applicable to that location. Then, either the normal or abnormal sound would be played depending on the settings that the instructor has selected in advance.

This system is the most cost-effective of all concepts considered since screenprinting the barcodes and small barcode scanners are both very inexpensive. A limitation to this design is that the barcodes would be visible, so students would know where to look for sounds. This could be avoided by printing decoy barcodes elsewhere on the vest (camouflage method) or by using UV ink, which is invisible to the naked eye but can be read by a barcode scanner.

*Design Selected*

After deliberating over the positioning system to be used for our design, as well as assessment via our concept selection scaling found below, we decided upon the barcode scanning system, as it scored highest.

| Table 1: Concept Selection | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Criteria | | | | | Score |
| | | Cost | Realism | Manufacturing Complexity | Vest Thickness | Palpation Integration | |
| Weight | | 0.4 | 0.2 | 0.15 | 0.15 | 0.1 | - |
| Design | Internal Speakers | 20 | 80 | 20 | 10 | 50 | 33.5 |
| | RFID | 50 | 50 | 60 | 100 | 0 | 54 |
| | Barcode | 80 | 30 | 70 | 100 | 0 | 63.5 |

The “stethoscope” of our design primarily operates from a miniature barcode scanner that will be placed inside a standard stethoscope head. The head of the stethoscope will connect to a port, where the user can connect their own headphones to the system, and connect the rest of the stethoscope to their computer via USB. This design allows for the user to experience the highest sound fidelity possible through their headphones, without giving up too much of the physical touch of an auscultation assessment. The student will use the “stethoscope” how they would a standard stethoscope, and will be asked by the instructor to perform a certain assessment. Using the software on the computer, the instructor will have selected which case (normal or abnormal) of sounds they want the student to hear through the stethoscope. Then, the student will hold the stethoscope over the standardized patient wearing the custom barcode printed shirt. Once the invisible ink barcode has been scanned by the stethoscope, the preselected conditions chosen by the instructor will determine which sounds come through the headphones of the student. A miniature USB barcode scanner can be purchased for approximately $60.00, and be small enough to fit inside the head of a stethoscope shell for the most realistic implementation. The junction for the USB and headphone joke will be approximately 2 feet from the head of the stethoscope, to give enough space between the hands of the user and the headphones they will be wearing during training, without having too much slack in the cords.

Thus, the final concept and design selection for each of the components are as follows. The shirt is constructed from a simple t-shirt that has been modified for custom barcodes to be heat transferred onto the surface, as well as the sleeves and sides cut, with the addition of straps and a zipper in the back to be adjustable. The “smart” stethoscope is made from an omnidirectional barcode scanner that has been deconstructed to be housed in our custom modeled and printed chestpiece. This scanner connects to an electrical box that is clipped to the waist, holding both an aux and USB cable, that are then connected to the computer from the box. These three physical portions of the design, working in conjunction with our backend code for sound selection, produce the anatomical sounds at the scanned location of each barcode, including the available selection of abnormal sounds.

## Product Description

The Medical Sound SimuVest designed by MTS is an auscultation simulator that uses barcode technology to map biologically significant locations. The SimuVest consists of three main components: 1) the adjustable vest with printed barcodes, 2) the smart stethoscope used to scan the codes, and 3) a software package containing a backend program to control audio playback and a graphical user interface (GUI) that the instructor uses to select which sounds they would like to play at each location on the vest.

*Vest*

The vest itself is primarily constructed out of a single layer of cotton fabric. It is open on the two sides and has two straps on each side to adjust the fit. A two-inch strip of fabric is attached to the collar to include auscultation points on the neck. To make it easier to put on and take off the vest, an 8-inch zipper is attached to the back of the collar with an elastic strip on each side to allow the top of the vest to fit a range of neck sizes. A total of 28 barcodes (3/4 inch tall and half an inch wide) are printed on the surface of the vest using heat transfer paper. Manufacturing the printed codes was successful; they have shown no sign of degradation or delamination after multiple wears and washing cycles. Each code contains a string of letters and numbers that corresponds to the location of interest. The position of each barcode corresponds to the real location that those sounds are heard on a patient. MTS worked with our stakeholder, Dr. McAllister, to ensure that the locations of the codes are accurate.

The final vest design incorporates various features to fulfill the functions and requirements specified by our primary stakeholder. One important requirement is adjustability and a comfortable, low-profile fit. The material choice of a single cotton layer makes the vest no less comfortable than a standard t-shirt—the design is comfortable to wear and poses no biocompatibility issues. Additionally, the two adjustable straps attached to the sides of the vest maximize adjustability for a diverse group of users. Another requirement is for sanitation and cleaning. The vest can withstand machine washing on a delicate cycle turned inside out. Additionally, there is limited contact with the standardized patient’s skin since the vest is designed to be worn over their own clothes.

**Fig. 1:** *Final vest design with printed barcodes (front only)*

*Smart Stethoscope*

The smart stethoscope consists of two parts that are physically connected with a cable: a chestpiece that houses the barcode scanner and an electronics box that houses cables and connection ports for USB and 3.5mm audio cables. Both components are 3D printed with PLA and are fastened with screws. Due to the size of the scanning equipment, the chestpiece is larger than a traditional stethoscope at approximately 3 x 3 x 2.5 cubic inches.

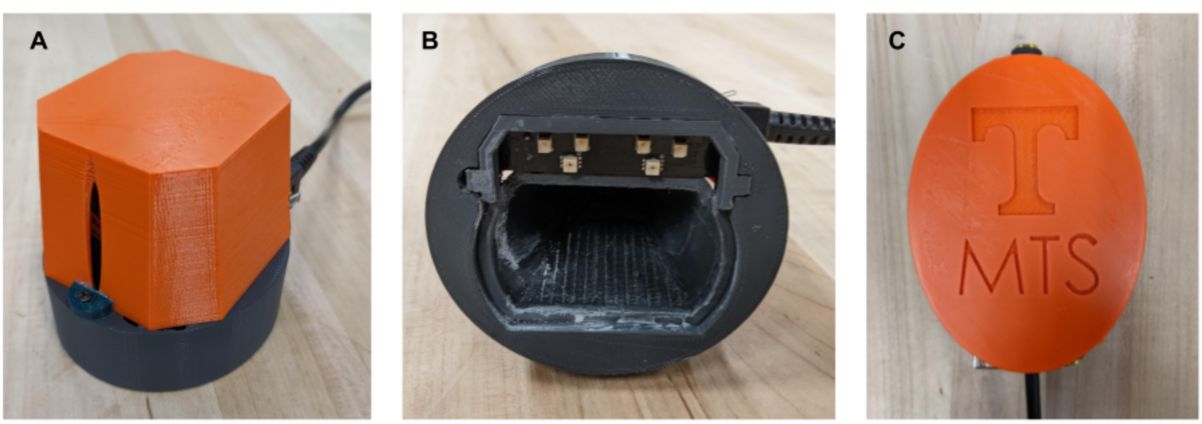


**Fig. 2:** *Smart stethoscope components. A) Chestpiece, side view. B) Chestpiece with internal light source, bottom view. C) Electronics box.*

To use the smart stethoscope, students will clip the electronics box to their waistband using the attached metal clip. They will connect any wired headphones or earbuds to the port located at the top of the box and connect the bottom 3.5mm port to a corresponding port on the controlling computer using the supplied 10’ audio cable. Next, the student will connect the supplied 10’ USB cable from the bottom of the electronics box to a USB port on the controlling computer. During the simulation, the student moves the chestpiece around the patient wearing the vest. When the chestpiece is held over a barcode, it automatically scans it and the computer plays the appropriate audio file over the headphones. To stop audio playback, the student must scan one of the two “stop codes” printed on the front and back of the vest.

*Software*

The software developed for this project consists of a backend program that controls audio playback depending on data from the barcode scanner as well as a GUI for instructor control. The backend program was written in MATLAB. Barcode data is read by the program as a simple keyboard input into the command window. Audio is played over the student’s headphones via a 3.5mm audio cable connecting the electronics box and the computer running the software. Program behavior is determined by the codes scanned by the smart stethoscope, whether the normal or abnormal case is selected, and whether or not audio is currently being played by the system. An overview of the backend program can be found in Fig. 3.

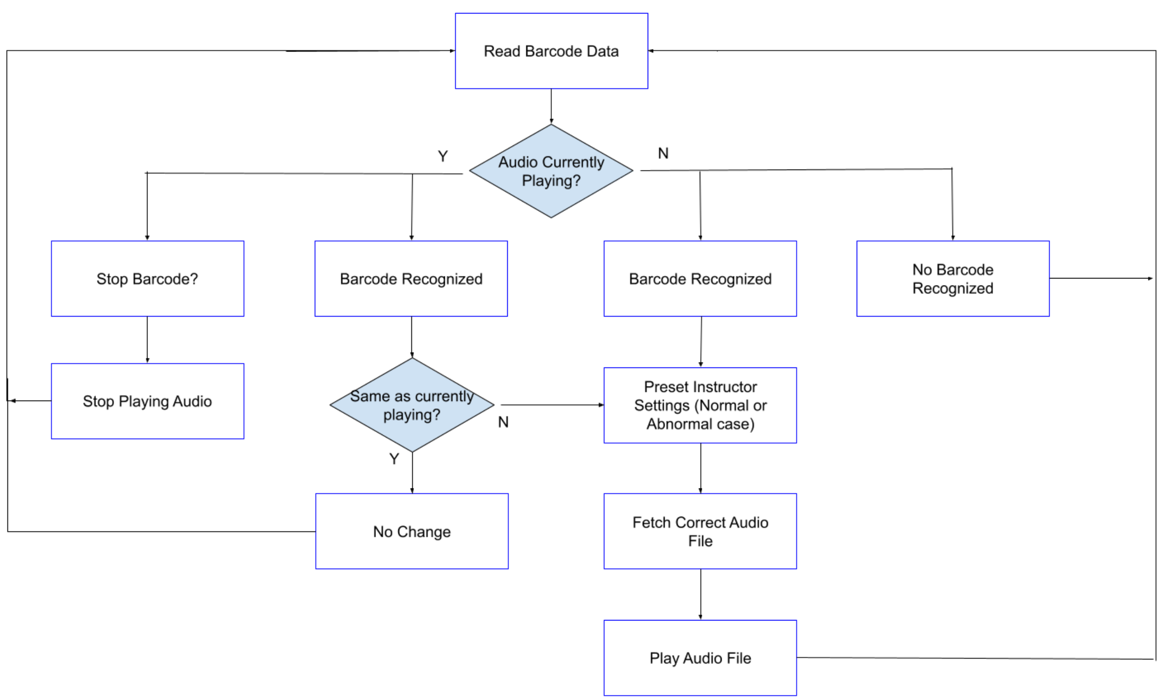


**Fig. 3:** *Backend Program Flowchart*

The GUI is the primary interface with which users interact. It was created using MATLAB App Designer and contains a graphical representation of the front and back of the vest with a color-coded button for each location of interest. Red buttons are for cardiovascular regions, blue buttons for respiratory, and green buttons for gastrointestinal. When the user clicks a button, the dropdown menu at the bottom right propagates with the sounds available for that location; each has one normal sound and one to three abnormal sounds. The user can then click on the sound desired. Once all sounds have been selected, the instructor would click the "update" button and move the run switch to "on" to begin the simulation.

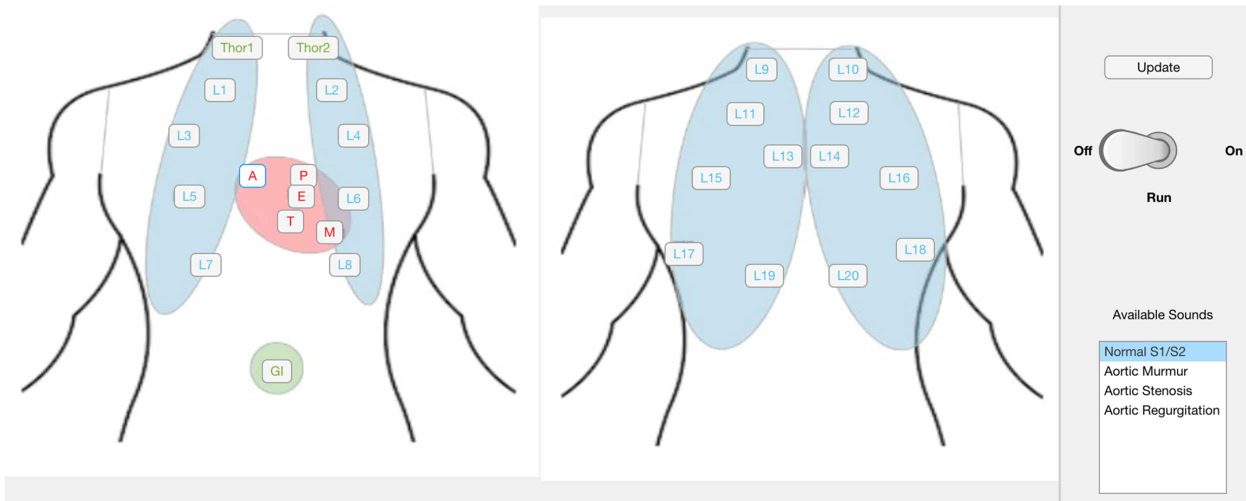


**Fig. 4:** *Screenshot of the GUI with sounds corresponding to the aortic location*

*Component Integration*

The three components of the design all rely on each other for full functionality. The smart stethoscope is closely connected with both the vest and the software, acting as a mediator between these two components. The stethoscope sends information, such as where the student is looking on the vest, to the software via a physical connection.

MTS encountered integration difficulties in the final design. As stated above, the stethoscope chestpiece was designed to be connected to the electronics box using a USB cable, which was then connected to the computer with another USB cable. These two cables were connected to each other within the electronics box using a USB connector. This design would allow the student to have more room to move away from the computer. Unfortunately, the barcode scanner could not transmit data across the USB connector, so the chestpiece must be directly connected to the computer using a 5.5 ft cable. Additionally, MTS could not fully integrate the backend program with the GUI as initially intended. This is because the backend program requires the use of the MATLAB command window to read data from the barcode scanner, which is unavailable in the MATLAB App Designer environment. To create a usable prototype, two example sound collections (one normal and one abnormal) have been created in advance so that the backend can be run independently during demonstrations.

## Design Evaluation

To evaluate the design and determine the performance of the SimuVest prototype, a series of tests were executed. Specifically, thirteen tests were completed on a pass fail scale with specific acceptance criteria to ensure the design created performs well and satisfies stakeholders needs. Tests were performed for the three major components of the SimuVest. For the vest aspect of the design, readability, durability and location accuracy tests of the barcodes were completed. The barcodes exceeded performance expectations by withstanding multiple washes and resisting wear during the allotted time of the performed evaluations. The barcodes passed the readability qualification test in that they are able to be scanned 100% of the time. Since Dr. McAlister placed the barcodes, the locations of the barcodes were deemed accurate based on her expertise and required no further testing. The scanner performed reliably by accurately and quickly reading the barcodes and relaying the information to the laptop.

The next aspect to be examined and evaluated was the audio produced by the SimuVest. Four audio verification tests were performed to evaluate the functionality of the codes as the scanner reads the barcodes. This process confirms that the correct audio file is retrieved and played, the scanner is able to scan another code and play that sound, and the stop code initiates the stop of the sound playing. The scanner passed the required acceptance criteria for all the audio verification methods.

The GUI and the backend code were evaluated for functionality and reliability. The GUI was evaluated by users to rate the ease of use and functionality of the interface. Since the GUI was unable to be interfaced with the code, the functionality was unable to be evaluated, however, the overall appearance and concept were evaluated and well received by the users. The backend code worked reliably and met the acceptance criteria.

Finally, the durability of the stethoscope chestpiece and the electronics box were drop tested to evaluate the functionality of the device after a drop. Since drops can occur in instructional settings, tests were performed to ensure the device still works after an accidental drop. The electronics box and the stethoscope both passed the tests performed. The clip on the electronics box passed the durability test as well after repeated use. Below depicts the results of UT nursing student feedback regarding the concept and features of the design.

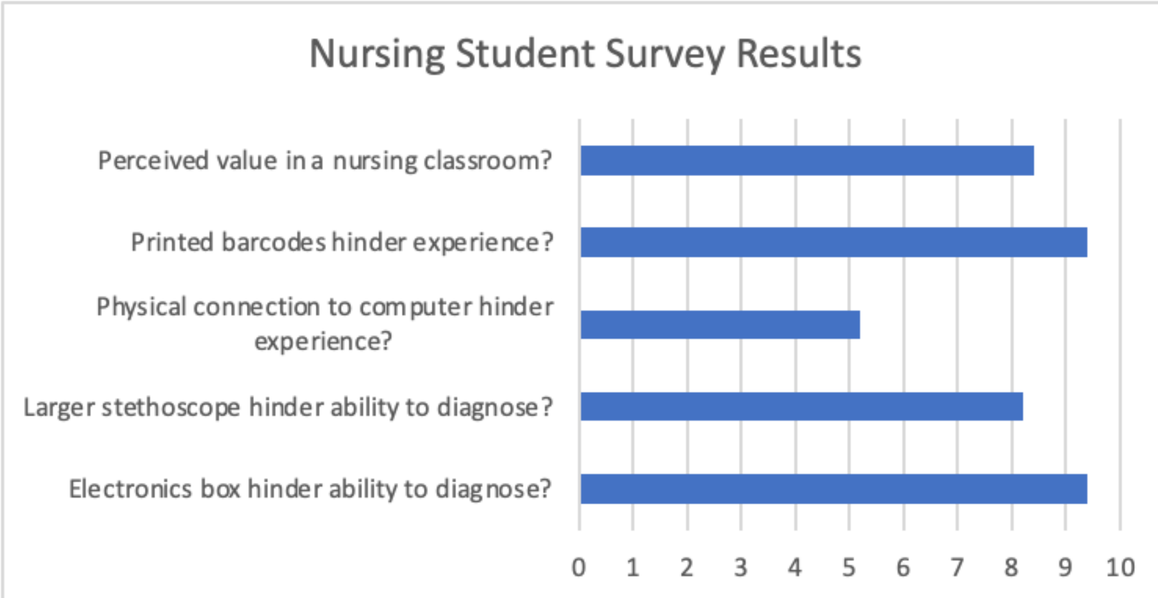


**Fig. 5:** *Results from the UT nursery student survey to evaluate the design*

The design meets the stakeholder requirements because the SimuVest produces high fidelity sounds at an affordable price. The device can produce abnormal and normal sounds in the necessary regions. The sounds produced were evaluated and determined to be quite similar to those of biologic pathologies. The vest itself is low profile, adjustable and easily sanitized. The price to produce the prototype was roughly $100, and to replicate this specific prototype would be around a similar price. However, after looking at bulk purchase options and evaluating the manufacturing process the device could be reproduced for $50. The device could then be marketed for $200 which is well below the competition. After presenting the design, Dr. McAllister was pleased with the result came up with by MTS.

## Recommendations and Future Work

The Medical Sound SimuVest in its current state offers many advantages over existing training simulation products. It is low-cost, portable, and reusable while offering nursing students valuable practice in auscultation. It utilizes barcodes and barcode scanning to remain affordable for underfunded nursing programs. The discretized codes allow exact anatomical locations to produce sounds consistently, and as more high fidelity recordings become available in the future, the system is simple to update.

For continued development, the team suggests changes to the initial prototype as well as other changes that would facilitate mass production at a reduced cost. The shirt must be made in a variety of sizes to accommodate standardized patients of different body types. A standard XS-XL t-shirt scale is sufficient for this and reasonably affordable. In addition, the current barcode scanner is insufficient in terms of functionality for a larger scale product. Future development would require a programmable barcode scanner that can be controlled by an app developed through a partnership with a programming team. This setup would be beneficial because it would allow for full integration between the user interface and the backend program as well as eliminate the need for the stop barcode on either side of the vest. To better facilitate auscultation practice, the team suggests finding a way to incorporate a method for nursing students to attach their own personal stethoscopes to the system and listen through their own earpieces. This could include attaching the chestpiece to the electronics box and using a speaker against the drum. To further reduce the difficulties of all the wires and connections between the smart stethoscope, computer, and headphones, a wireless connection to the computer would be ideal so nursing students could move around more comfortably.

Currently, the instructor must select normal or abnormal sounds individually by location. A future design could allow the instructor to select a condition from the GUI, and each barcode location is automatically updated to reflect the pathology of a condition. For example, a selection of ‘COPD’ would update lung sounds with their corresponding abnormalities, and the nursing student would be able to listen and diagnose based on what they hear.

For mass production, nursing programs could have the opportunity to purchase a subscription service where barcode templates are sent to the schools frequently, depending on how often they use the vests and if the washing machines used by the schools are wearing the barcodes down. Barcodes would also need to be screen printed instead of heat transferred to reduce the cost. Components that were 3D printed, such as the electronics box and smart stethoscope housing would be created using injection molding techniques to reduce costs. With all of this considered, the total cost of future production is estimated to be $48.44 per SimuVest. This is based on estimated costs for a white cotton shirt ($3.50), straps ($2.00), a zipper ($0.90), and screen printing ($0.04/shirt). A scanner from the same supplier as the prototype would cost $40, and the injection molding is estimated to cost $0.50/part, with 4 parts totalling $2.00. A markup price to $200/vest would sufficiently cover the costs of contracting these services out to other suppliers, shipping parts, and manufacturing.