MedAid Academy

Building Biomedical Engineering Capacity in LMICs:

An Evaluation of the Medical Aid International Biomedical Engineering Training Programme



Medical Aid International

Supporting Healthcare in Low Resource Environments

Executive Summary

The main aim of the project was to strengthen biomedical engineering capacity at a number of healthcare facilities across Low- to Middle-Income Counties (LMICs), using the online biomedical engineering training programme from Medical Aid International (MedAid). The project also sought to assess the impact and effectiveness of this training programme. 26 healthcare facilities and 80 biomedical engineers were funded by the Intuitive Foundation to participate in this initiative. The project participants and sites spanned 12 sub-Saharan African countries: Democratic Republic of the Congo, Ethiopia, Ghana, Liberia, Madagascar, Malawi, Namibia, Nigeria, Sierra Leone, Uganda, Zambia, and Zimbabwe. The project phases are set out below:

1. Candidate and site selection
2. Onboarding survey
3. Initial equipment audit
4. Online biomedical engineering course
5. Maintenance log
6. Final Equipment audit
7. End of project survey

Sites were chosen based on the suitability of the participants and healthcare facility to the project, the need for the biomedical engineering training, in addition to the potential positive impact of the project at each site.

Data to assess the effectiveness of the biomedical engineering course was obtained by comparing the data collected before the training took place, to a corresponding data set after the training had been completed. These data comparisons were a comparison between responses to the onboarding survey with the end of project survey, and a comparison between the initial equipment audit and final equipment audit. Data collected during the participant course feedback survey (at the end of the biomedical engineering course) was also used for this purpose.
The scope of this report was primarily to assess the changes between these sets of data to investigate the impact of the course, rather than to analyse in detail the absolute values of the surveys, audits, and feedback.

The biomedical engineering course from Medical Aid International was measured to be effective across all of these data sets.

As part of the online biomedical engineering course, an accompanying package of programme resources was provided to help participants apply the skills learnt during the course. Each biomedical engineer was provided with a full professional toolkit, set of textbooks, digital library of service manuals, and workplace attire. Each site also received a resource package, with resources both for the biomedical engineering team (including an oxygen analyser, a desktop magnifier, asset tag labels, and a laptop with a monitor, keyboard and mouse), as well as for the healthcare facility (a pulse oximeter, and a neonatal resuscitation kit).

> *"The course is extremely important to all Biomedical engineers in Kenya. If resources are available, I propose we train all the Biomedical engineers from the small level 2 hospitals to the National hospitals."*

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The project started with the onboarding survey, where participants were asked some questions about their background, in addition to their self-assessed abilities as biomedical engineers. They were then asked to complete the initial equipment audit, asking questions about 30 different types of common medical equipment expected at their healthcare facilities.

Upon completion of the initial equipment audit, the participants were enrolled in the online biomedical engineering training course from Medical Aid International. This was the course used to upskill the biomedical engineers, and was assessed for its effectiveness as part of the project.

The feedback provided by the biomedical engineers through the participant course feedback survey was extremely positive and provided excellent evidence for the effectiveness of the programme.

Participants scored the course highly (at 9.3 or above, scale 1-10) on whether or not they were satisfied with the course, would recommend the course, or would take future courses with Medical Aid International. They also reported that the provision of all the included programme resources (toolkit, textbooks, and digital service manuals), as well as the course itself, positively impacted their daily work (scores of 9.1 or greater, scale 1-10).

For some questions, the cohort was divided into those participants completing the original end of course feedback survey, and those completing an updated version.

Reported by those completing the original survey, the course also positively impacted the participants in terms of their daily practice confidence, communication ability, and their ability to train others. All of these metrics were well received, with an average score of 8.52-9.35 (on a scale of 1-10).

> *"I fixed our X- ray scanner that has been down and the hospital was planning to get a new one costing millions of FCFA thanks to Medical Aid international."*

Other key metrics for biomedical engineers were also measured, using an updated course feedback survey for some participants (about half the cohort), who measured notable increases in their self-assessed abilities to maintain and fix equipment, communicate with and train others, as well as their perceived respect level as biomedical engineers. The scale was again 1-10, with each metric increasing by a minimum of 2.4 points.

The difficulty of the course was also at a reasonable level, with a range of difficulty scores provided by the participants. On balance, participants perceived the course to be slightly more challenging than it was easy.

A broad mix of units were selected as being the most useful, demonstrating breadth of useful information contained within the course, with Unit 2 (Electrical Safety), Unit 3 (Electrocardiogram (ECG)), Unit 11 (Anaesthetics and the Operating Room), Unit 12 (First Aid) being the four most frequently selected units.

The next stage of the project was for a maintenance log of the equipment to be completed. This included logging the equipment type and asset tag number, the withdrawn from and returned to service date, the fault, work completed, parts used, where the solution was learnt, and any additional comments. This data was analysed in a separate report and so is not included in this report.

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Participants were then asked to again complete the same equipment audit that they previously completed, called the final equipment audit. This data was then compared against the responses provided in the initial equipment audit to look for any changes, i.e., the impact from completing the biomedical engineering course.

Again, the findings were that the biomedical engineering course was effective.

A significant amount of data was logged by the participants, with 1888 matching entries being logged in each of the initial and final equipment audit (making 3776 entries in total). One potential outlier site (06GH) was excluded from the dataset in certain areas.

Spare parts were lacking for almost all of the equipment surveyed, with only 13-19% of equipment having all spare parts available. There was a wide range of spare parts availability by equipment type, with pulse oximeters having particularly good availably (above 50%), but with most equipment types having under 20%.

The key finding from this section was the increased confidence of the biomedical engineers from completing the course. This is reflected in the very sizable reduction in “Don’t know” responses when comparing participant responses to the initial equipment audit to the final equipment audit. The range of these reductions primarily spans from 60% to 90% across the questions asked. The greatest reduction was 91.7%, with the lowest being 25.0%.

There were a few findings relating to changes in responses for specific items of equipment, for which training was provided in the online course. This suggests that these findings were caused by the improved knowledge provided by the course.

One such example of this was an increase in the proportion of anaesthetic machines with soda lime during the final equipment audit compared to the initial equipment audit. This increase was from 67% to 75%.

There was also an increase in the proportion of oxygen cylinders being secured/chained. There was an increase from 49% in the initial equipment audit, to 61% in the final equipment audit.

The final part of the project was for all of the participants to complete the end of project survey. As with the equipment audits, the change in participant responses between the onboarding and end of project survey were also used to assess the impact of the biomedical engineering course.

A comparison between these two surveys also showed the effectiveness of the biomedical engineering course, with participants reporting improvements in key metrics relevant to biomedical engineers.

These metrics included their self-assessed ability to maintaining equipment, fix equipment, communicate with medical personnel, train others, and feeling respected as an engineer. A Wilcoxon signed-rank test was applied to this data and all of the changes were found to be statistically significant. These improvements were (almost always) present regardless of the education level or experience level of the participant.

There was also a reduction in the proportion of participants reporting that the main reason for non-operational equipment at their healthcare facility was due to a lack of knowledge by the biomedical engineers/medical personnel, again, a positive outcome from the online training.

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The provision of a toolkit and other programme resources was also beneficial to the participants, with the proportion of those reporting adequate tools to perform their jobs increasing to 93% after the intervention, from just 30% beforehand. The proportion of participants with each tool, all of which were supplied, also rose significantly during the project. Participants also favourably viewed the provision of the textbooks, digital service manuals, in addition to the laptop (useful both for completing the course as well as researching solutions to maintenance/repair issues).

The project management was also favourably reviewed by the participants, with 95% reporting that the communication by Medical Aid International throughout the project was either a score of 9 or 10 (scale 1-10). The same proportion also felt well supported during the project, giving a score of 9 or 10 on the same scale. 92% of participants would also fully recommend the project (scoring 10 for this metric a), with no participant giving a score lower than 7 (scale again 1-10).

It is for all of the above, and evidence across all three datasets, that this report concluded that the biomedical engineers participating in this project were successfully upskilled, and that the biomedical engineering course and programme from Medical Aid International was therefore effective.

Medical Aid International would like to thank the Intuitive Foundation for providing the funding for this initiative and working together to make this project possible.



The supplied programme resources, which included over 250 fuses.

Case study:

"The hospital where I work has three ultrasound units. The tracker ball for one of these units developed a jerky motion instead of being smooth. Normally, we would have called in the company engineer and spent close to 90,000 INR which be about 1,000 pounds.

However, with a better understanding of the components of the machine and a little help research on-line, I was able to disassemble the USG machine, extract the tracker ball and identify that the cylindrical rods it sits on (which provide the x and y axis), were eroded. Fortunately, my town has a CNC machine whose staff agreed to make me a set of these 4mm cylindrical rods according to the damaged part I gave them. Fast forward a week later, I was able to install these rods and successfully, reassemble the USG machine and the tracker ball is as smooth as butter. I also used the opportunity to give the machine a deep clean particularly the rubber keypad which had accumulated a lot of dust and dirt, and also the keypad's contact points on the keypad itself as well as the contact points on the PCB. This resulted in the 'Set' button, which was performing erratically, to work normally. Total cost was 2,000 INR.

It was this course that gave me the confidence to embark on this seemingly monumental repair job."

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Message from the Chief Executive

Twenty five years ago, when I founded Medical Aid International, one subject continually arose in meetings, conferences and discussions during my travels across Low- and Middle-Income Countries (LMICs): the urgent need to strengthen biomedical engineering support within healthcare facilities.

Wherever we worked, whether equipping hospitals, installing medical equipment or supporting healthcare projects, we encountered dedicated biomedical engineers, technicians and hospital maintenance staff who were passionate about their work and eager to learn. Yet many lacked access to formal training, or even the most basic tools required to perform their roles effectively.

Having come from both a clinical and educational background, I recognised that addressing this challenge would require more than simply providing equipment. We therefore developed a comprehensive, LMIC focussed, online biomedical engineering training programme. This programme leverages the growing opportunities offered by online learning and is Assured by the globally recognised awarding body City & Guilds.

From the outset, we wanted the programme to be holistic in nature. We knew that high-quality technical content was essential, but equally important were access to quality tools and resources, and support for personal and professional growth. As a result, the extensive online course is supplemented with an extensive professional toolkit, textbooks, workplace attire, and includes both a Train the Trainer, and a First Aid training module. Combined, this enables participants to be well-resourced, and to develop both technical competence and wider professional skills.

The success of the programme has truly exceeded our expectations. It has had a major impact globally on individual engineers, healthcare facilities, governments and, increasingly, on the visibility and recognition of the biomedical engineering profession itself. The data, participant feedback, stories, and photographs contained within this report demonstrate the transformative effect that investment in biomedical engineering capacity can have on healthcare delivery.

I write this foreword from Uganda, having recently visited two of the hospitals featured in this report, where I have once again witnessed first-hand the difference this programme is making. Hospital managers, doctors, and biomedical engineers alike spoke enthusiastically without prompting about the improvements they have seen. It is clear that the programme is acting as a catalyst for change, helping to strengthen healthcare systems and improve patient care.



Tim Beacon working with MedAid trained biomedical engineers in Kenya, installing and commissioning an operating room.

This report highlights not only the achievements of the programme but also the significant challenges that many hospitals continue to face, including those resulting from inappropriate equipment donations and procurement decisions. It also underlines the critical importance of investing in skilled biomedical engineers who can ensure medical equipment remains safe, functional and available for patient care.

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Dr Catherine Mohr (centre) and Patrick Diamond (fourth from left), at one of the project sites in Ethiopia.

Having seen first-hand the reality of the lack of biomedical engineering support in many LMICs, I was therefore delighted to have the opportunity to partner with the Intuitive Foundation on this exciting and transformative initiative. Their commitment to developing biomedical engineering services in resource-limited settings has been incredibly encouraging and truly visionary. As such, I would like to extend my sincere thanks to them for funding and supporting this project, and in particular to Dr Catherine Mohr, President of the Intuitive Foundation. Her vision, belief in developing this biomedical engineering capacity building, and funding to make this happen have been truly inspiring. Many thanks also to Patrick Diamond, Surgical Education Learners Forum (SELF) Programme Manager, for helping oversee the project and working closely with us in designing and implementing this initiative.

I would also like to thank Jonathan Miller, Research and Education Manager at Medical Aid International, for authoring this report and managing the entire project, as well as Emily Spessert, formerly Head of Academic Research and Engineering Development at Medical Aid International, for her valuable contribution. My thanks also go to the wider Medical Aid International team whose dedication and logistical support helped make this programme possible.

It has been immensely rewarding to read the feedback from the biomedical engineers who have participated in the programme, reporting the substantial improvements in their technical knowledge, confidence and professional practice as a result of both the online training and the package of resources provided.

This reflects Medical Aid International's long-standing belief that training and resources must go hand in hand if lasting change is to be achieved. Together, they create a powerful combination capable of delivering sustainable improvements in healthcare services.

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It must, however, be said that the greatest frustration is not a lack of demand; we have over a thousand applicants on a waiting list to participate in our programme. The primary challenge remains funding. With additional support, the potential exists to expand this initiative significantly and create an even greater global impact.

My sincere thanks once again to the Intuitive Foundation and to everyone who has supported Medical Aid International on this journey.

I hope you enjoy reading this report and that it inspires further investment in the biomedical engineering professionals who play such a vital role in delivering safe and effective healthcare around the world.



Tim Beacon
Founder and Chief Executive, Medical Aid International
Honorary Fellow, City St George's, University of London



MedAid trained biomedical engineering graduates receiving their City & Guilds Assured Certificates.

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Introduction

In the experience of Medical Aid International, biomedical engineering is often an area which is under resourced in Low- and Middle-Income Countries (LMICs). This has many implications for the ability of the healthcare facility to provide a good standard of patient care, both in terms of equipment safety and availability.

This initiative, generously funded by the Intuitive Foundation, seeks both to address this gap in support for effective healthcare provision, while also gathering data about the effectiveness of the Medical Aid International online biomedical engineering course.

This assessment was completed by comparing the responses to two paired datasets collected during this project (with each dataset having a component collected before the online course was completed, as well as a component after the course was completed). Thus, the impact of any changes in responses would be primarily from the biomedical engineering training course provided. Additionally, feedback provided by the survey completed by participants at the end of the training course (**Appendix 3** and **Appendix 4**) was also analysed to judge the effectiveness of the programme.

The project selected 25 healthcare facilities, with an additional site added during the project, making 26 in total. This represented 80 biomedical engineers. The project participants and sites spanned 12 sub-Saharan African countries: Democratic Republic of the Congo, Ethiopia, Ghana, Liberia, Madagascar, Malawi, Namibia, Nigeria, Sierra Leone, Uganda, Zambia, and Zimbabwe.

The sites were selected on the basis of their need for the biomedical engineering training, the potential impact the project may have, their enthusiasm, the relevance of their answers during the application process, as well as their English ability (as the surveys and supporting resources were only available in English).

The participants at the successful sites were then asked to complete an onboarding survey (**Appendix 1**), asking questions about their background, as well as their self-assessed abilities as biomedical engineers. They were then asked to complete the initial equipment audit, asking questions about 30 different types of common medical equipment expected at their healthcare facilities.

Upon completion, the participants were provided with access to the online biomedical engineering training course from Medical Aid International, in addition to an accompanying package of programme resources (toolkit, textbooks, digital library of service manuals) to help them apply the knowledge from their training. Each site also received a resource package, with resources both for the biomedical engineering team (including an oxygen analyser, a desktop magnifier, asset tag labels, and a laptop with a monitor, keyboard and mouse), as well as for the healthcare facility (a pulse oximeter, and a neonatal resuscitation kit).

79 of the 80 participants selected to participate in the provided online biomedical engineering training course from Medical Aid International were able to complete the programme. The data collected during the course feedback survey was used as one way to assess the effectiveness of the training programme, detailed in the section **Participant Course Feedback Survey**.

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> *"I have managed to fix the autoclave which has been dormant for a period of over a year."*

The next stage of the project was for a maintenance log of the equipment to be completed. This included logging the equipment type and asset tag number, the withdrawn from and returned to service date, the fault, work completed, parts used, where the solution was learnt, and any additional comments. This data was analysed in a separate report and so is not included in this report.

Participants were then asked to again complete the same equipment audit that they previously completed, called the final equipment audit. This data was then compared against the responses provided in the initial equipment audit to look for any changes, i.e., the impact from completing the biomedical engineering course. These results are set out in the **Initial and Final Equipment Audit Data** section.

The final part of the project was for all of the participants to complete the end of project survey (**Appendix 2**). As for the equipment audits, the change in participant responses between the onboarding and end of project survey were also used to assess the impact of the biomedical engineering course. These results are set out in the **Onboarding and End of Project Survey** section.

Medical Aid International were delighted to work with the Intuitive Foundation on this initiative, and are grateful for the funding provided to make this project possible.



A MedAid trained biomedical engineer using the supplied programme resources to repair medical equipment.

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Methodology

Report and Project Aims

The main aim of the project was to upskill biomedical engineers across a number of sites (hospitals, clinics, etc.) in order to improve equipment maintenance, subsequently improving patient care.

The secondary aim of the project was to assess the effectiveness of the biomedical engineering course offered by Medical Aid International, which was the sole method by which training was delivered to the participants.

These two aims are intrinsically linked, as the effectiveness of the biomedical engineering course will directly translate into better trained biomedical engineers (with all the subsequent benefits).

Project Phases

The project was divided into several phases, each listed and detailed below:

1. Candidate and site selection
2. Onboarding survey
3. Initial equipment audit
4. Online biomedical engineering course
5. Maintenance log
6. Final Equipment audit
7. End of project survey

1. Candidate and Site Selection

Initial funding was provided for 70 participants across 25 sites by the Intuitive Foundation. The project was expanded to include a further site, taking the final numbers to 78 participants across 26 sites. At the discretion of Medical Aid International, but in consultation with the Intuitive Foundation, an additional 2 participants were given access to the online biomedical engineering course (but without the accompanying programme resources: toolkit, textbooks, and a digital library of service manuals).

Additionally, several more participants were given access to the course even after leaving the hospital, as a thank you for participating in the successful application process for their site. These participants were not classified as being part of the project.

The application process showed keen interest in the project, with 292 applications totalling 1083 engineers being received from across 29 countries. Exclusion criteria was applied, listed below:

- The facility must be in a low-to-middle-income country; this excluded one application from Albania.
- The facility must not have staff who have already completed the Biomedical Engineering Course from Medical Aid International; this excluded 18 sites.

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All applications were screened to check that all the requested information had been provided correctly by the site and participants. This included (but was not limited to) submitting a single application per site, providing all the names and contact details for each biomedical engineer to be participating in the project, as well as full contact information for the hospital manager. Any applications not completed correctly were ruled ineligible for the project at this stage. 73 applications were ruled out for the reasons set out above.

The applications that met these criteria then had their written paragraph about why their site should be selected assessed on the following metrics, as described in **Table 1**.

It should be noted that the average was weighted, such that English ability and need each counted for a third of the score, while the content portion of the score (also a third) was weighted equally between response relevancy, enthusiasm, and reach/impact. If an application was decided to fall between two score gradings in a given category, a rating could be given in half-point increments (e.g. 1.5, or 2.5).

Table 1. Applicant selection rubric.

	0	1	2	3
English Ability $\frac{1}{3}$ *of total score*	-	Response is unreadable.	Adequately written but has some distracting errors.	Clearly conveys the message without distracting errors.
Content: Response Relevancy $\frac{1}{9}$ *of total score*	-	Does not answer the question.	Attempts to answer the question.	Thoroughly answers the question.
Content: Enthusiasm $\frac{1}{9}$ *of total score*	-	Demonstrates no enthusiasm nor excitement towards project.	Demonstrates some enthusiasm and/or excitement towards project.	Demonstrates enthusiasm and/or excitement towards project.
Content: Reach/Impact $\frac{1}{9}$ *of total score*	-	Site and/or applicants demonstrate minimal ability to be a wider catalyst for change.	Site and/or applicants demonstrate some ability to be a wider catalyst for change.	Site and/or applicants demonstrate ability to be a wider catalyst for change.
Need $\frac{1}{3}$ *of total score*	-	Appears to be well-funded, advertises speciality services and specialised equipment.	Appears to have some funding, lacks speciality services and equipment.	Appears to have minimal/no funding, lacks basic services and equipment.

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More details about the specifics of each of the criteria in **Table 1** and why these criteria were selected are provided below.

English Ability

While the course is available in both English and French, the equipment audits, onboarding and end of project surveys, and the vast majority of communication with the participants were in English. This meant possessing a high level of English proficiency would be necessary to comprehend what was being asked, and hence the ability of participants to accurately complete the project.

Given only reasonable comprehension was required for the project, responses were only scored less favourably if the meaning of the content became unclear. Grammatical, spelling, and formatting errors were ignored, unless these detracted from the clarity of the content.

Two sites were selected which were primarily French speaking, given the course was available in French. These sites were given additional support to complete the project, although the majority of communication was still conducted in English. Throughout the project, the Medical Aid International research team were satisfied that both sites fully understood the project requirements and were able to carry them out.

Content: Response Relevancy

Here, the response each application provided to the prompt "Please write a short paragraph detailing why your healthcare facility should be selected." was assessed in terms of how well the information provided addressed the prompt. Specific details about how the project would benefit the hospital, patients, or why their site would be well suited were awarded highly. General information about the hospital or local community scored less well.

Content: Enthusiasm

Given the significant investment of time and effort required to undertake the project, the enthusiasm of the participants was assessed. Aspects which caused applications to score more highly included:

- Expressions of excitement or eagerness about the project.
- Expressions highlighting both benefit to the hospital as well as personal development from participating in the project.
- Specific references to information provided to applicants in the MOU or application (for example, references to the resources provided, having a dedicated biomedical engineering space (a project requirement), etc.). These references underline that they have already spent time engaging with the project's requirements and so are also likely to engage well with the work throughout the project.
- References to sharing the knowledge gained from the project or course with other healthcare facilities.

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Content: Reach and Impact

Consideration was also given to the potential for positive impact of the project at each site and its surrounding community/region. Factors that positively influenced the score included:

- The site having a large number of beds (300+).
- The site being the only healthcare facility in the region.
- The facility having a large catchment area.
- References to teaching others or sharing knowledge with other sites/biomedical engineers.

The impact of the course's first aid module:

> *"I witnessed a car accident 4 days ago while I was travelling. Two persons in the car wear seriously injured, [the] driver went unconscious and one person had a broken arm. When I went there the first thing I did was to remove the driver from the car and place him in a recovery position. Secondly, the people who had serious injuries, I had to look for a pad and applied pressure on the bleeding area. And the lady with the broken arm. I had to put the broken arm across the chest and support it with a bandage."*

Need

The biomedical engineering training course provided is pitched at a foundational level. It was therefore decided that the training would be most beneficial to those facilities with more limited resources and training, i.e., those with the greatest need. The provision of the programme resources (toolkit, textbooks, digital library of service manuals, laptop, desktop magnifier, soldering iron, etc.) would also be more in need at these sites, making them more appropriate for selection. It was therefore decided to included need as a key factor in the site selection criteria.

Post Site Selection

Each of the 25 successful sites were then notified that their applications had been approved and were subsequently sent the MOU and participant consent forms to be signed for formal acceptance into the project. Unfortunately, 2 sites were unable to fulfil these criteria in a timely manner; consequently, they were replaced by the next most highly scoring sites (which also allowed the number of participants for the project to remain constant).

2. Onboarding Survey

Each participant was asked to complete an onboarding survey to provide some information about themselves and their educational background, their hospital and equipment status, their current level of resources and tools, as well as self-reported level of ability across numerous characteristics relevant to biomedical engineers.

This survey was then repeated at the end of the project so any changes in participant responses could be identified as a result of participating in the project (primarily from completing the online biomedical engineering training course).

The full onboarding survey questions are detailed in **Appendix 1**. The corresponding end of project survey questions are detailed in **Appendix 2**.

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3. Initial Equipment Audit

Participants were then asked to complete an initial equipment audit survey, with detailed questions about 30 common items of equipment which might be found at their facility. In total, responses for 29 of these 30 items of equipment were provided throughout the course of the project. Each site was instructed to log all equipment present on the list (set out in **Table 6**), regardless of whether the item was currently in use, in storage, or decommissioned. It was not possible to monitor adherence to the instructions provided.

The objective was to obtain a baseline background and operational status for the equipment at each healthcare facility, which could then be compared with the final equipment audit (completed after the participants had completed the online biomedical engineering course). This allowed for the impact of the course to be measured.

The questions asked included (but were not limited to) asking about how the equipment was acquired, the make and model, when it was last used, if there are any safety concerns, if it performs its job satisfactorily, if it switches on, if all accessories/consumables/spare parts are available, if an equipment manual is available, and other item specific questions.

At this stage, no definitions or examples of suitably functioning equipment were provided. This resulted in a wide range of interpretations of the questions, for example, the meaning of "safe" equipment. This will have varied by county, facility, and participant.

Participants were asked to asset tag each piece of equipment information was entered for, such that each piece of equipment could be individually identified and referenced during subsequent project phases. The asset tags were simply an ascending numerical sequence (i.e., 0001, 0002, 0003, 0004, etc.), each provided as an adhesive label for simple attachment to the equipment.



A MedAid trained biomedical engineer using skills from the train the trainer module of the course to teach others.

> *"[The train the trainer module] helped me improve my ability to pass on knowledge and train others, which is important in my role as a senior biomedical with over 10 years of experience."*

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4. Online Biomedical Engineering Course

Participants next completed the biomedical engineering course. This provided training and essential knowledge on a variety of topics directly relevant to biomedical engineers. The content spans the list of topics below:

- **Unit 0:** Health and Safety
- **Unit 1:** The Frequency Spectrum
- **Unit 2:** Electrical Safety
- **Unit 3:** Electrocardiogram (ECG)
- **Unit 4:** Defibrillation
- **Unit 5:** Patient Monitoring
- **Unit 6:** Infusion Devices
- **Unit 7:** Premature Baby Incubators (PBIs)
- **Unit 8:** Ultrasound
- **Unit 9:** Surgical Diathermy/ESU
- **Unit 10:** Hygiene Guidelines
- **Unit 11a:** Anaesthetics, Oxygen and Suction Devices
- **Unit 11b:** The Operating Department and Sterilisation
- **Unit 12:** First Aid
- **Unit 13:** Train the Trainer

This training provided a shared basis for all participants in terms of many aspects of the equipment audit questions, for example, which equipment should be considered “safe”. The impact of this training was anticipated to be reflected in the answers participants provided during the final equipment audit.

Participants were required to watch each video on the course in sequence, watching it fully before being able to move on to the next topic. At the end of each unit was a multiple choice question (MCQ) test, with both the question and answer order shuffling randomly between each attempt to facilitate robust learning. Participants were required to score 100% on the end of unit test before being allowed to proceed to the next unit.

Participants were also provided with a package of programme resources to help them implement the knowledge gained from undertaking the online training. Each engineer received a full professional toolkit, textbooks, digital library of service manuals, and workplace attire. Each healthcare facility also received a resource package to thank them for participating in the project, with some items for the biomedical engineering team (consisting of an oxygen analyser, a desktop magnifier, asset tag labels, and a laptop with a monitor, keyboard and mouse), and others for the wider medical team (a pulse oximeter, and neonatal resuscitation kit).

Feedback from each participant was collected at the end of the course. Full details of this can be found in the **Data Exclusions and Comments section**, and the full feedback surveys are provided in **Appendix 3** and **Appendix 4** (as two versions of participant feedback survey were used across the project).

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This feedback provided direct evidence of the impact of the course on the participants, especially on a practical level in their daily work. These findings are set out in the Data Analysis section of the report.

For participants studying the French version of the course, the feedback surveys used were identical, simply translated into French. The data here was treated as directly comparable for the two groups and merged into a single dataset.

5. Maintenance Log

Participants were also asked to keep an online maintenance log of all maintenance and repair events conducted at their hospital for the 3 month period after all of the biomedical engineers at the hospital (participants) had completed the course.

This included information on the asset tag number of the equipment being repaired (so the data could be matched to the initial and final equipment audit data), the equipment type, the out of service date, return to service date, equipment fault, work conducted, which spare parts were used, where the solution was learnt (e.g., the Medical Aid International online biomedical engineering course), and any additional comments.

This data has been analysed separately and is contained in a separate report, hence these findings are beyond the scope of this report.

6. Final Equipment Audit

Each site was then required to complete a further equipment audit, identical to the initial equipment audit. The rationale was that any changes in the responses between the two audits could be attributed to the online biomedical engineering course, which each participant had completed by such time.

For this reason, participants were asked to use the same asset tag numbers as used in the initial equipment audit to facilitate such comparisons.

7. End of Project Survey

Participants were then requested to complete an identical survey to the onboarding survey. This allowed the responses of both to be compared, with specific focus on the impact on the equipment at their hospital in general terms, their level of resources and tools, as well as self-reported level of ability across numerous characteristics relevant to biomedical engineers.

Additional questions were added to the end of project survey relating to the management and effectiveness of the project overall. The full onboarding survey questions are detailed in **Appendix 2**.

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Data Analysis

The data collected during this project can be sorted into a number of key categories and sources, each relating to a specific phase of the project. These include:

- Onboarding survey data
- Initial equipment audit data
- Online biomedical engineering course feedback survey data
- Maintenance log data
- Final equipment audit data
- End of project survey data

The project was deliberately constructed such that comparisons could be made between several of the data sets to achieve the project's aim of evaluating the biomedical engineering course offered by Medical Aid International.

Some of this data has already been extensively reviewed in previous reports. This would include the initial equipment audit data, as well as the maintenance log data. For this reason, analysis of the maintenance log data has been excluded from this report. For details on this, please refer to the separate maintenance log report.

Whilst the initial equipment audit data is included, the main rationale is a comparison to the final equipment audit data to elucidate the effectiveness of the biomedical engineering course, rather than an analysis of the specific equipment contained in either the initial or final equipment audit. Such analysis is considered beyond the scope of this report. Please refer to the Comprehensive Review of Hospital Equipment in LMICs for a detailed breakdown of the initial equipment audit data.

In order to evaluate the effectiveness of the biomedical engineering course, three main sources of data were used:

- A comparison between the onboarding survey responses, and the end of project survey responses.
- A comparison between the initial equipment audit data, and the final equipment audit data.
- Online biomedical engineering course feedback survey data.

The rationale behind the comparisons above is that the participants completed the course between these events (i.e., between the initial and final equipment audit, and between the onboarding and end of project survey). This means that changes in responses should primarily be caused by completing the online biomedical engineering course, which was the only controlled changed made during the project. Of course, unknown external factors, such as external additional training, cannot be accounted for by this report and may also have influenced the data.

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To ensure a valid comparison, the questions asked in both the initial equipment audit and final equipment audit remained consistent. This was also true for the onboarding survey, and end of project survey, with the exception of some additional questions to the end of project survey, aiming to assess the project's effectiveness/management, and gather feedback on the initiative as a whole.

Data Exclusions and Comments

Onboarding and End of Project Survey

The criteria for inclusion in the data analysis was that each participant must have completed both the onboarding survey, and end of project survey. Each included participant must also have answered "Yes" to the survey question: "Do you consent to the use of your anonymised data in future research?"

In total, 60 participants met this criteria, with participants from a wide range of sites being represented. For some questions, a very small number of participants either did not answer the question, or the answer was unclear. These responses were not considered during the data analysis, and the matching response in either the onboarding or end of project survey was also removed. The number of participants where valid data exists is listed on a per figure basis.

Initial and Final Equipment Audit Data

Some sites were unable to complete the entirety of the project due to a number of factors; the initial and final equipment audit data from these sites was excluded from the data analysis. The number of sites excluded from the project in this way was 3.

At the first of these, the sole biomedical engineer assigned to the project left the hospital. It was decided that any data already collected would not be comparable to any future data sets, and so the decision was taken to exclude this site.

Similarly, the original sole biomedical engineer left at the second site in question. In this instance two replacement biomedical engineers were present and were given access to the course, but the data collected was excluded on the same grounds.

One biomedical engineer was unable to start the final equipment audit for personal reasons. Given there was no data comparison that could be made between the initial and final equipment audit, this data was also excluded from the data analysis.

It should also be noted that other biomedical engineers at some of the hospitals left during the project, given its significant length. In some cases, these were replaced by new arrivals who were not assigned to work on the project. However, it cannot categorically be stated that these engineers had no input into the entries made to either the initial or final equipment audit, or the maintenance log.

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Additionally, one site changed biomedical engineer very early on in the project, with the course place and programme resources being transferred to the new engineer. Given the change was made early on, the equipment audit data remained comparable and so has been included in the project. The outgoing engineer was provided with access to the biomedical engineering course, but was no longer considered to be part of the project.

Overall, data from 23 sites was included in the initial and final equipment audit comparison. The entries from each site were then carefully checked to ensure a suitable comparison could be made between entries in the initial and final equipment audit. Specifically, the matching criteria used was:

- Both entries must be taken at the same hospital.
- Both entries must have the same equipment type.
- Both entries must use the same asset tag number.

Any other entries which did not fulfil this criteria were excluded from the data analysis. This resulted in 1888 pairs of matching entries (i.e., 1888 initial equipment audit entries, and a corresponding 1888 final equipment audit entries). These entries were all given equal weighting in the data analysis.

Additionally, one site (06GH) was identified as being a potential outlier for certain questions, and given it produced approximately one third of the total responses, was able to skew the overall picture in these areas, Figure 39. For this reason, for any such questions analysis has been produced both with the data from this site included, as well as a separate set of data where it was excluded. Each time this occurred, it was highlighted in the relevant section of the report.

The rationale behind not excluding the site entirely is that (apart from one question relating to equipment safety which appears to have been misunderstood), no reasoning was found to suggest that the data provided was inaccurate. It was therefore decided that the approach outlined above was preferable.

It should also be noted that some equipment was unable to be logged during the final equipment audit by the biomedical engineers as routine cleaning of the equipment at some sites had removed some of the asset tags. In such cases, participants were asked to only log the equipment with the original asset tags remaining.

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Participant Course Feedback Survey

Participant course feedback surveys were received from 79 participants who completed the biomedical engineering course in full. The reason this number is higher than the 78 funded participants is because two additional participants who were given access to the course (but not the programme resources: toolkit, textbooks, and a digital library of service manuals). One participant who was funded did not complete the course, resulting in the final figure of 79 successful course graduates.

No participants were fully excluded from the data analysis as each fully completed the course, meaning their feedback accurately reflects their opinions and assessment of the online biomedical engineering training programme. However, to remove any severe outliers, any scores which were over 5 standard deviations away from the mean were removed from the dataset (keeping all other valid scores for the participant unaltered).

It should be noted that there was a change made to the participant course feedback survey mid-way through the project. This was in order to add more detailed questions about the course and its effectiveness. Wherever possible the original questions were kept comparable, although often with minor wording changes for clarity. In total, 31 participants completed the original participant course feedback survey, with 48 participants completing the updated version. Please refer to **Appendix 3** and **Appendix 4** to read the full participant course feedback surveys.

As mentioned during the **Project Phases** summary, for participants studying the French version of the course, the feedback surveys used were identical, simply translated into French. The data here was treated as directly comparable for the two groups and merged into a single dataset.

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Onboarding and End of Project Survey Comparison

The first few questions of both surveys refer to the age of the participants as well of their years of experience as biomedical engineers. As expected, these show limited changes, with the participants being slightly older and more experienced in the end of project survey compared to the onboarding survey, **Figure 1** and **Figure 2**.

Question 0: What is your age?

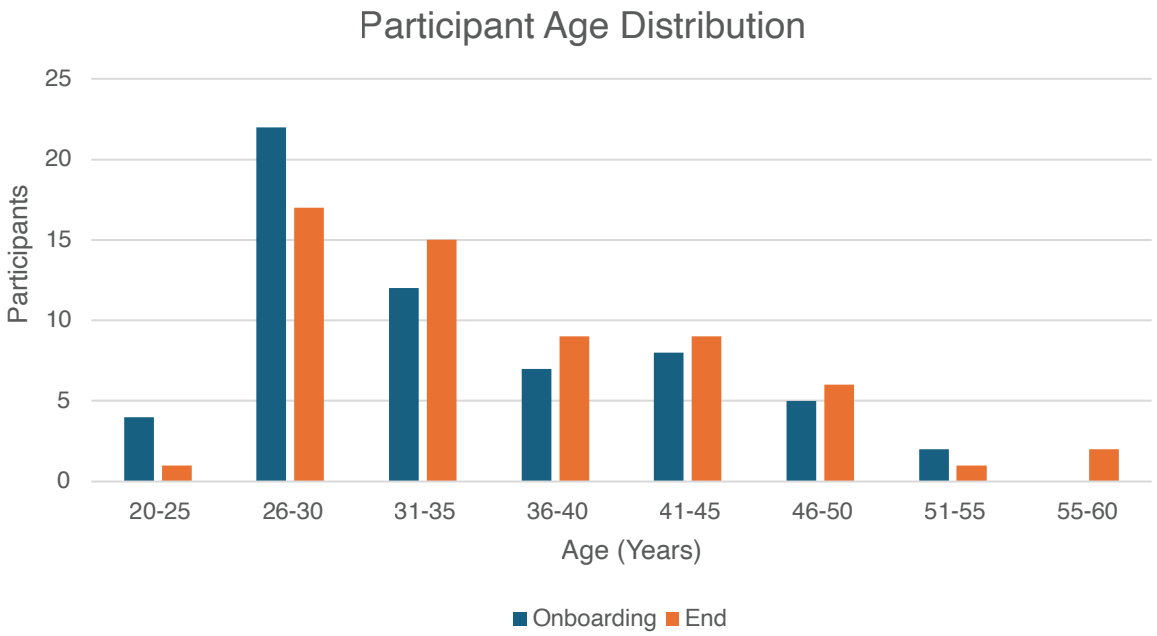


Figure 1. Distribution of the age of participants, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

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Question 1: How many years have you been working as an engineer/technician?

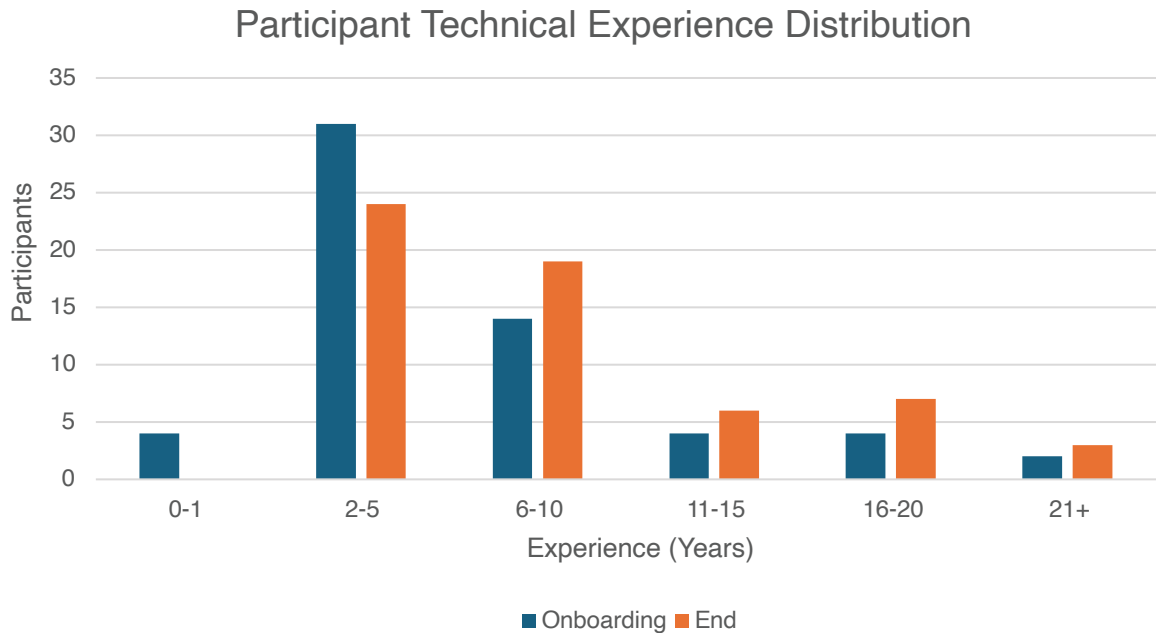


Figure 2. Distribution of the years of experience, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

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Question 2a: Did you go to university for engineering?

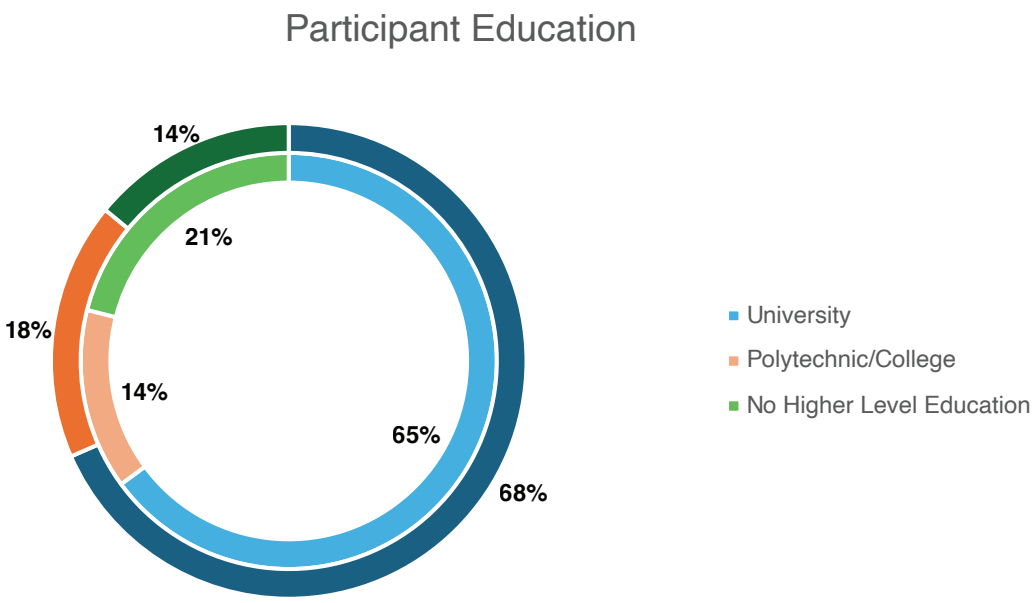


Figure 3. Proportion of participants with a level of higher education, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=57). Inner ring (light colours) is onboarding survey, outer ring (darker colours) is end of project survey. Two participants excluded for not entering education level during the end of project survey, one participant excluded for stating a reduction in education level between the onboarding and end of project survey.

There was a small change recorded in the level of education of the participants throughout the project, with the proportion increasing of both those with a university degree, or college/polytechnic level training – resulting in a corresponding reduction in those with no higher-level education, **Figure 3**.

While this question was originally intended to look only at university level education, many participants wrote in the "Other" option to say that they had attended a college/ polytechnic institution, hence the inclusion of this category.

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Question 3: Have you received any biomedical engineering training outside of formal education (for example: supplier led trainings, online courses)?

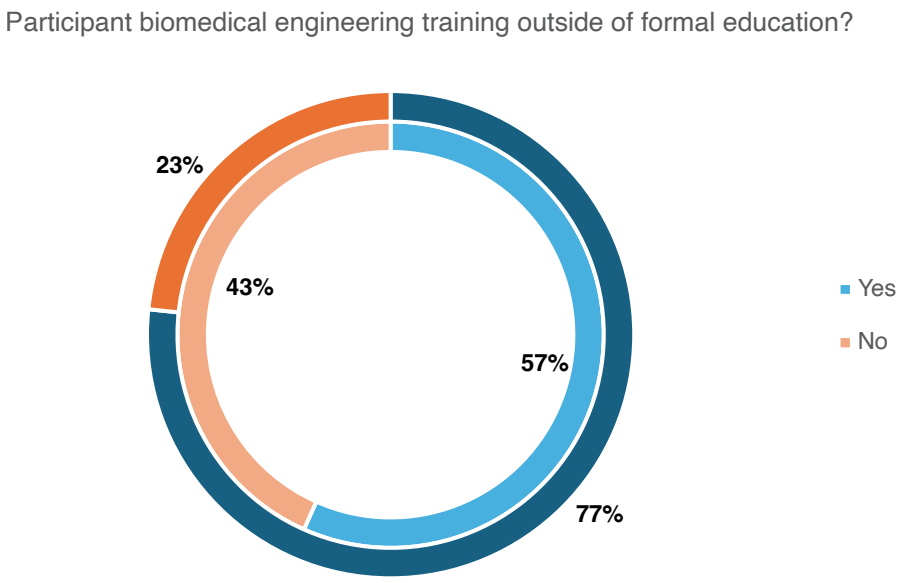


Figure 4. Proportion of participants reporting to have received biomedical engineering training outside formal education, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60). Inner ring (light colours) is onboarding survey, outer ring (darker colours) is end of project survey.

There was a significant change in the number of participants who reported having completed biomedical engineering training outside of formal education, when comparing the onboarding to end of project survey responses. This is likely due to many participants considering the online biomedical engineering course as part of the project to fall under this category, **Figure 4**.

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Table 2. Participant self-assessed confidence across various metrics, Likert scale (1-10) used (n=60).

	Question	Onboarding Survey Average (1-10)	End Survey Average (1-10)	Improvement
4	On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to maintain the equipment at your facility?	8.00	8.77	**+0.77**
5	On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to fix the equipment at your facility?	7.77	8.70	**+0.93**
6	On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to professionally communicate with medical personnel (doctors, nurses, surgeons, etc.)?	8.60	9.15	**+0.55**
7	On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to train medical personnel (doctors, nurses, surgeons, etc.) on how to use the medical equipment at your healthcare facility?	7.98	8.97	**+0.99**
8	On a scale of 1-10 (1 being not at all, 10 being highly respect) how much do you think the medical personnel (doctors, nurses, surgeons, etc.) at your healthcare facility respect you as an engineer?	7.77	8.77	**+1.00**

The next group of questions asked related to the self assessment of the participants in terms of their perceived confidence in their abilities across a number of key fields related to biomedical engineering. Across all the measured categories participants reported an improvement after completing the course (i.e., in the end of project survey compared to the onboarding survey), **Table 2**.

> *"This is an excellent fundamental biomedical engineering course that I strongly believe every engineer or technician should complete before working with medical equipment. Throughout the course, I realized that some of the concepts and practices I had been applying in my work were being done correctly, while others needed improvement. The course has provided me with a deeper understanding of our profession and inspired me to continue seeking more knowledge in the field of biomedical engineering.*
> *For this, I am truly grateful…"*

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Question 4: On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to maintain the equipment at your facility?

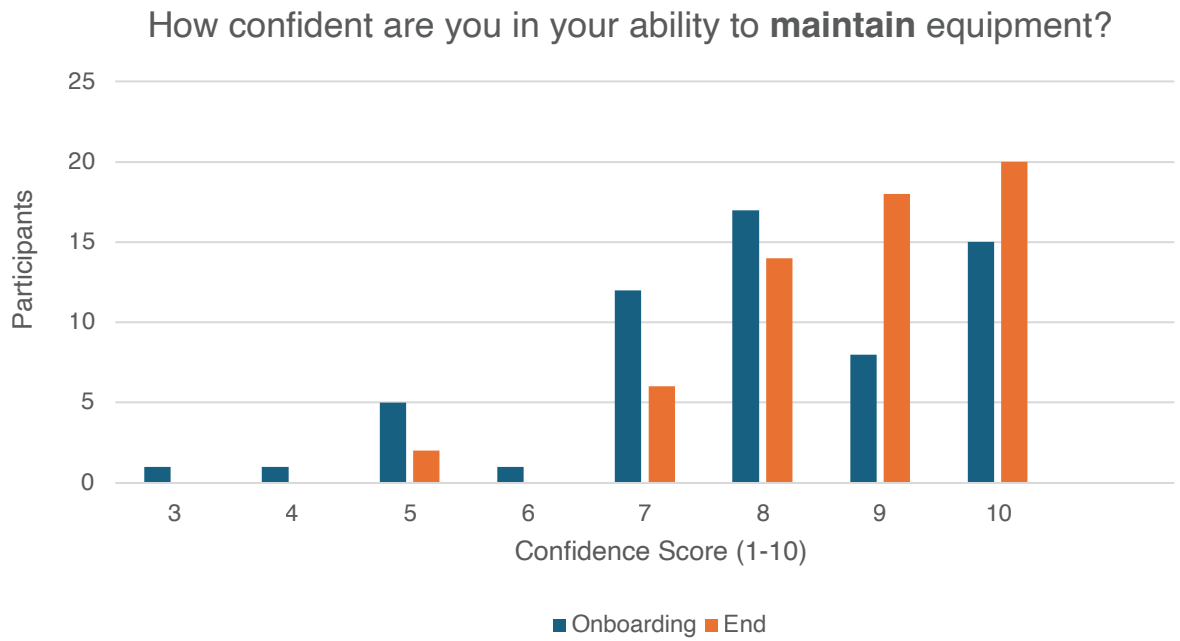


Figure 5. Distribution of participant scores to the prompt: "*On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to maintain the equipment at your facility?",* Likert scale, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

Looking in detail at each category showed participants report that their confidence for both core biomedical engineering skills, maintaining and repairing equipment, was noticeably higher after completing the online biomedical engineering course. For both categories, the participant scores rose from a minimum of 3/10 before completing the course, to scores of 5/10 or above, with the typical participant giving a rating of 7/10 or above. These findings are shown in **Figure 5** and **Figure 6**.

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Question 5: On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to fix the equipment at your facility?



Figure 6. Distribution of participant scores to the prompt: "*On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to fix the equipment at your facility?",* Likert scale, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

Given there are additional qualities which are useful for a well-rounded biomedical engineer to possess, these were also examined as part of the project. These aspects included how confident the biomedical engineers were at communicating with medical personnel, their confidence in their ability to train others, as well as their level of perceived respect at the hospital. All of these metrics showed a marked improvement, **Figure 7**, **Figure 8**, and **Figure 9**.

> *"I was able to repair the anesthesia machine, which was refusing to administer anesthetic agents to the patient."*

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Question 6: On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to professionally communicate with medical personnel (doctors, nurses, surgeons, etc.)?

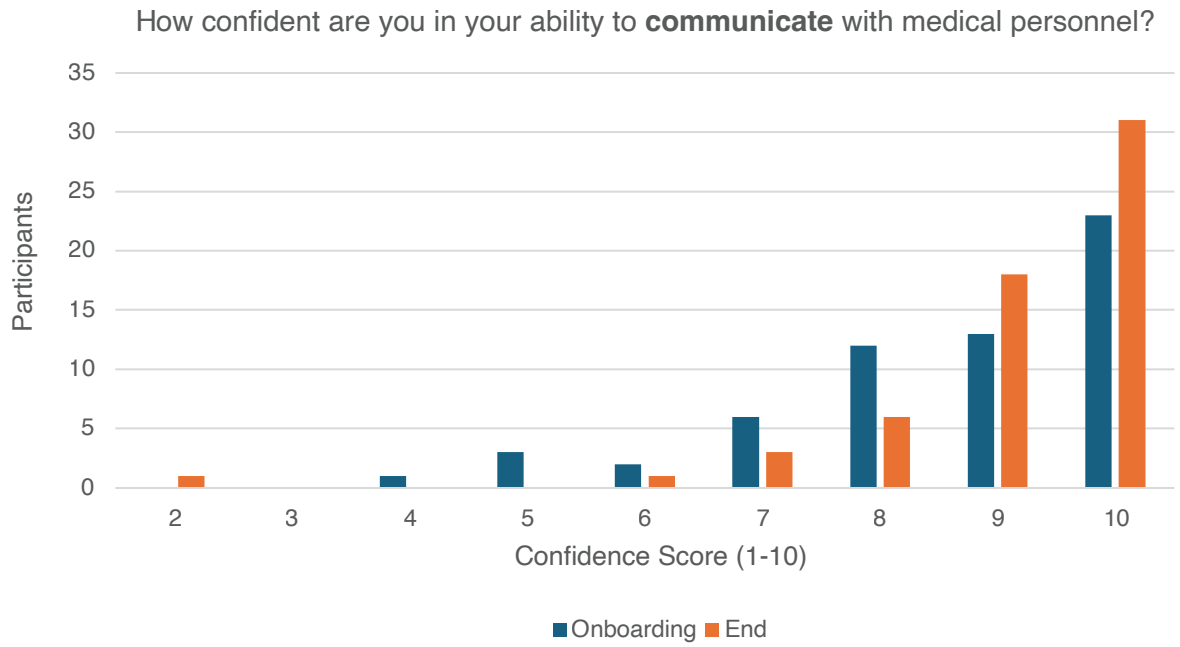


Figure 7. Distribution of participant scores to the prompt: "*On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to fix the equipment at your facility?",* Likert scale, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

Looking in more detail at participant confidence to communicate with medical personnel, **Figure 7**, it was found that the score profile is shuffled towards the higher end of the spectrum when comparing the end of project survey to the onboarding survey. The only slight anomaly was a single participant rating the course 2/10 on this metric in the end of project survey, compared to the previous low of 4/10 during the onboarding survey.

This participant scored the course 8/10 for this metric in the onboarding survey and 2/10 at the end of project survey. Perhaps this individual reflected on his/her previous practice and, through the training from the course, determined that he or she was less confident than previously thought.

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Question 7: On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to train medical personnel (doctors, nurses, surgeons, etc.) on how to use the medical equipment at your healthcare facility?

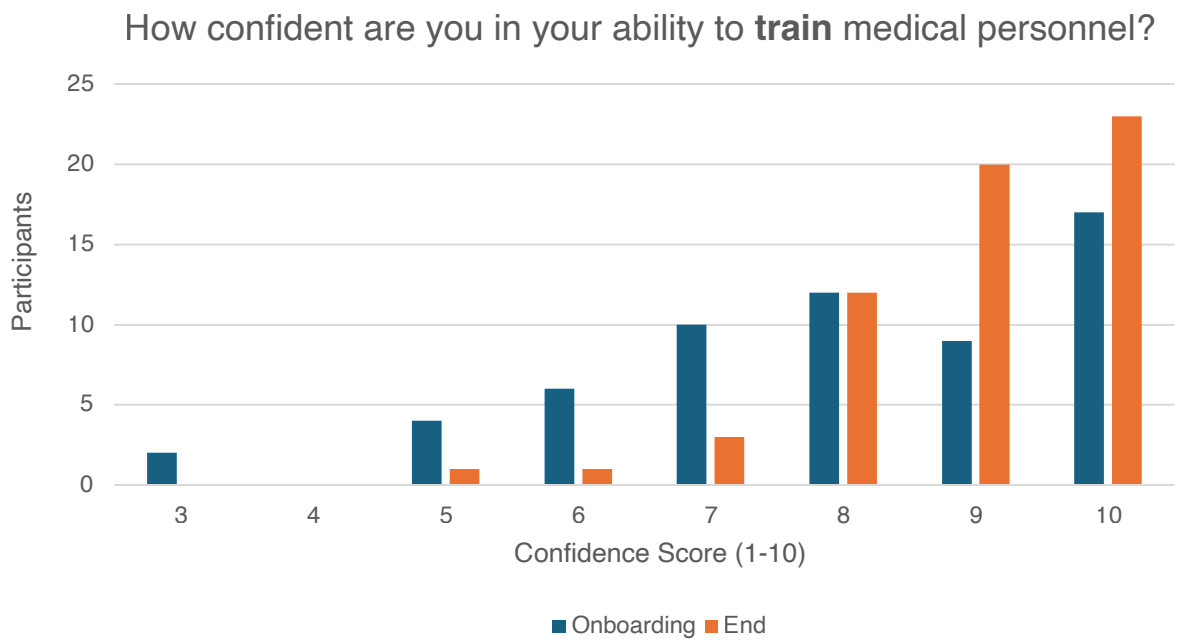


Figure 8. Distribution of participant scores to the prompt: "*On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to train medical personnel (doctors, nurses, surgeons, etc.) on how to use the medical equipment at your healthcare facility?",* Likert scale, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

A similar trend was seen when examining participants' confidence in their ability to train others, as well as their perceived respect at their hospital. Minimum scores increased for both categories from 3/10 during the onboarding survey, to 5/10 for the end of project survey, **Figure 8** and **Figure 9**. This also improved the average score, true across all metrics, **Table 2**.

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Question 8: On a scale of 1-10 (1 being not at all, 10 being highly respect) how much do you think the medical personnel (doctors, nurses, surgeons, etc.) at your healthcare facility respect you as an engineer?

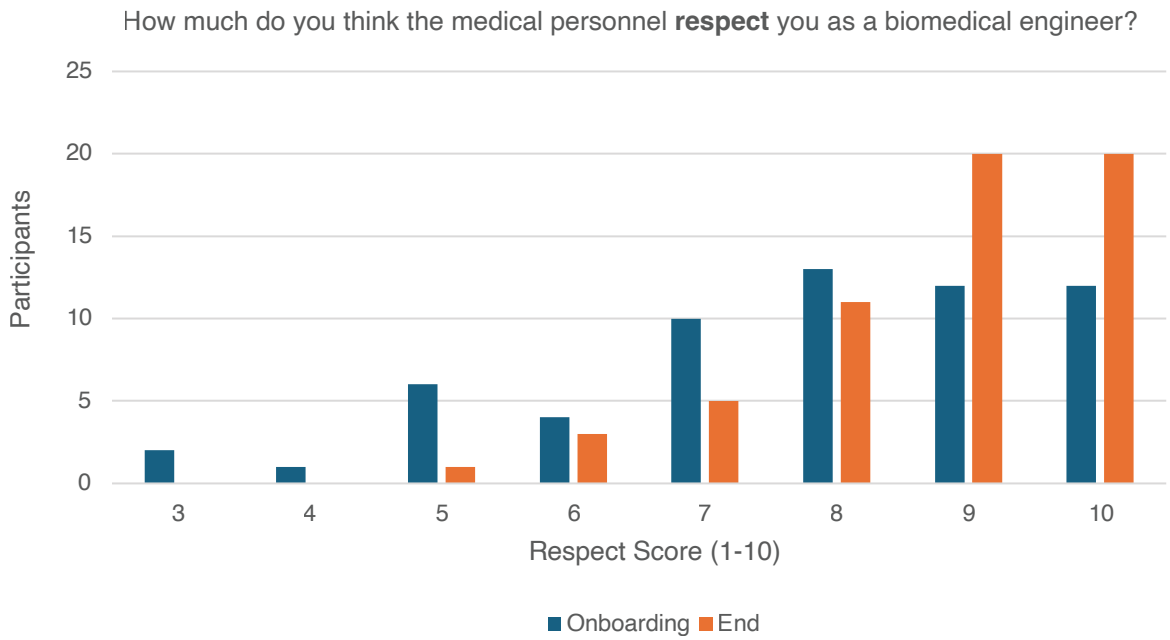


Figure 9. Distribution of participant scores to the prompt: "*On a scale of 1-10 (1 being not at all, 10 being highly respect) how much do you think the medical personnel (doctors, nurses, surgeons, etc.) at your healthcare facility respect you as an engineer?",* Likert scale, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

It is clear that the online biomedical engineering course played a key role in this reported improvement of the participants, meeting both key aims of the project: both to upskill biomedical engineers and to assess the effectiveness of the online biomedical engineering course. The surveys were conducted many months, or even over a year apart, and so it is unlikely that participants would have remembered (and therefore been influenced by) their previous survey response.

The data suggests a real impact on the participants in shaping their biomedical engineering skills. It is hypothesised that the online training provided strengthened participants' ability to both repair and maintain equipment.

The Train the Trainer unit of the course is also likely to have contributed to the improvement in participants' confidence in training others. This unit features details on how best to conduct discussions and collaborate with others, contributing to the increased confidence around communicating with other medical professionals.

Finally, it is thought that improvement in perceived respect will have been through an increase in self-belief by the participants, both from their improved skills, but also the psychological effect of being well resources, having correct workplace attire, and also having external support.

All of the above is reflected in the data shown in **Table 2**. For ease of visualisation, the data in **Table 2** has been represented graphically in **Figure 10**.

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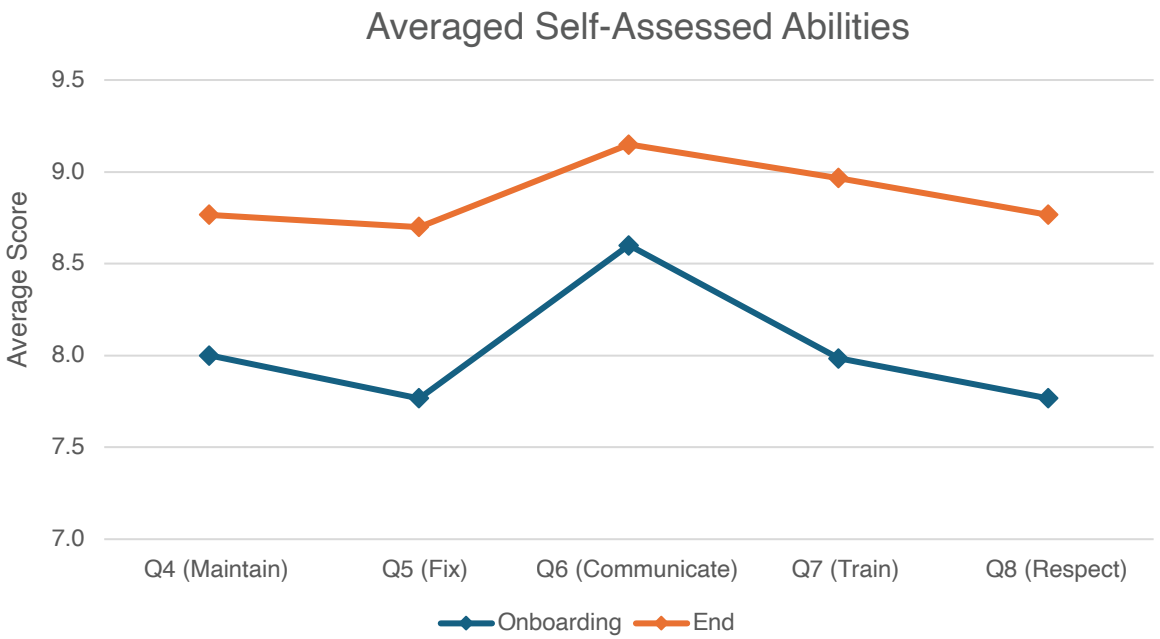


Figure 10. Average of participant scores to the prompts listed in **Table 2**, Likert scale used, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

A statistical analysis of the participants' scores was conducted using a Wilcoxon signed-rank test to determine if the change was significant ($p<0.05$). This was determined to be the case across all metrics, with a summary of the findings detailed in **Table 3**. The strength of these results lends credence to the claim that the biomedical engineering course is an effective learning tool and had a large impact on the participants.

> *"The training was very informative and helped improve my understanding of equipment and procedures. The explanations were clear and the topics were relevant to everyday work. I appreciate the opportunity to participate in this training and believe it will help me perform my duties more effectively."*

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Table 3. Summary of the parameters from the Wilcoxon signed-rank test conducted on each of the parameters measured in the onboarding and end of project surveys, with both standard values and values corrected for the number of ties (n=60).

	Question	n (Non-Zero Difference Pairs)	W	μW	σW	σW (Corrected)	Z	Z (Corrected)	r	r (Corrected)	p	p (Corrected)
4	On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to maintain the equipment at your facility?	40	154.50	410.00	74.40	72.95	-3.43	-3.50	0.54	0.55	5.94×10^{-4}	4.61×10^{-4}
5	On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to fix the equipment at your facility?	38	74.50	370.50	68.95	67.59	-4.29	-4.38	0.70	0.71	1.77×10^{-5}	1.19×10^{-5}
6	On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to professionally communicate with medical personnel (doctors, nurses, surgeons, etc.)?	41	230.00	430.50	77.17	74.96	-2.60	-2.67	0.41	0.42	0.01	0.01
7	On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to train medical personnel (doctors, nurses, surgeons, etc.) on how to use the medical equipment at your healthcare facility?	39	104.00	390.00	71.66	70.84	-3.99	-4.04	0.64	0.65	6.58×10^{-5}	5.41×10^{-5}
8	On a scale of 1-10 (1 being not at all, 10 being highly respect) how much do you think the medical personnel (doctors, nurses, surgeons, etc.) at your healthcare facility respect you as an engineer?	45	164.00	517.50	88.59	87.09	-3.99	-4.06	0.59	0.61	6.60×10^{-5}	4.93×10^{-5}

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It is also helpful to break down the data by the education level of the participants, which is shown in **Figure 11**, **Figure 12**, and **Figure 13**. To assist the reader, each of the figures retains the same vertical axis scale. To ensure a fair comparison, a small number of participants were removed from the data (for this portion of the analysis only). This included:

- 5 participants whose level of education changed (increased) between the onboarding and end of project survey.
- 1 participant whose level of education changed (decreased) between the onboarding and end of project survey.
- 2 participants who did not respond to the question on education level (Question 2a/2b) during the end of project survey, leaving no point of comparison.

It is notable that the course yielded an improvement in participant ability across all assessed metrics regardless of education level, save for one exception seen in Figure 13. The exception in question was the self-assessed communication ability of those with no higher-level education.

Given the sample size for both the college level of education (n=7), and no higher-level education (n=8), these findings are less robust than for those with a university level of education (n=37). With this small sample size in mind, fluctuations in the responses of a handful of participants create the possibility of skewing the data.

One further possible reason for the aforementioned exception may be that participants' familiarity with effective communication strategies might not be as well developed as knowledge for other metrics and so participants could be less able to accurately and confidently judge their ability in this area.

It should also be noted that there was a likely outlier in the data when investigating the communication ability of those with no higher-level education. One participant rated his/her ability communicating with others at 2/10 during the end of project survey, but 8/10 in the onboarding survey, i.e., a regression in ability. Again, due to the limited number of participants in this subgroup (n=8), this outlier appears to have skewed the results. However, given a score of 2/10 is a perfectly valid score (as there is no evidence to suggest that this is not the participant's accurate reflection) it has been retained in the dataset.

For interest, removing the participant with the outlier data yielded a slight improvement in this category, with the self-assessed ability to communicate for the subgroup with no higher-level education increasing from 8.57 to 8.71, **Figure 14**.

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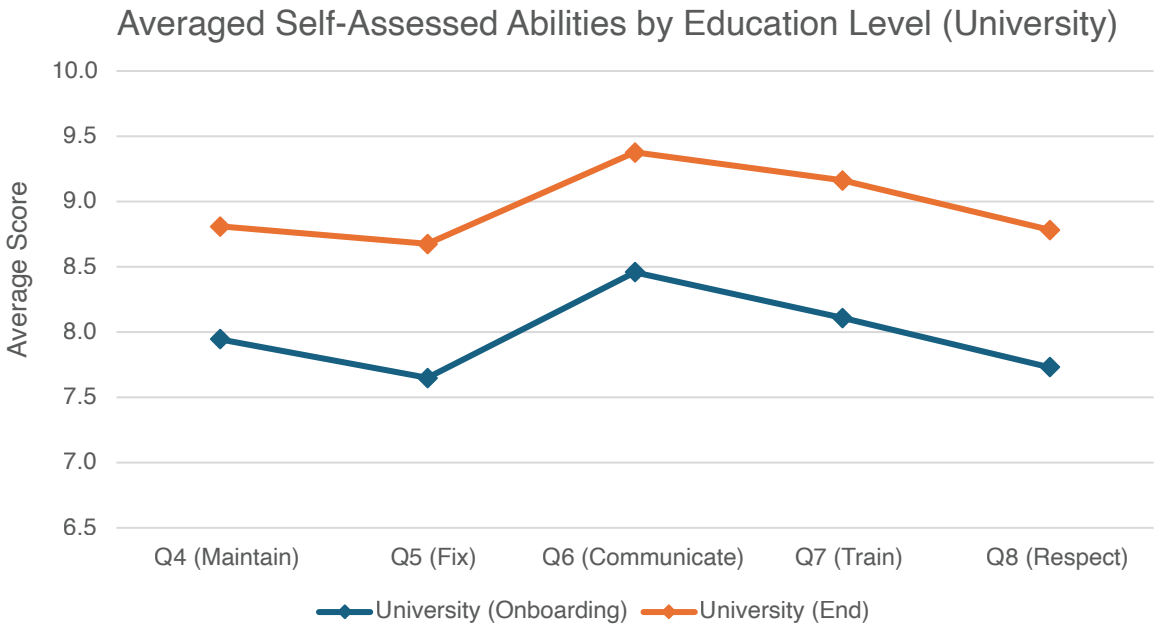


Figure 11. Average of participant scores to the prompts listed in **Table 3,** Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, with university level of education reported in both onboarding and end of project survey (n=37).

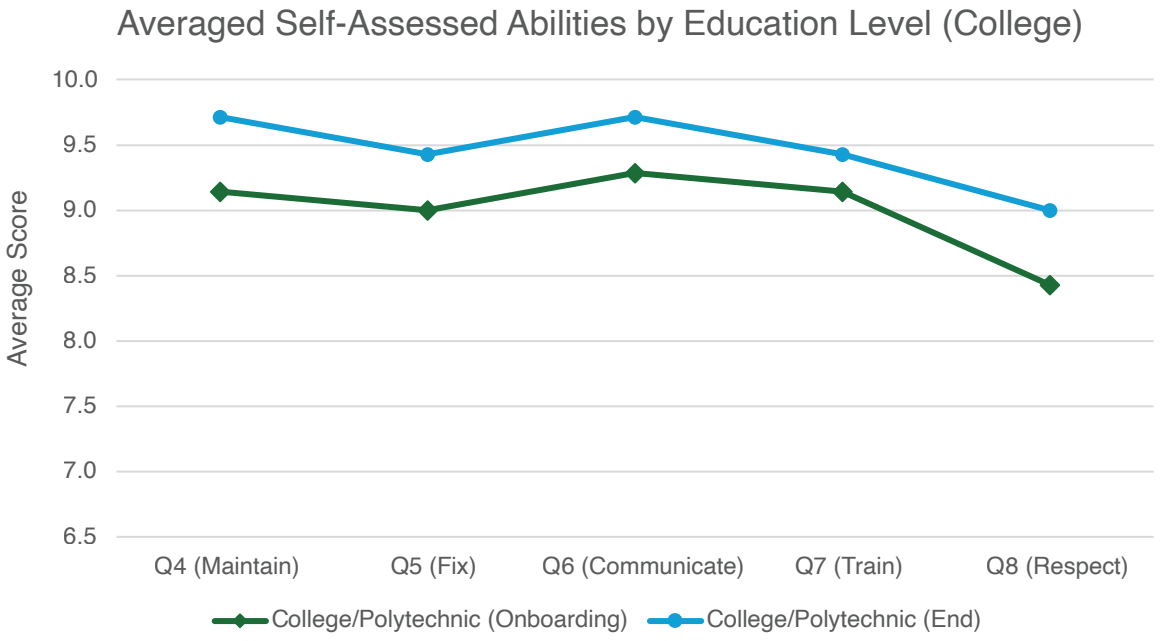


Figure 12. Average of participant scores to the prompts listed in **Table 3,** Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, with college/polytechnic level of education reported in both onboarding and end of project survey (n=7).

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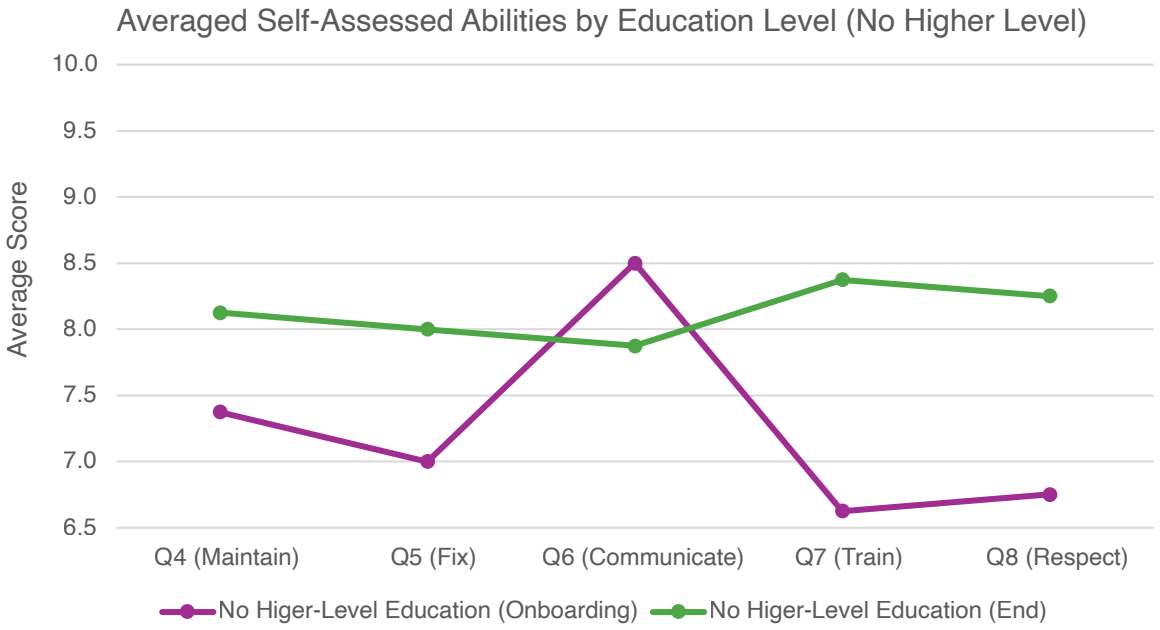


Figure 13. Average of participant scores to the prompts listed in **Table 3**, Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, with no higher-level education reported in both onboarding and end of project survey (n=8).

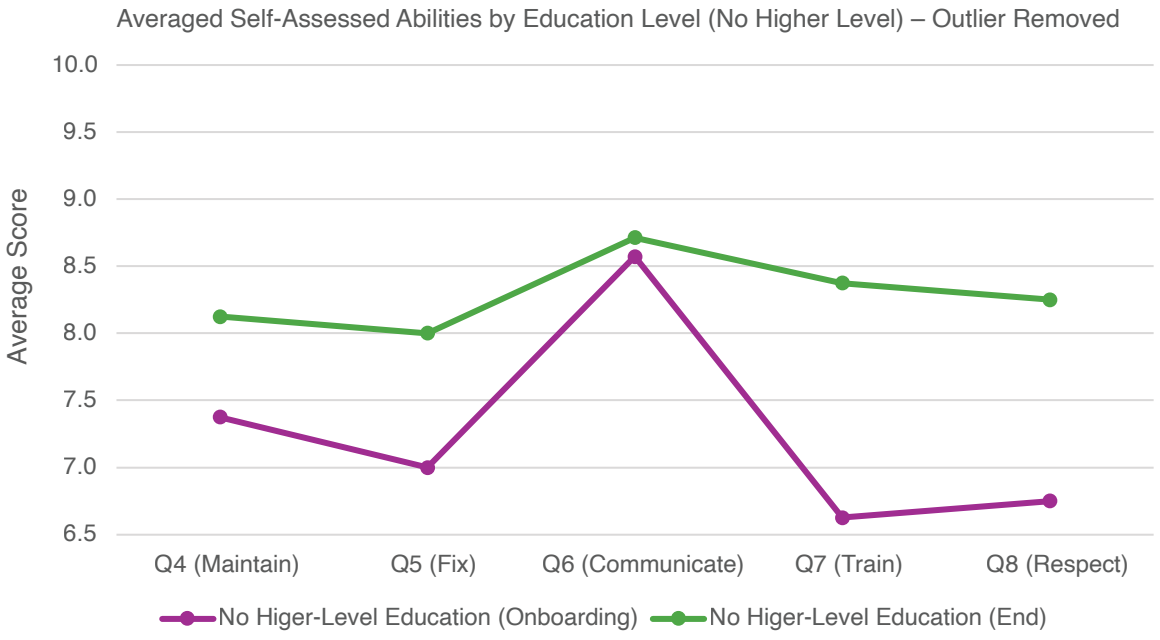


Figure 14. Average of participant scores to the prompts listed in **Table 3**, Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, with no higher-level education reported in both onboarding and end of project survey, single suspected outlier removed (n=7).

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For completeness, the data used to generate **Figure 11**, **Figure 12**, and **Figure 13**, has been included in **Table 4**. It is notable that the participants who attended college or a polytechnic institution appear to self-assess their abilities to be higher (both during the onboarding and end of project survey). It is possible that this style of training is better suited to the realities faced in low resource environments. Those with no higher-level education reported their abilities to be below participants with either a college or university level education. These results are illustrated in **Figure 15** and **Figure 16**, with the data also being pulled from **Table 4**.

Table 4. Summary data table used to generate **Figure 11**, **Figure 12**, **Figure 13**, **Figure 15**, and **Figure 16**.

Education Level (Survey)	Q4 (Maintain)	Q5 (Fix)	Q6 (Communicate)	Q7 (Train)	Q8 (Respect)
University (Onboarding)	7.9	7.6	8.5	8.1	7.7
University (End)	8.8	8.7	9.4	9.2	8.8
College/Polytechnic (Onboarding)	9.1	9.0	9.3	9.1	8.4
College/Polytechnic (End)	9.7	9.4	9.7	9.4	9.0
No Higer-Level Education (Onboarding)	7.4	7.0	8.5	6.6	6.8
No Higer-Level Education (End)	8.1	8.0	7.9	8.4	8.3

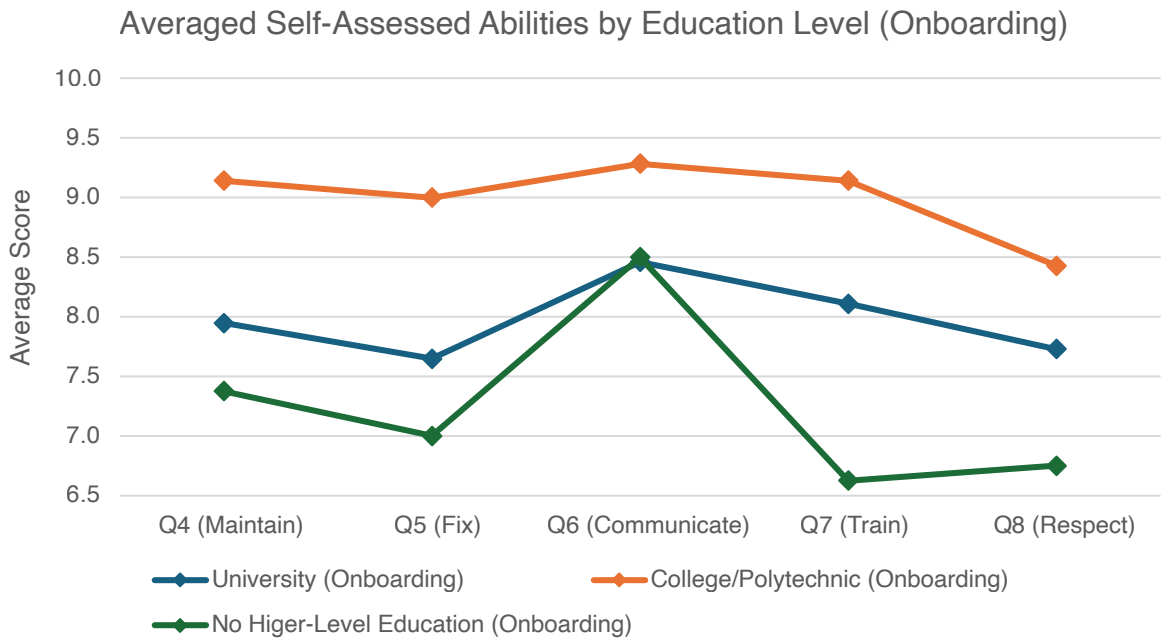


Figure 15. Average of participant scores to the prompts listed in **Table 3,** Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, grouped by level of education reported in both surveys, results for onboarding survey shown (n=37 for university, n=7 for college/ polytechnic, n=8 for no higher-level education).

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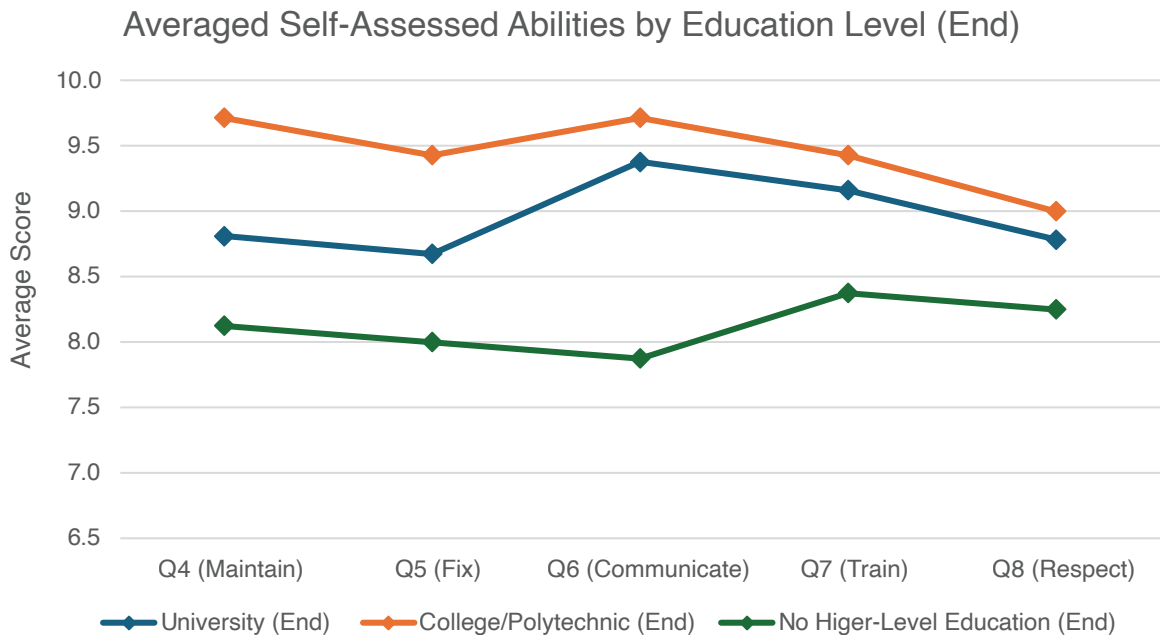


Figure 16. Average of participant scores to the prompts listed in **Table 3,** Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, grouped by level of education reported in both surveys, results for end of project survey shown (n=37 for university, n=7 for college/ polytechnic, n=8 for no higher-level education).

Another helpful breakdown looked at participants' self-assessed abilities across the same metrics listed in **Table 3**, but broken down by years of experience working as a biomedical engineer. These results are shown in **Figure 17**, **Figure 18**, **Figure 19**, **Figure 20**, and **Figure 21**.

As before, to ensure a fair comparison, a significant number of participants were removed from the data (for this portion of the analysis only). This included:

- 26 participants whose years of experience changed (increased) between the onboarding and end of project survey.
- 1 participant who did not respond to the question on years of experience (Question 1) during the onboarding survey, leaving no point of comparison.

It should be noted that due to the hight number of participants changing experience level, the number of participants included in some of the datasets is rather small, for example the number of participants in either 11-15, 16-20, or 21+ bracket is 3 or fewer.

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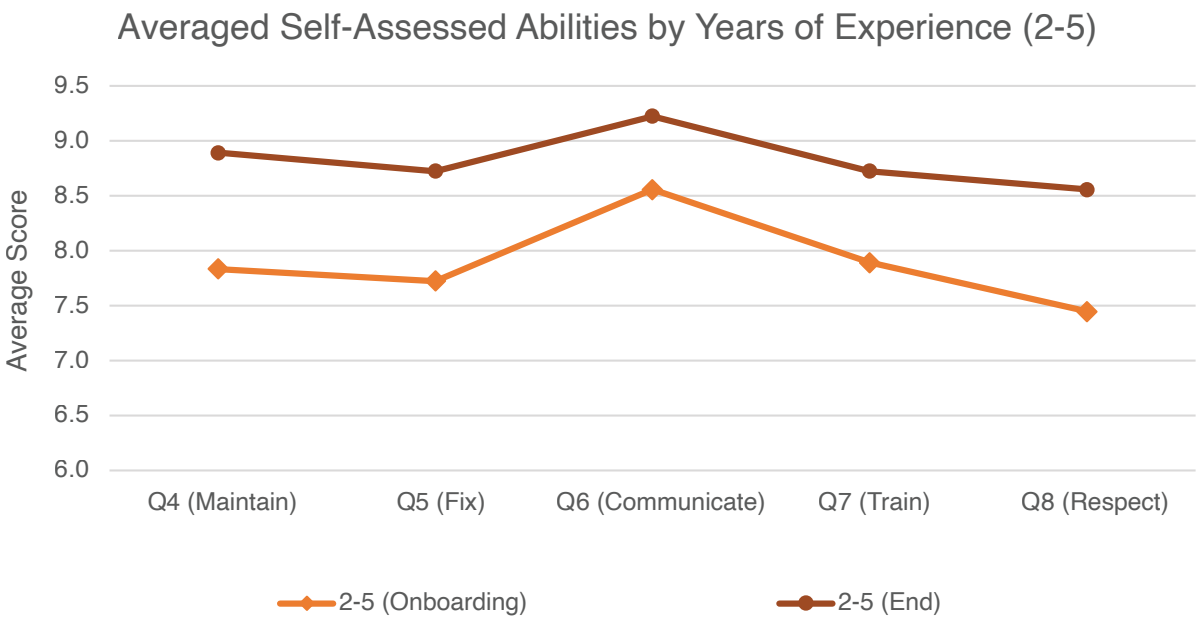


Figure 17. Average of participant scores to the prompts listed in **Table 3,** Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, grouped by years of experience reported in both surveys, results for participants with 2-5 years of experience (n=18).

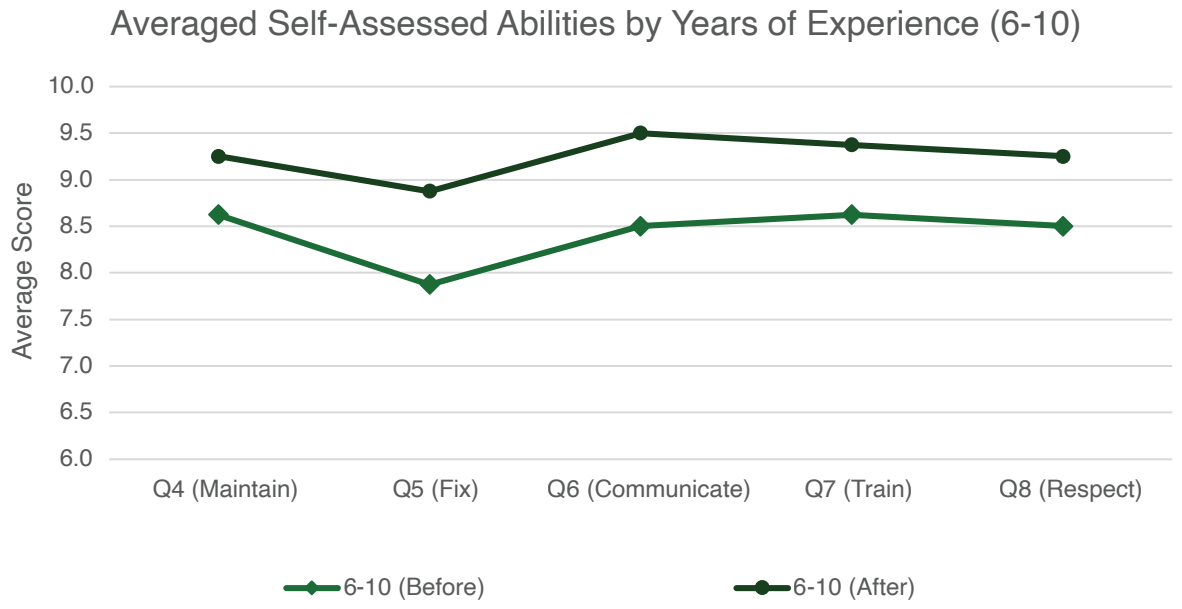


Figure 18. Average of participant scores to the prompts listed in **Table 3,** Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, grouped by years of experience reported in both surveys, results for participants with 6-10 years of experience (n=8).

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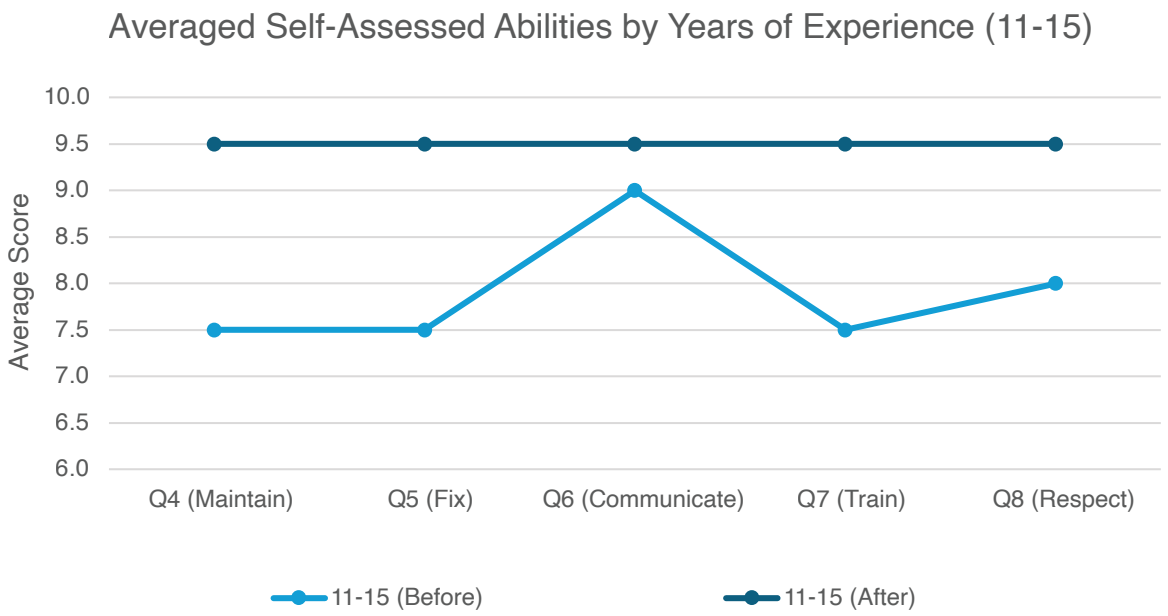


Figure 19. Average of participant scores to the prompts listed in **Table 3**, Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, grouped by years of experience reported in both surveys, results for participants with 11-15 years of experience (n=2).

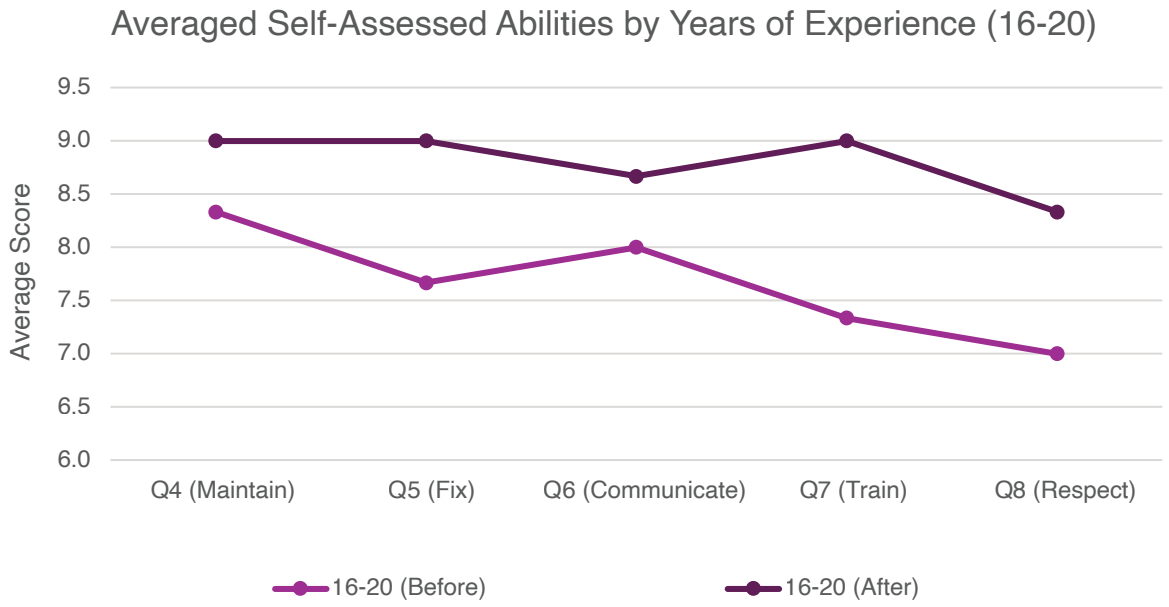


Figure 20. Average of participant scores to the prompts listed in **Table 3**, Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, grouped by years of experience reported in both surveys, results for participants with 16-20 years of experience (n=3).

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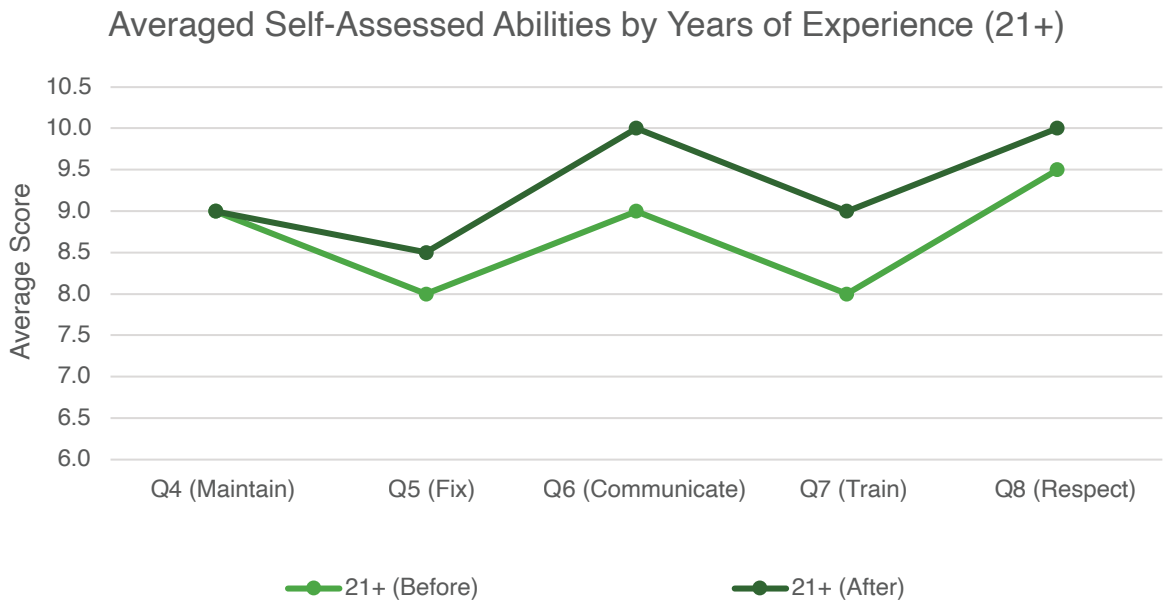


Figure 21. Average of participant scores to the prompts listed in **Table 3**, Likert scale used, respondents completing both the onboarding and end of project survey, agreeing for their anonymised data to be used, grouped by years of experience reported in both surveys, results for participants with 20+ years of experience (n=2).

Again, for completeness, the data used to generate **Figure 17**, **Figure 18**, **Figure 19**, **Figure 20**, and **Figure 21** has been included in **Table 5**. Each of the sub-groups showed an increase in participant self-assessed abilities across all metrics, showing that the biomedical engineering programme was of benefit to participants, regardless of years of experience.

Table 5. Summary data table used to generate **Figure 17**, **Figure 18**, **Figure 19**, **Figure 20**, and **Figure 21**.

Years of Experience (Survey)	Q4 (Maintain)	Q5 (Fix)	Q6 (Communicate)	Q7 (Train)	Q8 (Respect)
2-5 (Onboarding)	7.8	7.7	8.6	7.9	7.4
2-5 (End)	8.9	8.7	9.2	8.7	8.6
6-10 (Onboarding)	8.6	7.9	8.5	8.6	8.5
6-10 (End)	9.3	8.9	9.5	9.4	9.3
11-15 (Onboarding)	7.5	7.5	9.0	7.5	8.0
11-15 (End)	9.5	9.5	9.5	9.5	9.5
16-20 (Onboarding)	8.3	7.7	8.0	7.3	7.0
16-20 (End)	9.0	9.0	8.7	9.0	8.3
21+ (Onboarding)	9.0	8.0	9.0	8.0	9.5
21+ (End)	9.0	8.5	10.0	9.0	10.0

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Regarding **Figure 19**, where the end of project survey average for the subgroup of participants with 11-15 years of experience remained consistent throughout at 9.5. This data has been investigated and has been validated, with the two participants scoring the course 9/10 and 10/10 consistently, averaging 9.50 for each category.

The proportion of non-operational equipment at the sites was also considered as a good benchmark of the success of both the project at large, and additionally the efficacy of the biomedical engineering course. A reduction in the proportion of non-operational equipment at the sites could be down to the participants fixing equipment using knowledge from the course. This pattern appears to be realised in **Figure 22**, with a clear trend for sites to have a lower level of non-operational equipment in the end of project survey, compared to the onboarding survey.

The midpoint of each data bracket was used to generate an average proportion of non-operational equipment reported by each participant. When averaged, the proportion of non-operational equipment fell from 23% in the onboarding survey, to just 19% in the end of project survey. When instead the raw data was used, these figures became 25% in the onboarding survey and 21% in the end of project survey.

Question 10: In your best guess, what percentage of the equipment on-site is non-operational?

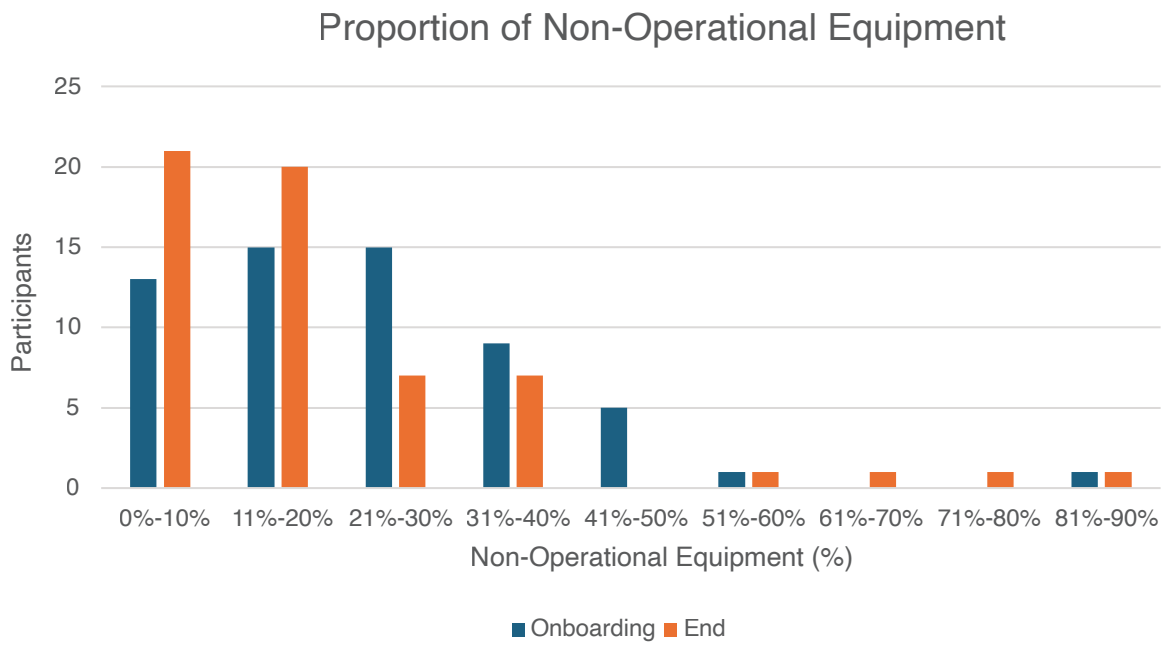


Figure 22. Number of participants reporting each proportion of non-operational equipment at their respective sites. Data generated on a per participant basis, rather than per site, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=59).

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It is also possible that some participants may have misunderstood the question to be asking about the proportion of operational equipment at their site (hence the extremely high proportion of 51% or above at some sites). There is no way of discerning if these are outliers, but upon removal, the picture was even starker.

Question 10: In your best guess, what percentage of the equipment on-site is non-operational?

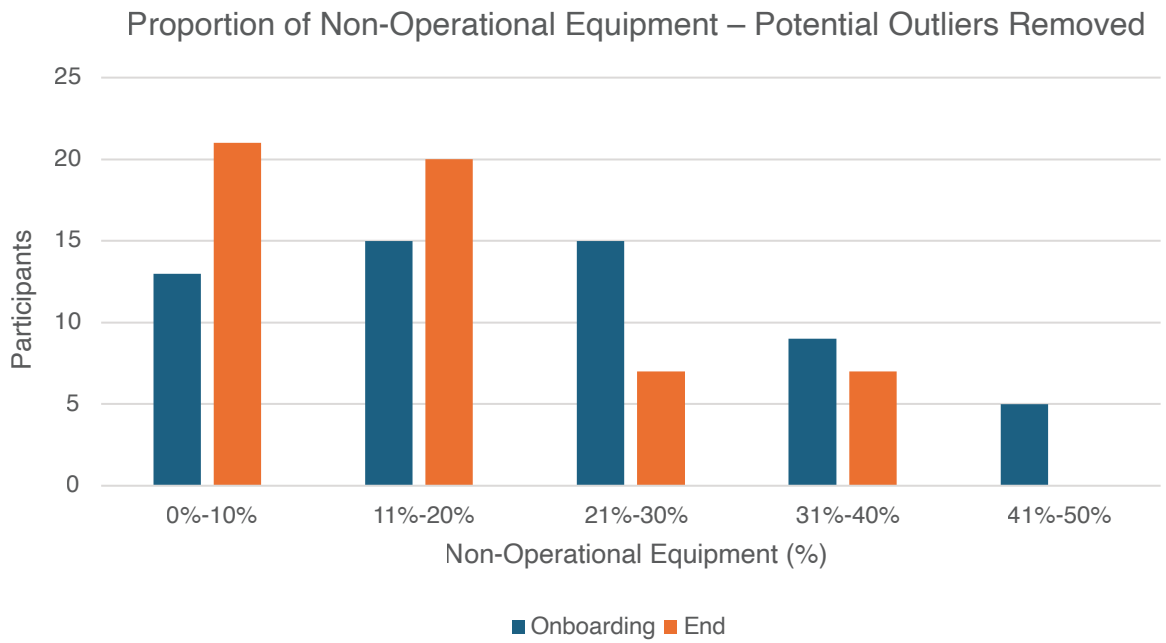


Figure 23. Number of participants reporting each proportion of non-operational equipment at their respective sites. Data generated on a per participant basis, rather than per site. Dataset restricted, with entries above 51% removed, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=57 for onboarding survey, and n=55 for end of project survey).

Conducting the same analysis using the midpoint of each data bracket in the same way as before, but for the modified data set, yielded a reduction in the proportion of non-operational equipment from 22% in the onboarding survey, to 15% in the end of project survey. When instead the raw data was used, these figures became 23% in the onboarding survey and 16% in the end of project survey.

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Another way the impact of the biomedical engineering course was measured was by looking at the way in which the main reasons reported for non-operational equipment changed between the two surveys, **Figure 24** and **Figure 25**. The reported changes are again further evidence of the effectiveness of the biomedical engineering programme.

The course particularly addresses any knowledge gaps which might prevent engineers or medical personnel from knowing how to use the equipment. This was reflected in the reduction in this being the main reason for non-operational equipment from 8% in the onboarding survey, to just 2% in the end of project survey.

There was also some indication that participants were better able to identify equipment broken beyond repair (which rose from 5% to 8%), as well as being more aware of the correct consumables needed for each piece of equipment (which rose from 2% to 5%). Overall, the lack of spare parts remained the most critical limiting factor in repairing non-operational equipment; this value remained close to three quarters in both surveys: 73% in the onboarding survey, and 78% in the end of project survey.

Question 11: In your opinion, what is the number one reason medical equipment at your healthcare facility is non-operational?

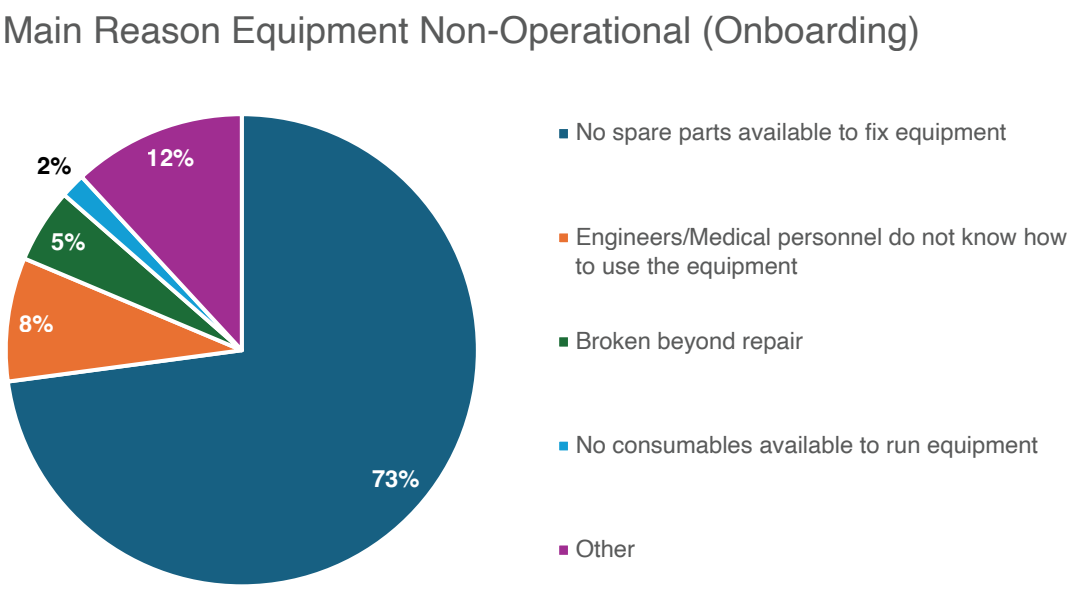


Figure 24. Proportion of participants reporting each of the listed reasons as the main reason equipment is non-operational at their site during the onboarding survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=59).

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Question 11: In your opinion, what is the number one reason medical equipment at your healthcare facility is non-operational?

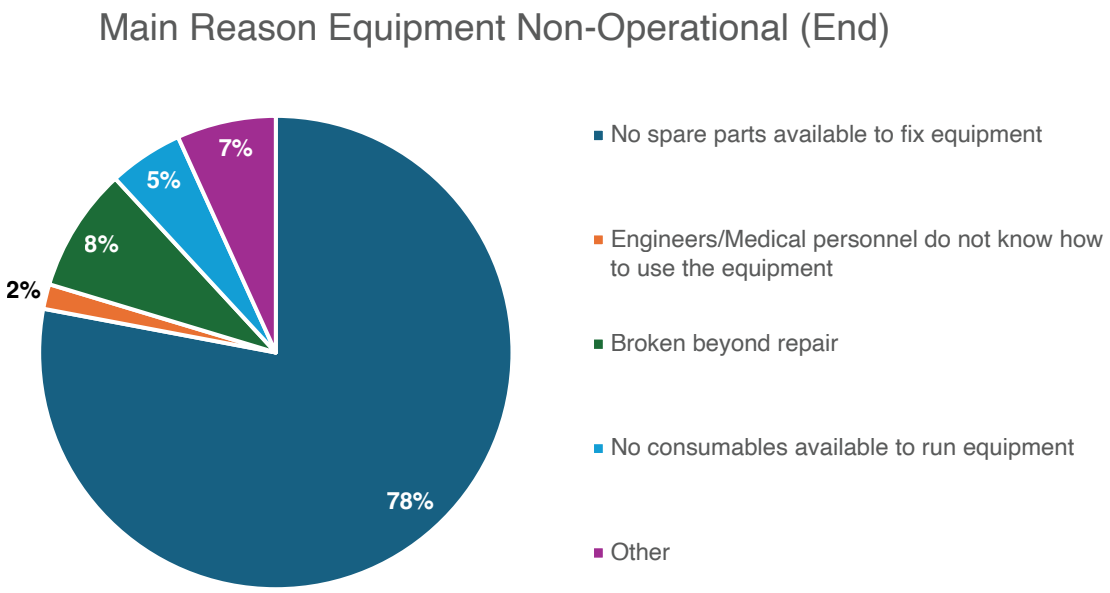


Figure 25. Proportion of participants reporting each of the listed reasons as the main reason equipment is non-operational at their site during the end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=59).

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A key factor at sites was the lack of available tools to conduct repairs on equipment. This was another element which the project sought to address in order to meet the main aim: to upskill biomedical engineers across a number of sites (hospitals, clinics, etc.), with the goal of improving equipment maintenance – subsequently improving patient care. The data from participants across both surveys clearly showed this to be the case, **Figure 26** and **Figure 27**.

The intervention of providing a full, professional toolkit was successful, with the proportion of participants reporting sufficient tools at their site rising from a mere 30% during the onboarding survey, to an impressive 93% in the end of project survey. Only 2% of participants reported not having enough tools in the end of project survey, compared to 37% in the onboarding survey.

Question 12: Do you have the tools needed to maintain and fix the equipment?

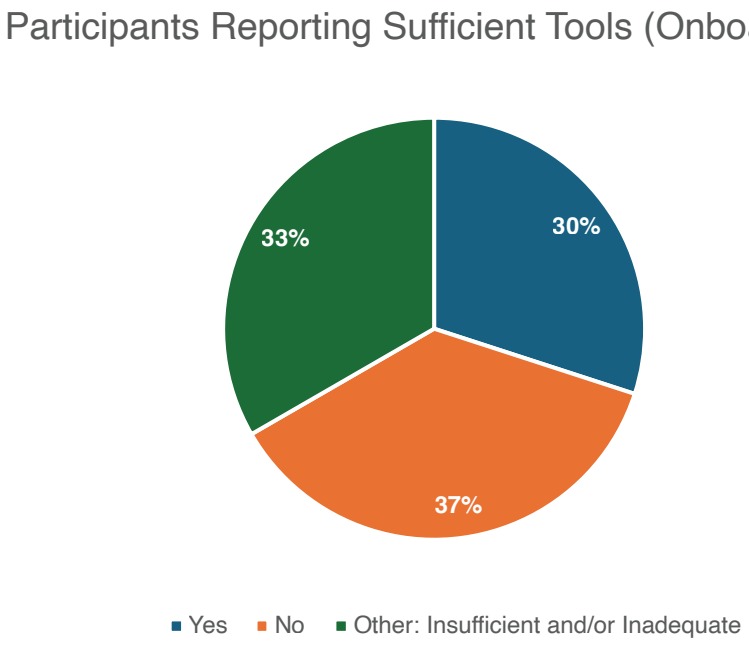


Figure 26. Proportion of participants reporting whether or not they have the tools needed to maintain and fix equipment at their site, data from onboarding survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

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Question 12: Do you have the tools needed to maintain and fix the equipment?

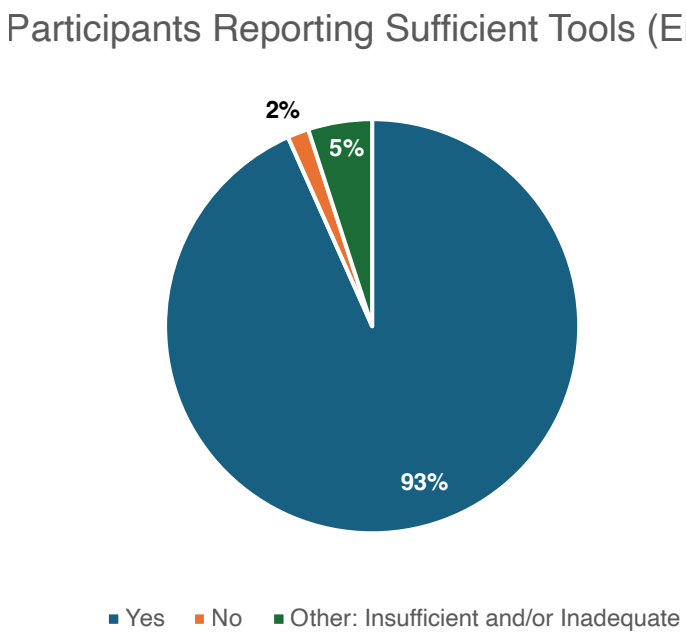


Figure 27. Proportion of participants reporting whether or not they have the tools needed to maintain and fix equipment at their site, data from end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

"In Malawi, biomedical engineers lacks resources, the tool kit that you have provided will help me to diagnose and troubleshoot the equipment accurately and with ease, now I will be able to work professionally and improve the quality of service delivery at my institution as well as the entire country. Thank you very much Medical Aid team for you overwhelming support."

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Question 13: Do you have the following tools (select all that apply)?

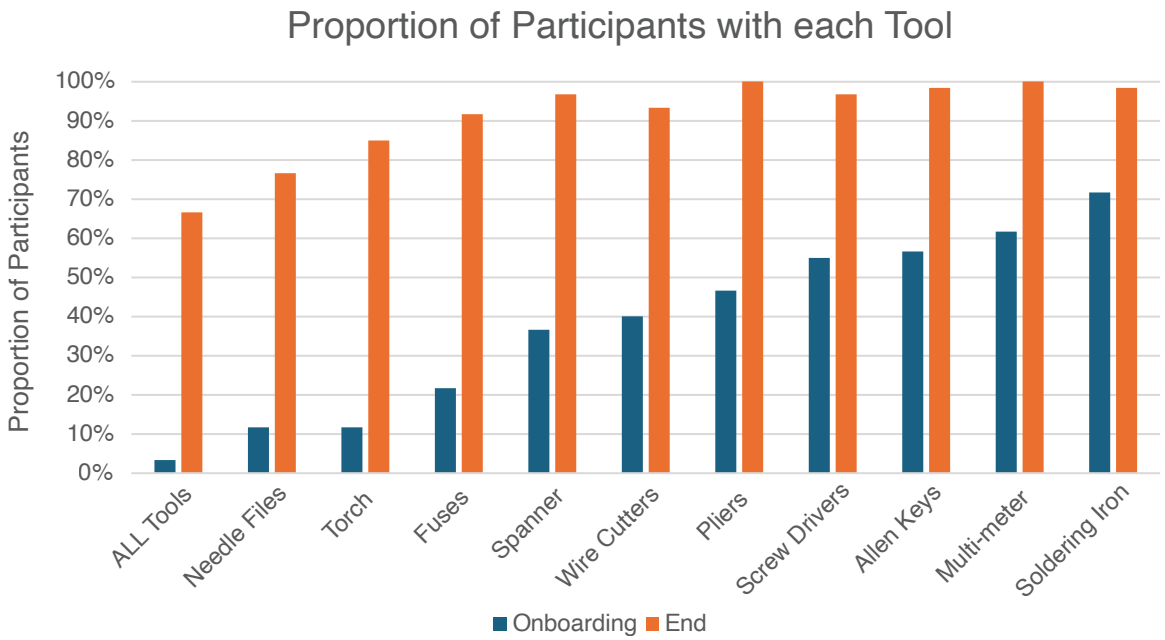


Figure 28. Proportion of participants reporting whether or not they have each of the tools listed, as well as all the tools listed, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

A further question around the tools each participant had access to was asked to determine if there were any specific areas of need, **Figure 28**. By supplying a toolkit containing all of these items, participants were significantly better equipped (when comparing before the intervention, the onboarding survey, with after the intervention, the end of project survey). The number of participants reporting having all the listed tools rose from 3% in the onboarding survey, to 67% in the end of project survey. The proportion of participants with all tools was also represented separately, **Figure 29** and **Figure 30**.

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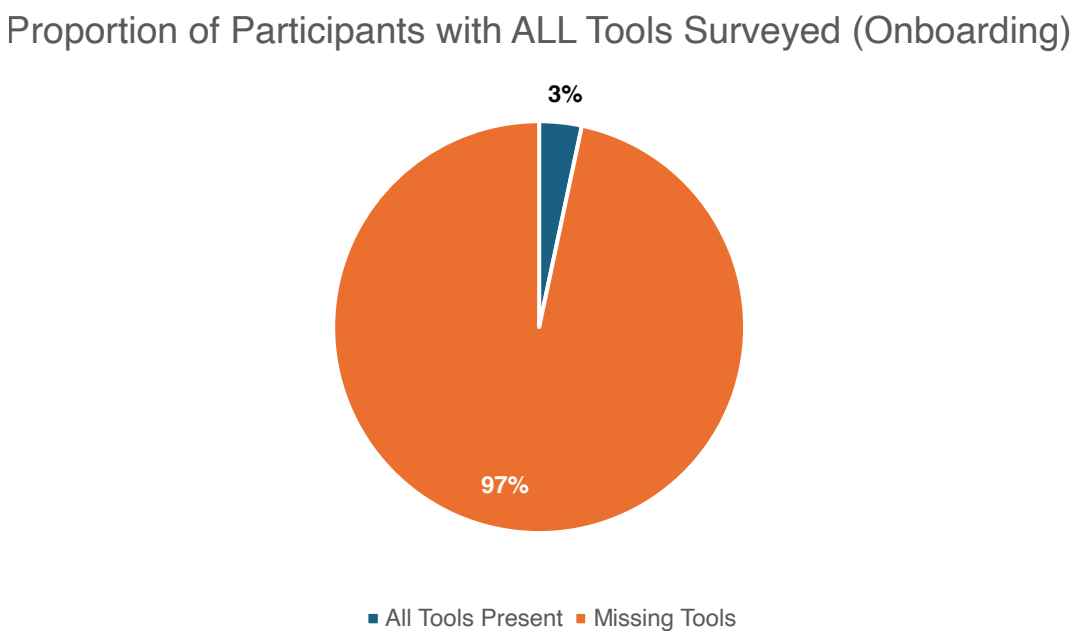


Figure 29. Proportion of participants reporting whether or not they have all tools listed in **Figure 28** in the onboarding survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

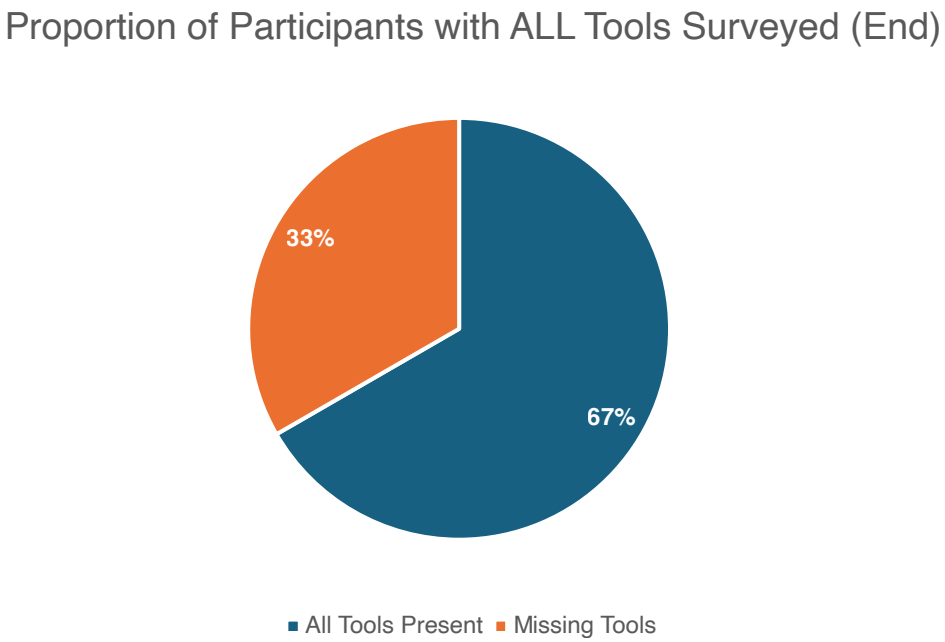


Figure 30. Proportion of participants reporting whether or not they have all tools listed in **Figure 28** in the end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

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To better understand the impact of the project and how things could be improved for future initiatives, participants who completed the end of project survey were also asked a number of additional questions about the resources supplied, as well as the management of the project overall.

The resources supplied were well suited to the environment, with participants reporting positive feedback across all resource types, **Figure 31**. As was suggested from the data showing a significant improvement in the availability of tools participants had access to, **Figure 28**; the toolkit was rated as being very useful by the participants – almost universally (97%), **Figure 32**. The set of textbooks were rated as the next most useful (92%), **Figure 33,** with the device manuals (88%), **Figure 34,** and laptops (85%) being rated as marginally comparatively less useful, **Figure 35**. Encouragingly, only a maximum of 2% of participants rated each resource as not useful.

Question 14: Please rate how useful you found the following items: Toolkit, Textbooks, Digital Service Manuals, Laptop.

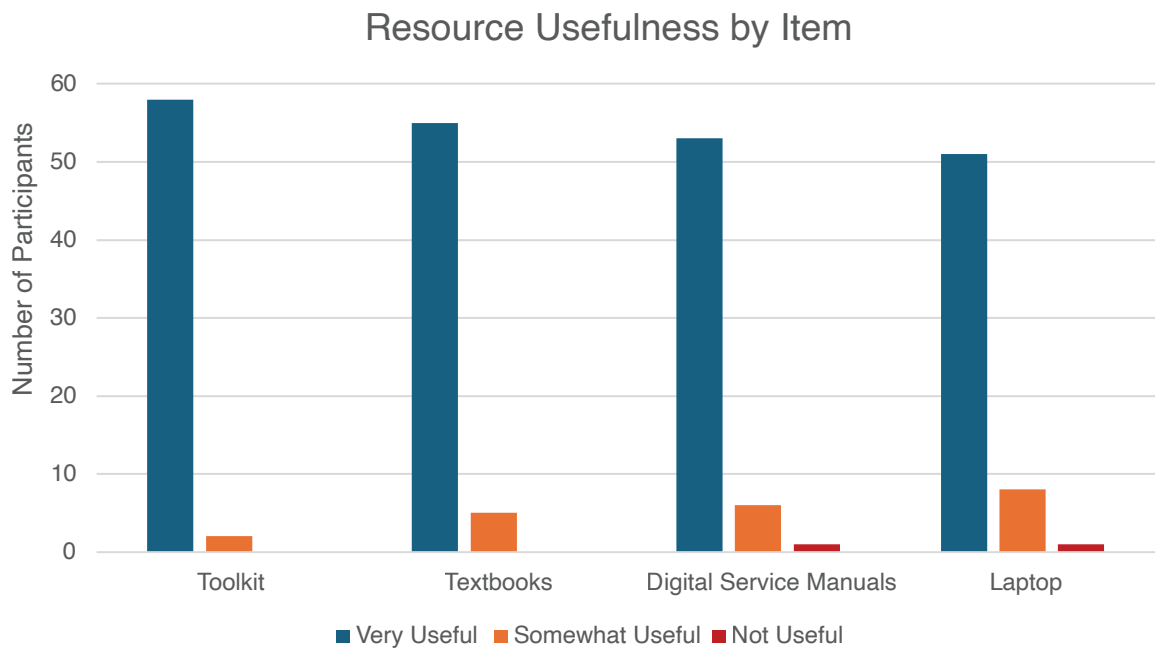


Figure 31. Number of participants reporting each category of usefulness for each of the programme resources supplied, data from the end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

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Question 14: Please rate how useful you found the following items: Toolkit.

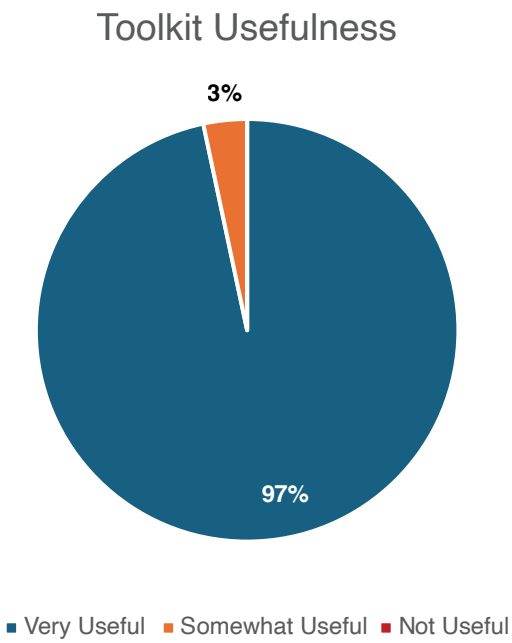


Figure 32. Proportion of participants reporting each category of usefulness for the toolkit supplied as part of the programme resources, data from the end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

Question 14: Please rate how useful you found the following items: Textbooks.

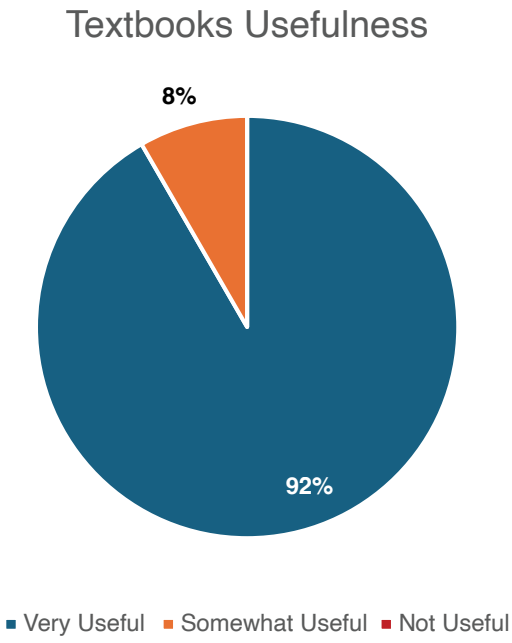


Figure 33. Proportion of participants reporting each category of usefulness for the textbooks supplied as part of the programme resources, data from the end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60)

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Question 14: Please rate how useful you found the following items: Digital Service Manuals.

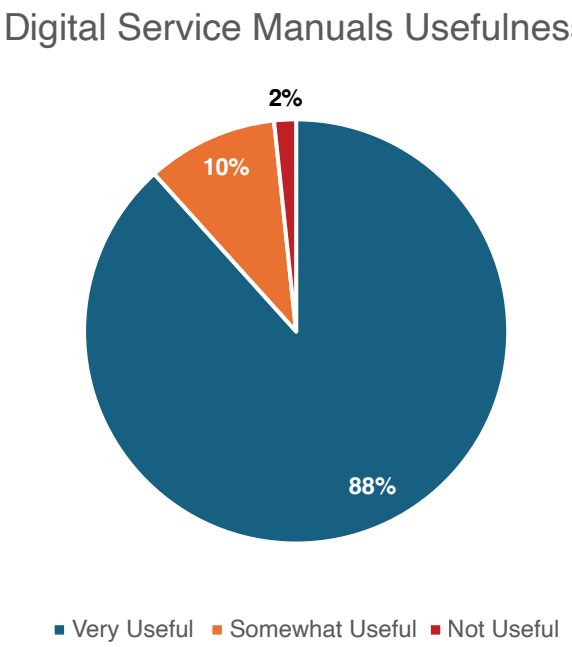


Figure 34. Proportion of participants reporting each category of usefulness for the digital library of service manuals supplied as part of the programme resources, data from the end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

Question 14: Please rate how useful you found the following items: Laptop

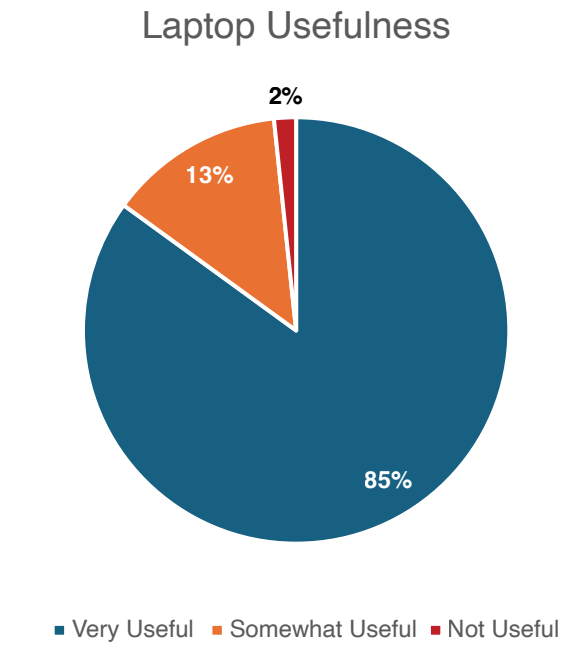


Figure 35. Proportion of participants reporting each category of usefulness for the laptop supplied as part of the programme resources, data from the end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

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In terms of the project management, the feedback from the participants across all aspects measured was also very positive. 95% of the participants involved rated the communication by Medical Aid International (MedAid) as being 9 or 10, with 10 representing excellent communication, **Figure 36**. The same positive sentiment was also reflected when participants were asked about the level of support provided by Medical Aid International (MedAid) throughout the project, where again 95% of participants gave a score of 9 or 10, **Figure 37**.

Participants were also keen to recommend the project, with an identical 95% rating the project to others with a score of 9 or 10 out of 10, with no scores lower than 7, **Figure 38**. Particularly impressive was the fact that 92% of participants recommended the project with a score of 10/10.

Question 15: On a scale of 1-10 (1 being poor communication, 10 being excellent communication) how would you rate the communication from Medical Aid International throughout the project?

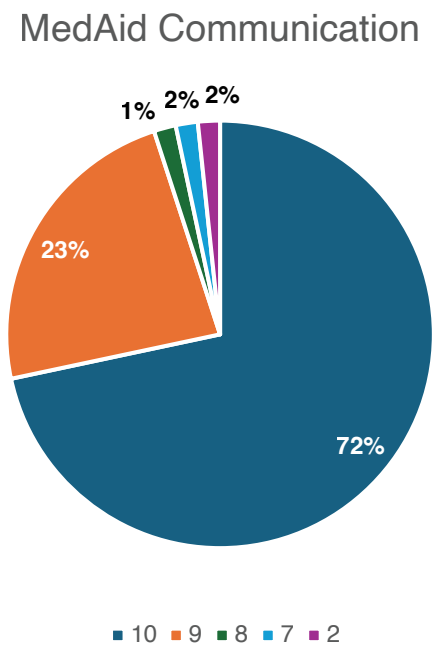


Figure 36. Proportion of participants reporting each score for communication from Medical Aid International throughout the project, only non-zero value scores shown, data from the end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

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Question 16: On a scale of 1-10 (1 poorly supported, 10 being well supported) how would you rate the level of support from Medical Aid International throughout the project?

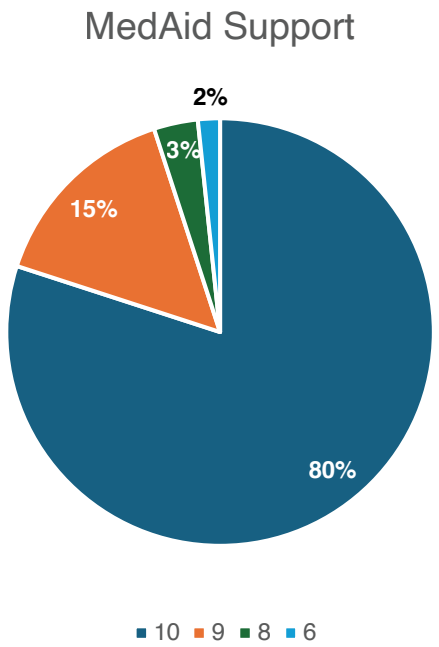


Figure 37. Proportion of participants reporting each score for support from Medical Aid International throughout the project, only non-zero value scores shown, data from the end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

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Question 17: On a scale of 1-10 (1 would not recommend, 10 being strongly recommend) how strongly, if at all, would you recommend this project to others?

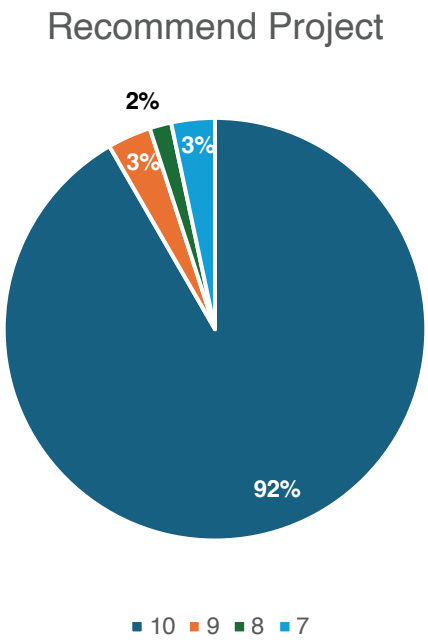


Figure 38. Proportion of participants reporting each score in terms of recommending this project to others, only non-zero value scores shown, data from the end of project survey, respondents completing both the onboarding and end of project survey and agreeing for their anonymised data to be used (n=60).

"Thank you to the MedAid International team for an excellent and practical course. It has enhanced my knowledge and confidence as a biomedical engineer, and I look forward to applying what I have learned in my work and participating in future training opportunities."

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Initial and Final Equipment Audit Comparison

The number of entries included in the data analysis is set out in **Table 6** and **Table 7**.

Table 6. Number of matching entries meeting set criteria (see **Data Exclusions and Comments**) for both the initial and final equipment audit. Descending order by equipment type. Data from one potential outlier site (06GH) included.

Equipment Type	Initial	Final	Total
Patient Monitor	411	411	822
Infusion Pump/Syringe Driver	301	301	602
Oxygen Concentrator	181	181	362
Suction Machine	140	140	280
Oxygen Cylinder	83	83	166
Ventilator	80	80	160
Anaesthetic Machine	64	64	128
Operating Table	57	57	114
Steriliser/Autoclave	56	56	112
Operating Lights	54	54	108
Infant Incubator	52	52	104
Infant Radiant Warmer	51	51	102
Ultrasound Scanner (Imaging Machine)	50	50	100
Surgical Diathermy/ESU	49	49	98
Dialysis Equipment	47	47	94
Pulse Oximeter	47	47	94
Defibrillator	44	44	88
X-ray/C-arm	31	31	62
Endoscopy Equipment System (Scopes, Light, Video Display, Irrigation Pump)	15	15	30
Operating Microscope	14	14	28
Oxygen Pipeline	13	13	26
CPAP (Concentrator-Connected)	12	12	24
Backup Electricity Generator	11	11	22
Head Lamp	10	10	20
Blood Gas Analyser	6	6	12
Laryngoscope Handle (with Light)	3	3	6
Electric or Air-Powered Bone Drill/Saw	2	2	4
Laparoscopy Equipment System (Scopes, Light, Video Display, Insufflator with Gas)	2	2	4
CPAP (Pipeline/Cylinder Oxygen-Connected)	2	2	4
Operating Table Traction Device	0	0	0
Grand Total	**1888**	**1888**	**3776**

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Table 7. Number of matching entries meeting set criteria (see **Data Exclusions and Comments**) for both the initial and final equipment audit. Descending order by equipment type. Data from one potential outlier site (06GH) excluded.

Equipment Type	Initial	Final	Total
Patient Monitor	254	254	508
Oxygen Concentrator	181	181	362
Suction Machine	114	114	228
Oxygen Cylinder	56	56	112
Infusion Pump/Syringe Driver	56	56	112
Anaesthetic Machine	53	53	106
Ventilator	50	50	100
Steriliser/Autoclave	48	48	96
Pulse Oximeter	47	47	94
Infant Incubator	47	47	94
Operating Lights	45	45	90
Infant Radiant Warmer	45	45	90
Ultrasound Scanner (Imaging Machine)	45	45	90
Operating Table	45	45	90
Dialysis Equipment	40	40	80
Surgical Diathermy/ESU	37	37	74
X-ray/C-arm	24	24	48
Defibrillator	21	21	42
Endoscopy Equipment System (Scopes, Light, Video Display, Irrigation Pump)	14	14	28
CPAP (Concentrator-Connected)	12	12	24
Backup Electricity Generator	11	11	22
Operating Microscope	11	11	22
Head Lamp	10	10	20
Laryngoscope Handle (with Light)	3	3	6
Laparoscopy Equipment System (Scopes, Light, Video Display, Insufflator with Gas)	2	2	4
CPAP (Pipeline/Cylinder Oxygen-Connected)	2	2	4
Oxygen Pipeline	2	2	4
Electric or Air-Powered Bone Drill/Saw	2	2	4
Blood Gas Analyser	1	1	2
Operating Table Traction Device	0	0	0
Grand Total	**1278**	**1278**	**2556**

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As mentioned during the **Project Phases** section, during the initial audit no definitions or examples of suitably functioning equipment were provided. This resulted in a wide range of interpretations of the questions, for example, what does “safe” equipment look like? This will have varied by country, facility, and participant.

However, when completing the final equipment audit, participants had also completed the online biomedical engineering course. During this programme, examples of both safe and unsafe equipment were provided, in addition to other information which may have changed the perspectives of the participants. It is the impact of these changes from undertaking the course which should be manifested in differences between the initial and final equipment audit data.

The first section of the initial and final equipment audit comparison set out the findings made when the **Topline Data Summary** was investigated, i.e., when looking at all data combined from all of the equipment applicable to each question asked in the equipment audits. From here key trends were identified, with other findings detailed in a later section (**Specific Equipment Findings**).

As mentioned in the **Data Exclusions and Comments** section, one site was identified as a potential outlier for the initial and final equipment audit (06GH). This site also contributed a large fraction (about 30%) of overall equipment audit responses, the distribution of which is shown, **Figure 39**. To prevent this site from skewing the data, where the pattern changes significantly if this data is excluded, alternative data analysis has also been shown where this outlier site was removed. Unless explicitly stated otherwise, the data analysis included the data from site 06GH.

The site in question was a large, comparatively well resourced hospital, which accounts both for the significant number of entries, as well as the data pattern differing from other sites.

The rationale behind not excluding the site entirely is that (apart from one question relating to equipment safety which appears to have been misunderstood), no reasoning was found to suggest that the data provided was inaccurate. It was therefore decided that the approach outlined above was preferable.

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Topline Data Summary

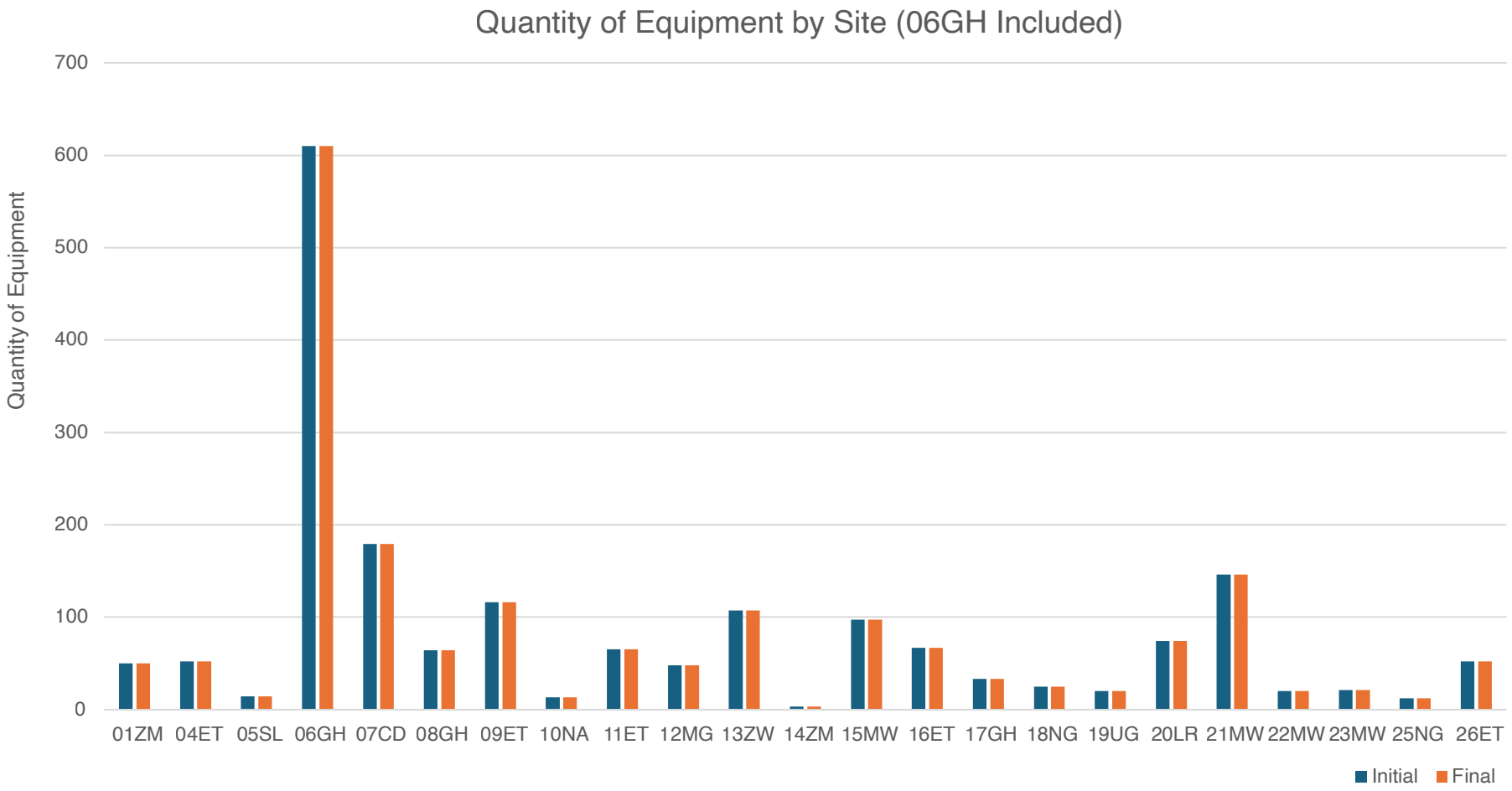


Figure 39. Quantity of equipment by site in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, (n=1888 in both the initial and final equipment audit). Data from potential outlier site included (06GH).

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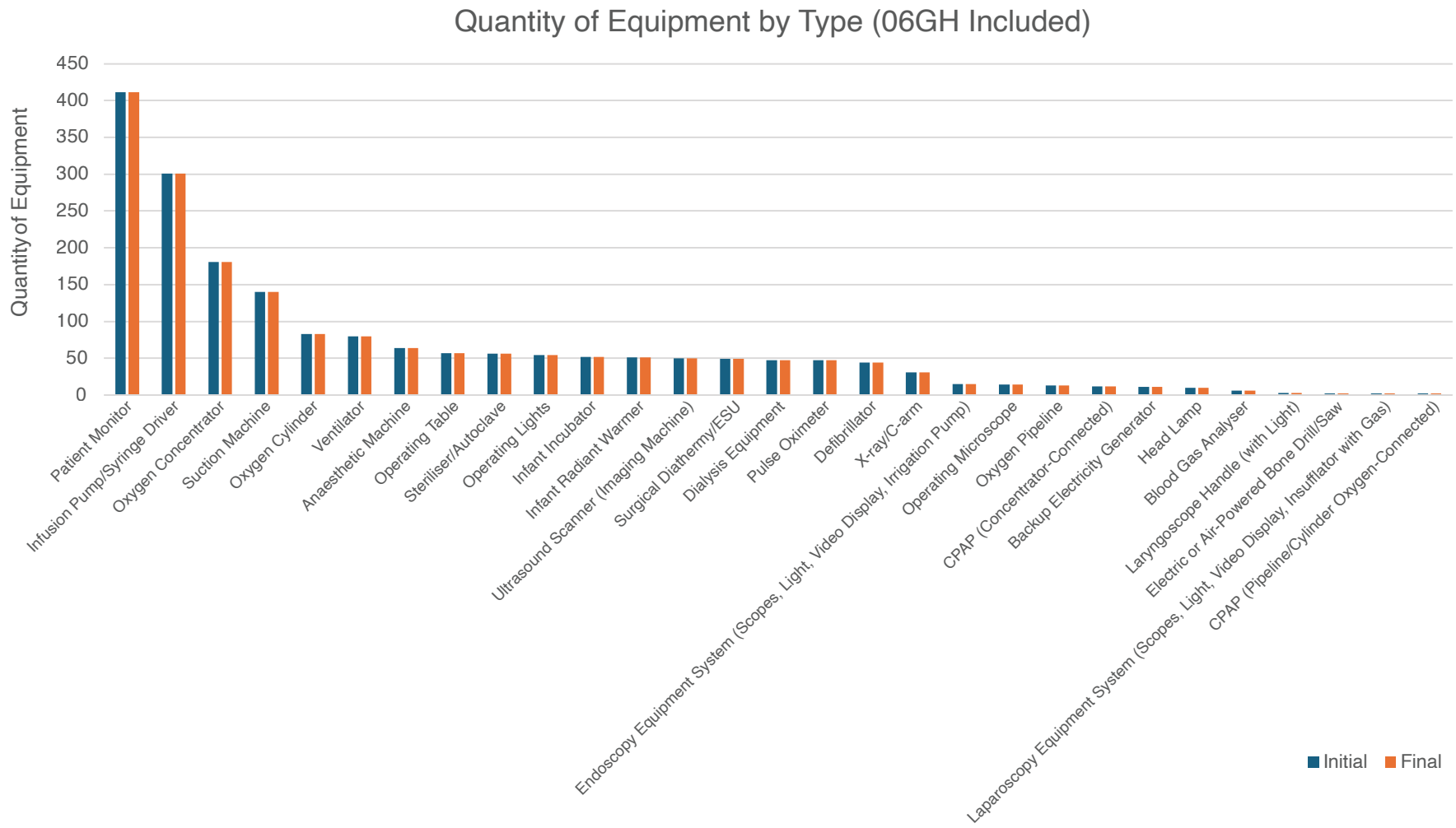


Figure 40. Quantity of equipment by type in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, only non-zero values shown (n=1888 in both the initial and final equipment audit). Data from potential outlier site (06GH) included.

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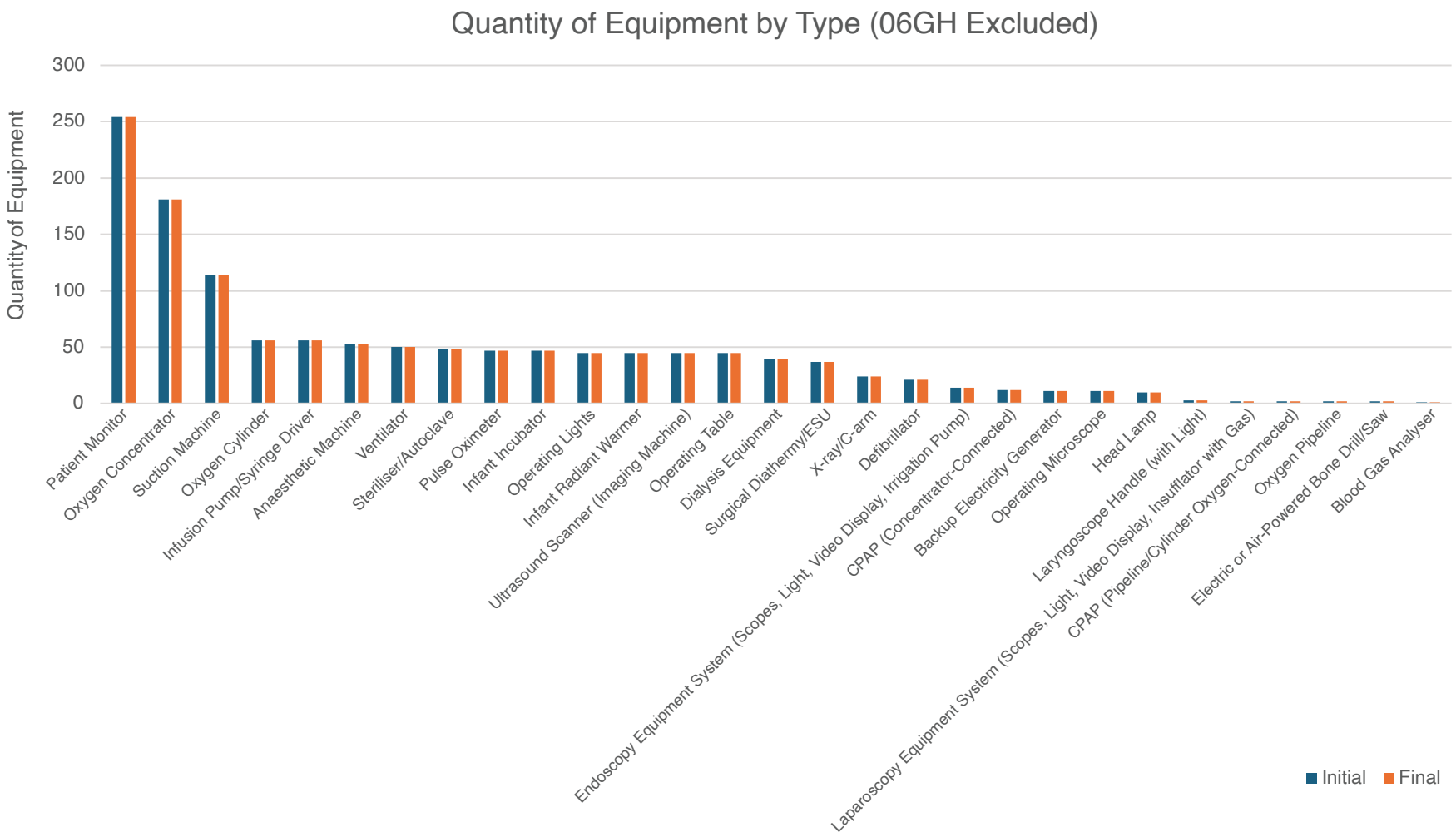


Figure 41. Quantity of equipment by type in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, only non-zero values shown (n=1278 in both the initial and final equipment audit). Data from potential outlier site (06GH) excluded.

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Considering all the data collected, including (06GH), the most logged pieces of equipment by type were patient monitors, infusion pumps/syringe drivers, oxygen concentrators, and suction machines. Together these accounted for 1033 matching entries in both the initial and final equipment audit, making up 55% of the total equipment logged, **Figure 40**.

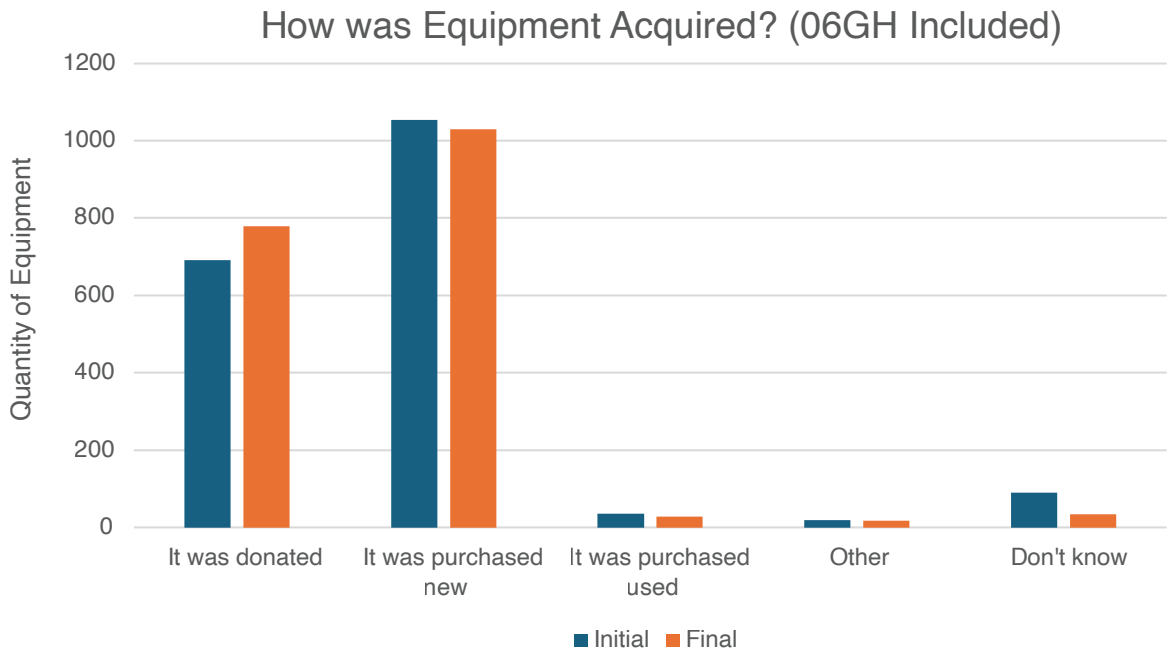


Figure 42. Quantity of equipment by participant response to the prompt "How did you acquire this equipment?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1888 in both the initial and final equipment audit).

The proportion of equipment acquired by each method remained relatively stable, with the proportion of donated equipment increasing from 37% in the initial equipment audit, to 41% in the final equipment audit. The proportion of equipment purchased new remained almost identical, at 56% and 55% in the initial and final equipment audit, respectively. It was also interesting to note that the proportion of don't knows fell considerably, from just over 5% of responses in the initial equipment audit, to just 2% in the final equipment audit, **Figure 42**.

Given this was the same equipment in both equipment audits (all non-matching entries were excluded), it is encouraging to see the data remained fairly consistent across this category, as anticipated. This suggests that the graduates were able to collect this data reliably, given the equipment audits were conducted many months apart.

When 06GH was excluded from the data set the same broad pattern emerges, but with a far smaller proportion of equipment being purchased new (about 35%); the primary method by which equipment was acquired became donations, approximately 55-60%, Figure 43. This fits in well with knowledge that site 06GH is comparatively well resourced and in a major city, hence it was more likely to purchase equipment new than other sites.

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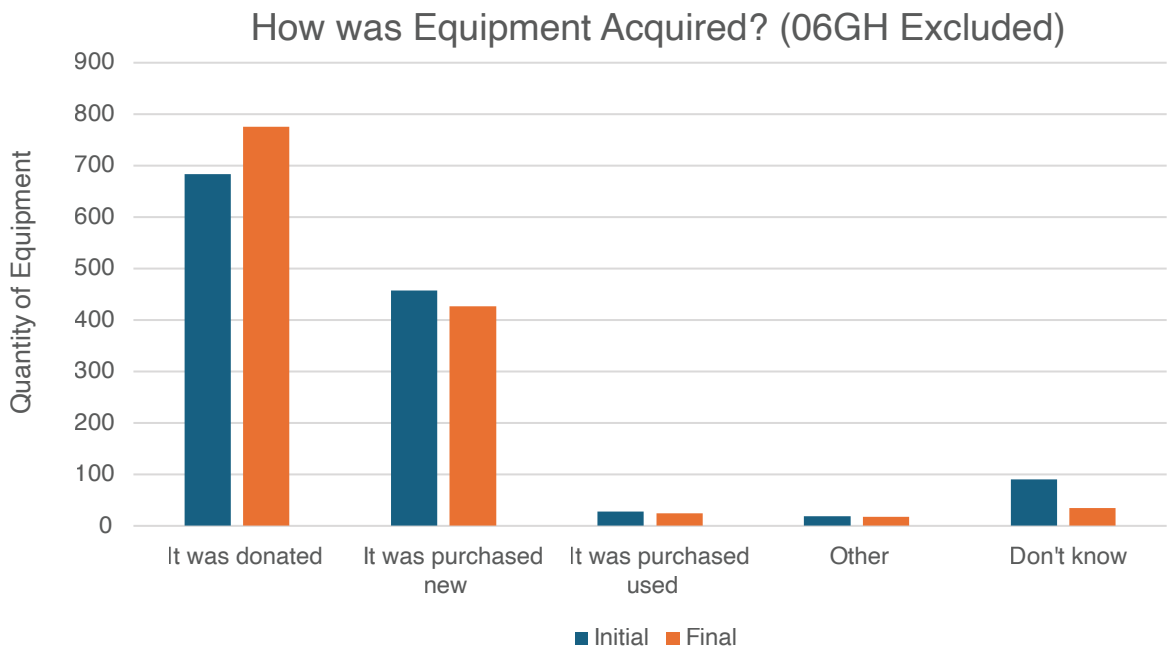


Figure 43. Quantity of equipment by participant response to the prompt "How did you acquire this equipment?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=1278 in both the initial and final equipment audit).

A similarly static picture was present considering when the equipment was last used, i.e., with most categories remaining broadly stable between the initial and final equipment audit. The only major changes were a reduction in equipment which was never used (from 4% to 1%), in addition to a reduction in "don't know" responses (from 2.4% to just 0.4%), **Figure 44**.

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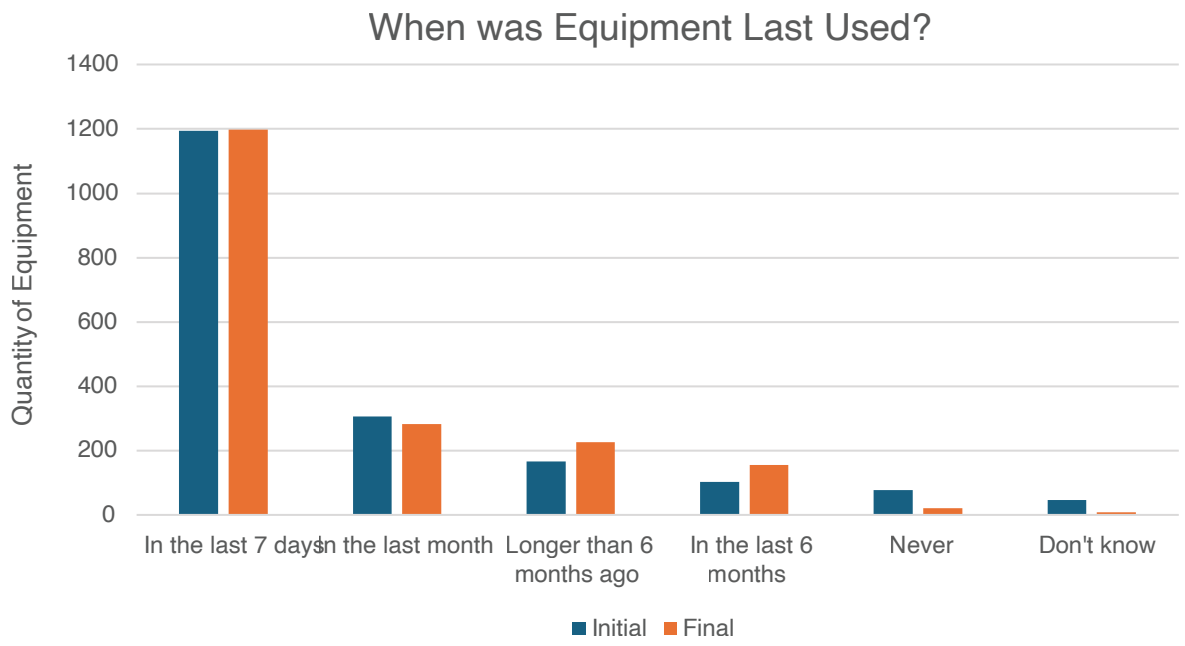


Figure 44. Quantity of equipment by response to the prompt "When was the last time the equipment was used?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1888 in both the initial and final equipment audit).

One very interesting change in the data when a comparison was made between the two equipment audits was an apparent massive discrepancy in participant response when asked about their perceived safety concerns for the equipment, **Figure 45**. In the initial equipment audit, participants reported that they only had safety concerns about 14% of equipment, **Figure 46**. However, when they were asked again in the final equipment audit, this figure had risen to 46%, **Figure 47**. It was also notable that the proportion of don't know responses also fell, as for the other questions, from 2.4% in the initial equipment audit, to 0.4% in the final equipment audit.

However, upon further analysis, all of these changes appear to be caused by the potential outlier 06GH. Their data is essentially inversed, with the participants at this site responding almost exclusively with "Yes" responses to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in the initial equipment audit, and then with "No" to the same question in the final equipment audit. This appears to have been caused by confusion as to the meaning of the prompt (i.e., which response means the equipment is safe). When the data from 06GH was removed from the dataset, these changes are removed and a consistent, stable picture was found, **Figure 48**, **Figure 49**, and **Figure 50**.

There remained a significant reduction in "Don't know" responses, from 3.6% to 0.6%, which continued the trend of increased confidence of the participants in their responses.

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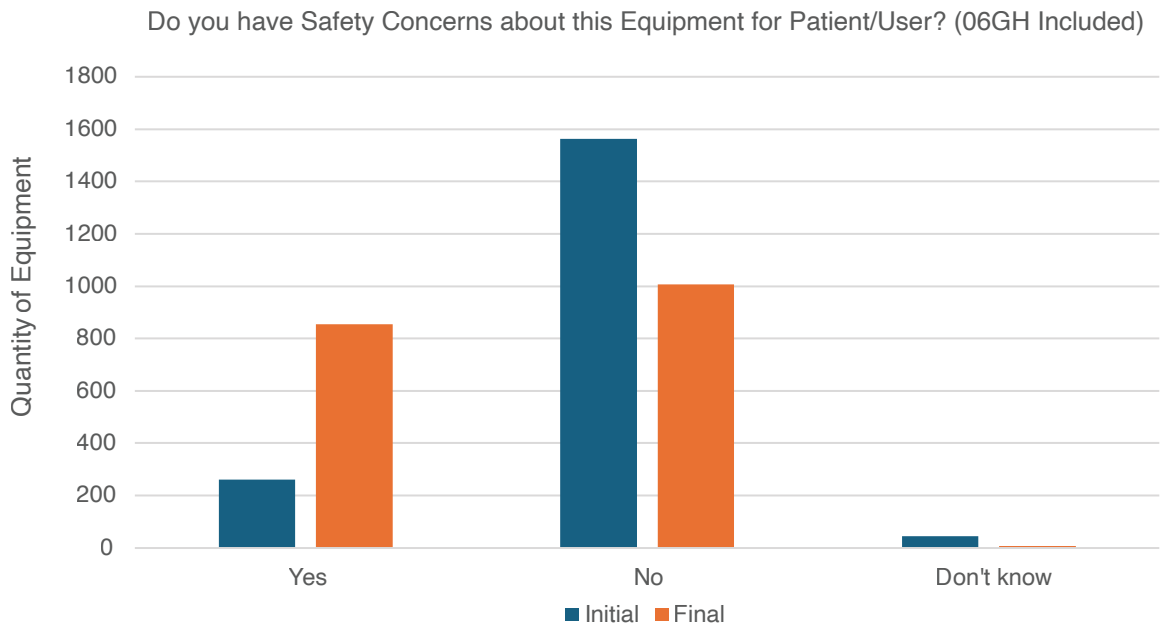


Figure 45. Quantity of equipment by response to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1867 in both the initial and final equipment audit).

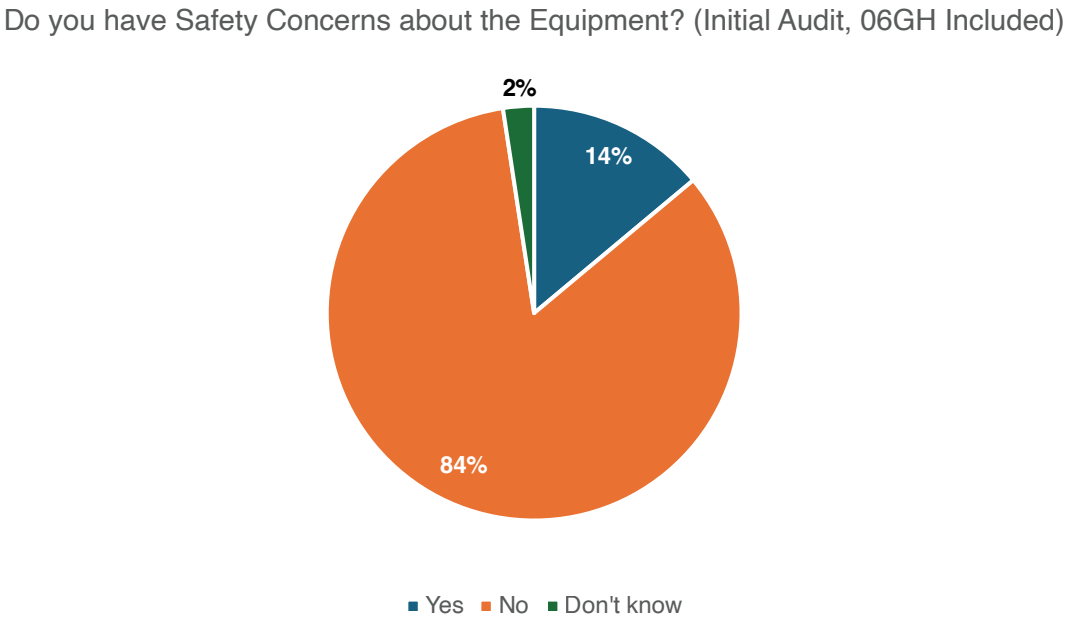


Figure 46. Proportion of equipment by response to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in the initial equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1867).

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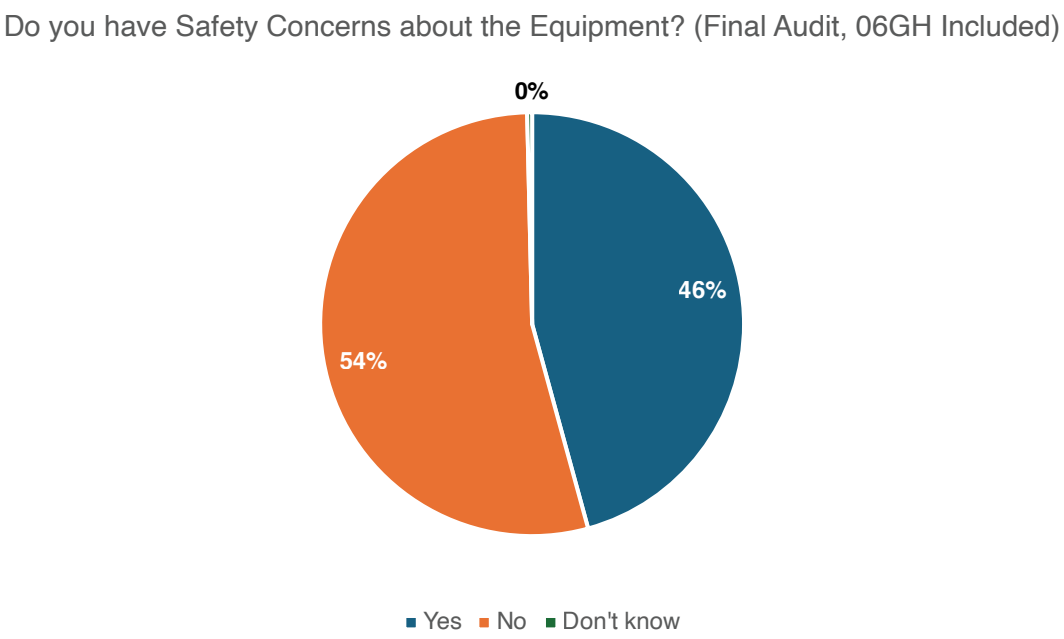


Figure 47. Proportion of equipment by response to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in the final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1867).

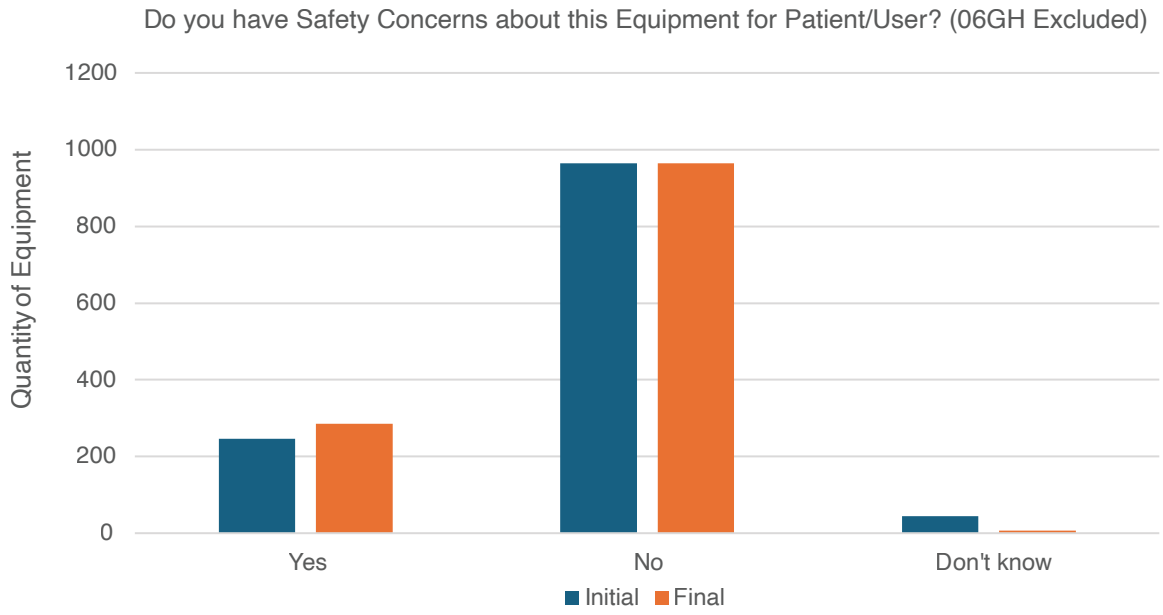


Figure 48. Quantity of equipment by response to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=1257 in both the initial and final equipment audit).

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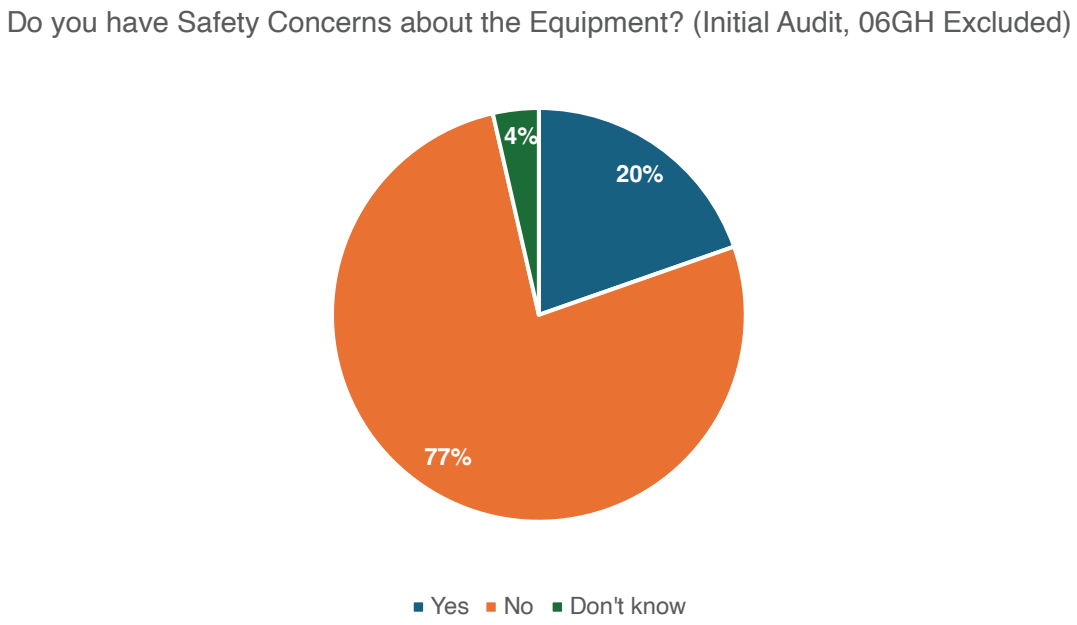


Figure 49. Proportion of equipment by response to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in the initial equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=1257).

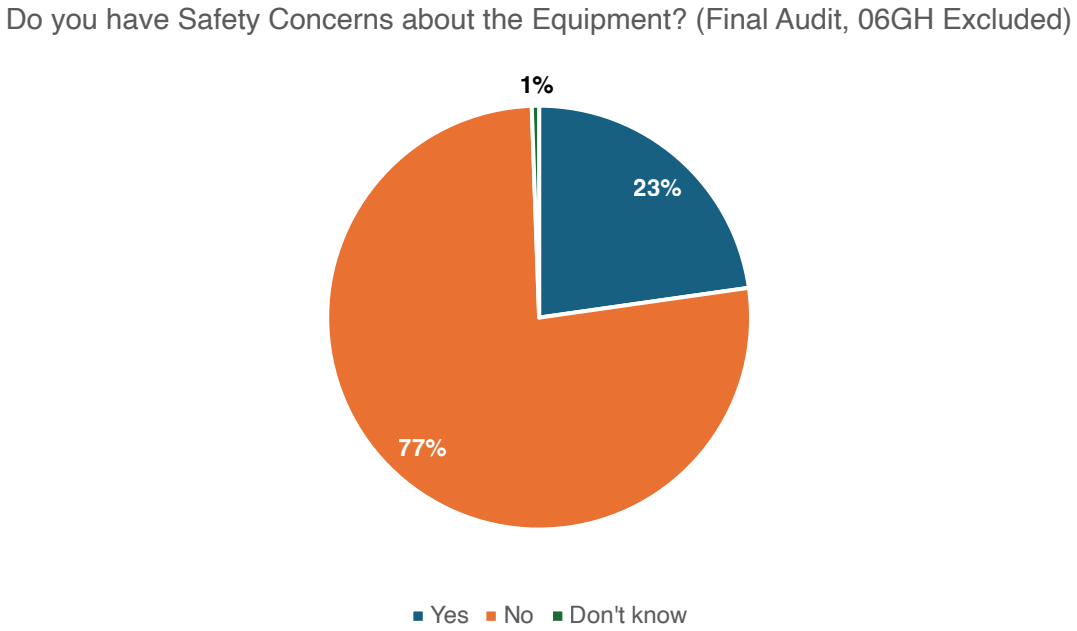


Figure 50. Proportion of equipment by response to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in the final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=1257).

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A very small number of equipment types (backup electricity generators and head lamps) were asked a similar question, but with the focus on general safety (not mentioning the patient or user aspect). These findings only covered 21 pieces of equipment, but for completeness have been shown in **Figure 51**. None of the data featured was from site 06GH in any case, so no exclusion was necessary.

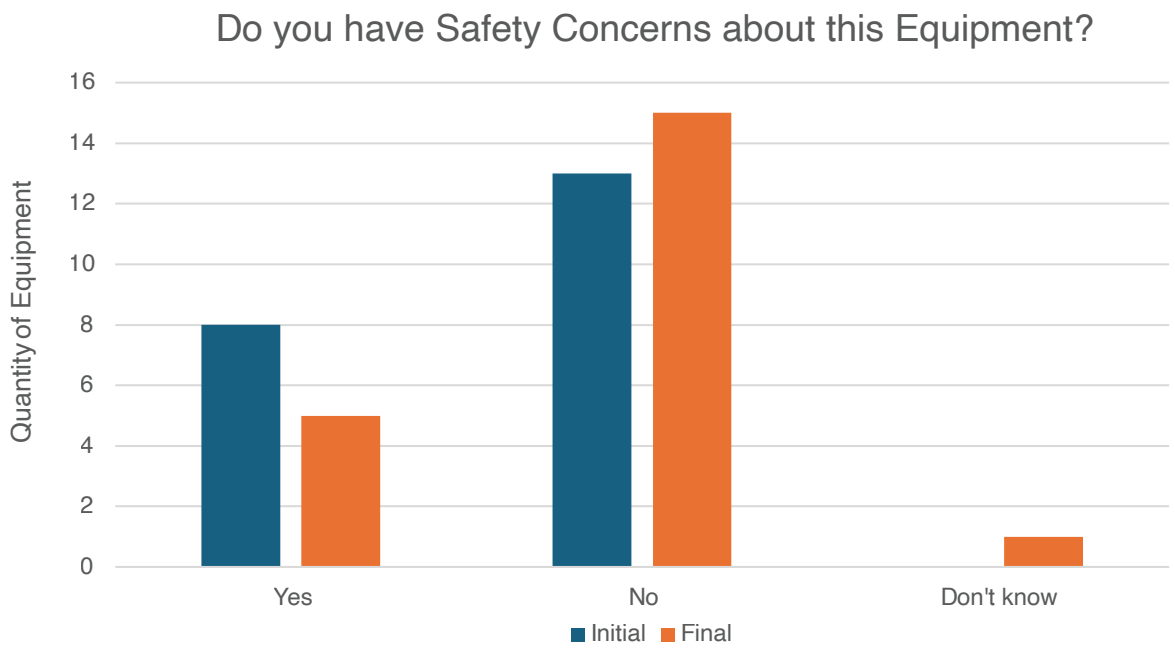


Figure 51. Quantity of equipment by response to the prompt "Do you have any concerns about the safety of this equipment?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, no data collected for this question by potential outlier site (06GH), (n=21 in both the initial and final equipment audit).

It was also discovered that there was limited change in the job satisfaction of equipment as rated by the participants between both equipment audits, **Figure 52**. The effect of the data from site 06GH was negligible and so the data was included. The margin of change was only -0.7% for the response "Yes" (84.9% initial, 84.2% final), +3% for the response "No" (12% initial, 15% final). The don't know response change, whilst in absolute terms was small, was proportionally far more significant. The reduction was from 2.5% in the initial equipment audit to 0.4% in the final equipment audit, which was a significant reduction of 83%.

Similarly small variations in participant responses were observed in relation to whether or not the equipment switched on, **Figure 53**, with the proportion of "Yes" responses falling from 93% to 91% between the initial and final equipment audit, while the proportion of "No" responses increased from 6% to 9%. The "Don't know" proportion also fell from 1.4% to 0.1% in the same way (a significant reduction of 92%). Again, the data from site 06GH was congruent with data from other sites.

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The changes in responses when considering the if the battery backup for the equipment was working also fit the previous trend, **Figure 54**. As previously observed, "Yes" responses increased from 44% to 47% between the two equipment audits, with the proportion of "No" responses remaining steady at 51%, and the "Don't know" responses falling from 5.0% to 1.9%, a reduction of 61%. As before, the pattern seen in the data was broadly similar both with and without data from site 06GH.

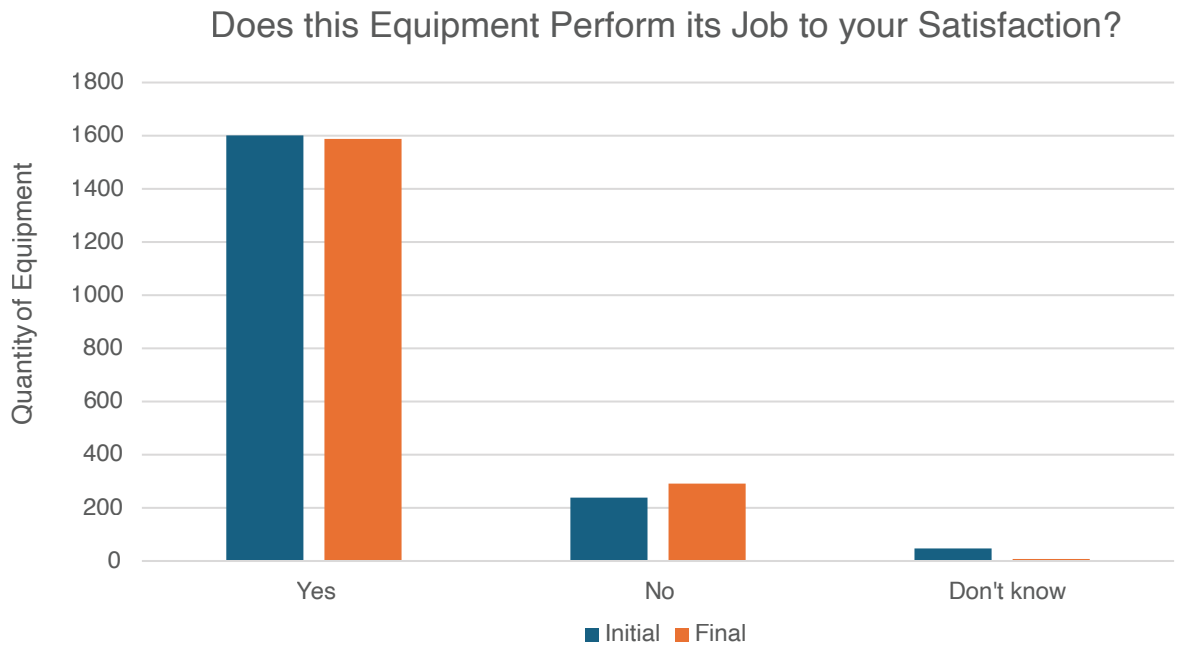


Figure 52. Quantity of equipment by response to the prompt "Does the equipment perform its job to your satisfaction?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1888 in both the initial and final equipment audit).

"The training was very informative and well-structured. It improved my understanding of different medical devices and their safe use."

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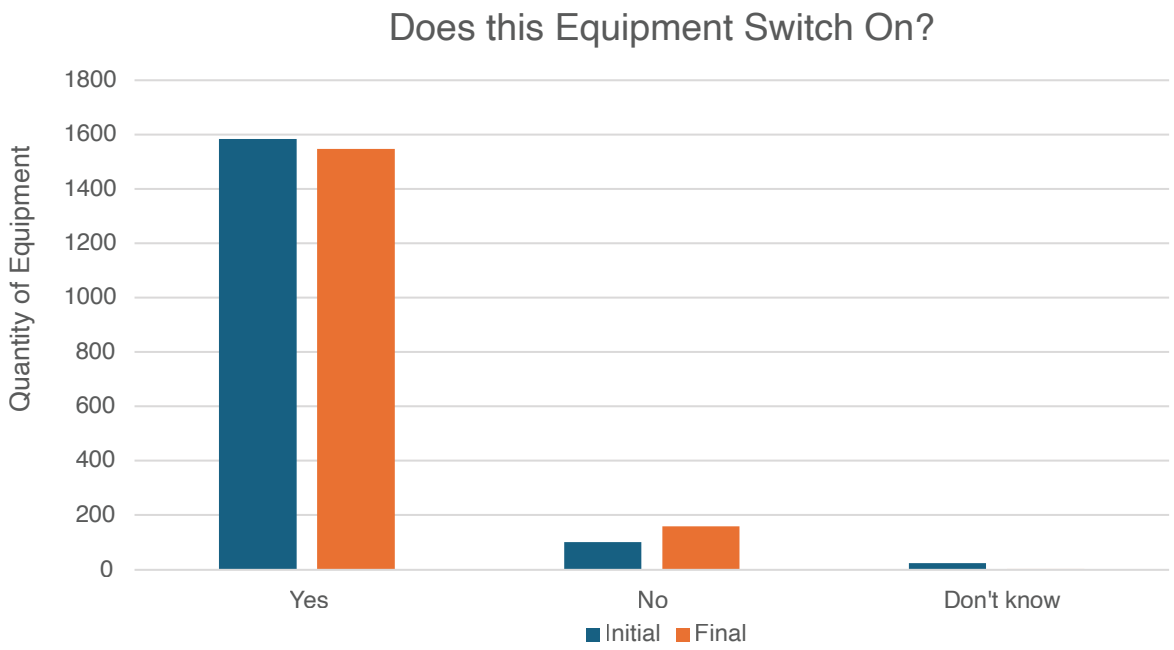


Figure 53. Quantity of equipment by response to the prompt "Does it switch on?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1708 in both the initial and final equipment audit).

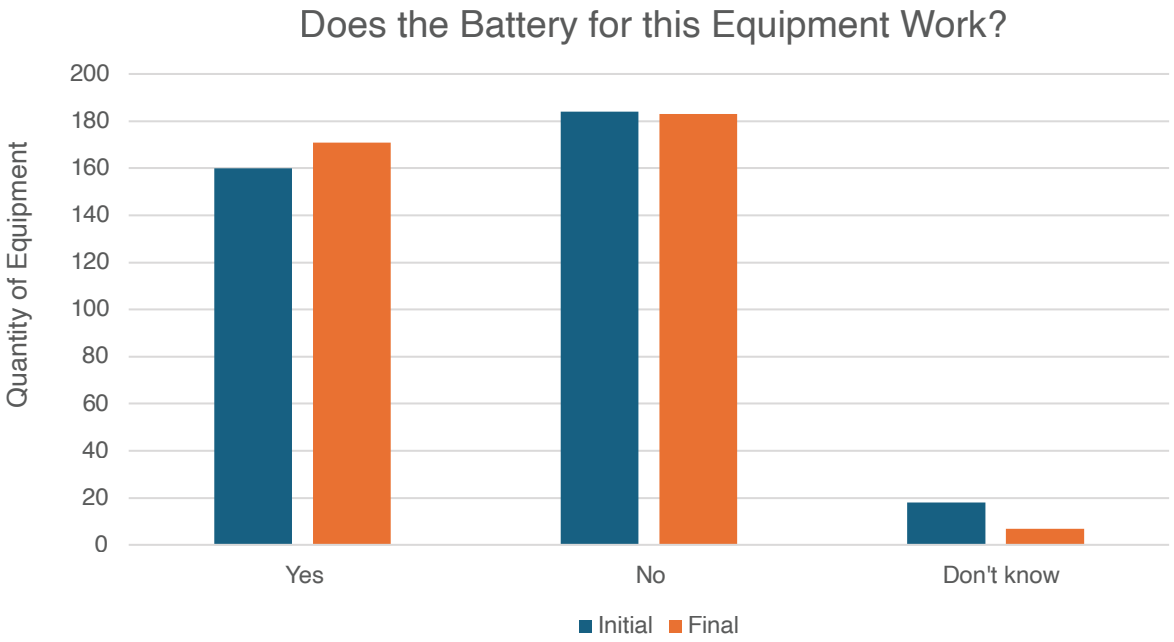


Figure 54. Quantity of equipment by response to the prompt "Does the battery work?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=362 in the initial equipment audit, and n=361 in the final equipment audit; one piece of equipment received a blank entry for this question in the final audit).

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One key point raised is the severe lack of spare parts to repair equipment. This was raised both by previously seen data from the onboarding and end of project surveys, **Figure 24** and **Figure 25**, and also by the data from the initial and final equipment audit, **Figure 55**. The proportion of equipment where spare parts were available was only 13% for the initial equipment audit, and 19% for the final equipment audit, **Figure 56** and **Figure 57**. Throughout this section, the impact on the findings around spare part availability from site 06GH was minimal, with its data having been included.

As this project did not make the provision of spare parts one of its main objectives, aside for the provision of over 250 fuses as part of each resource package, it is therefore difficult to draw any definitive conclusions from this data, aside from to highlight the significant barrier to equipment repair biomedical engineers face from the lack of available spare parts.

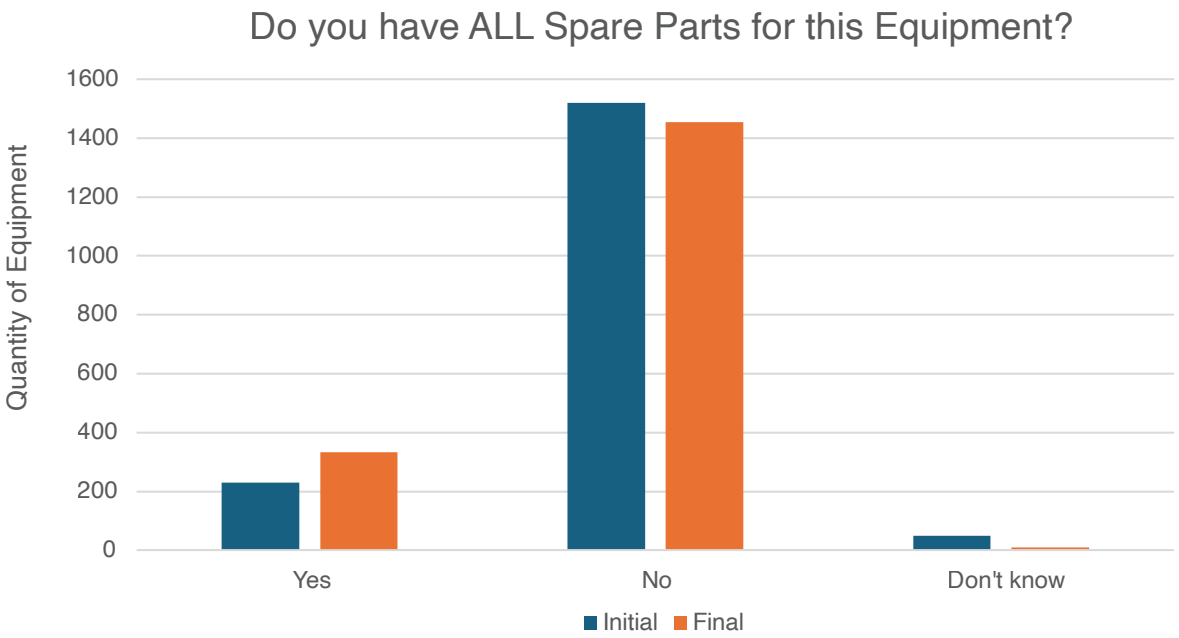


Figure 55. Quantity of equipment by response to the prompt "Do you have ALL the spare parts needed for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1799 in both the initial and final equipment audit).

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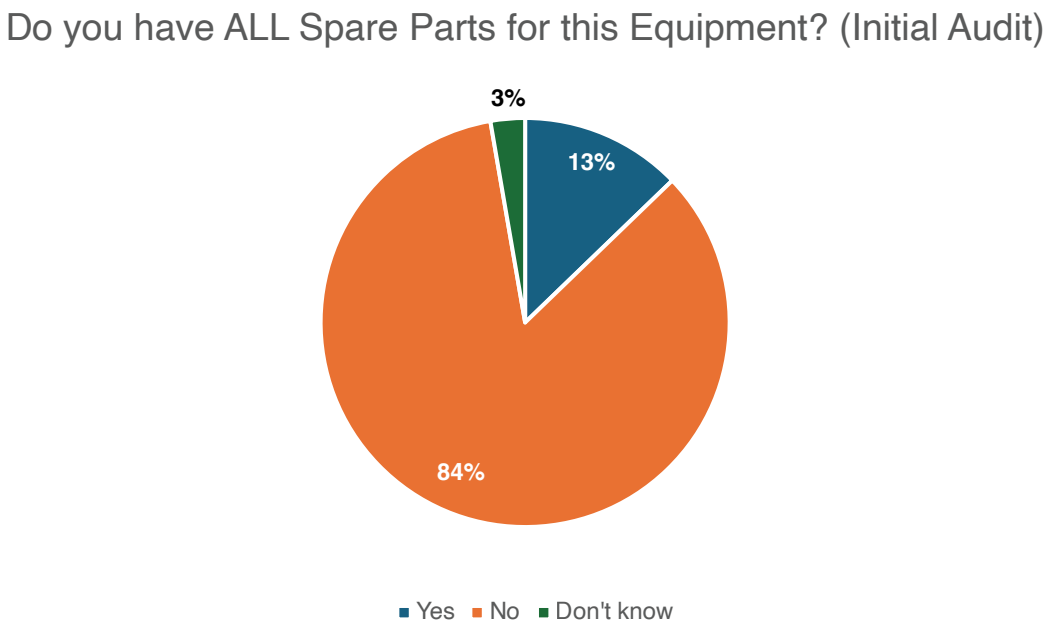


Figure 56. Proportion of equipment by response to the prompt "Do you have ALL the spare parts needed for this device?" in the initial equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1799).

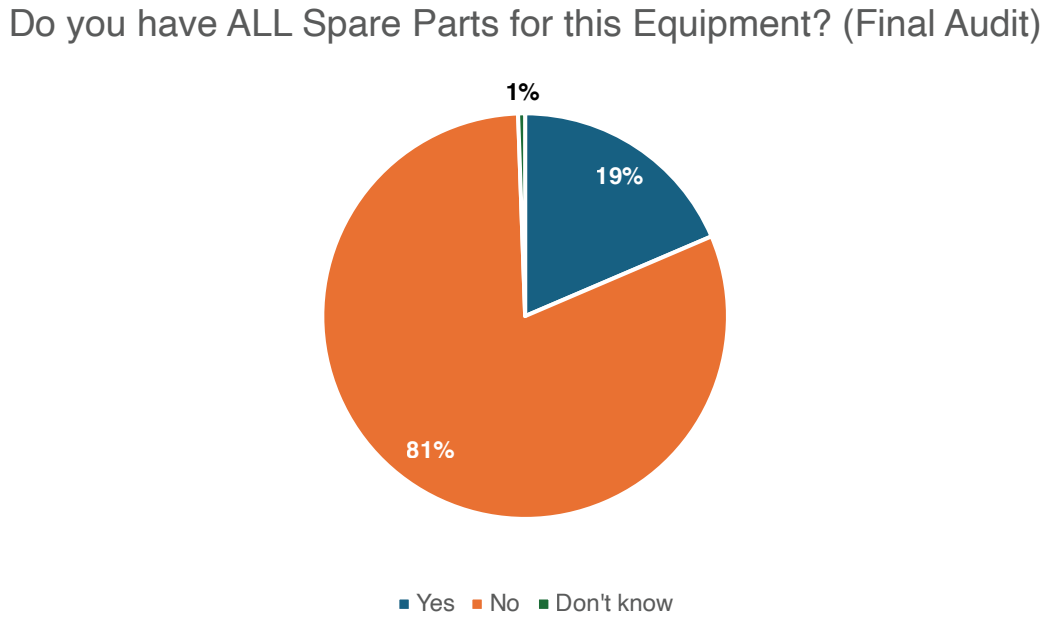


Figure 57. Proportion of equipment by response to the prompt "Do you have ALL the spare parts needed for this device?" in the initial equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1799).

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The proportion of each type of equipment where all necessary spare parts were available was also investigated, **Table 8** and **Table 9**. Equipment with minimal entries (n<20) was treated with caution due to the small sample size, although included in the tables for completeness.

However, it was interesting to note that there was a wide range reported for the availability of spare parts for equipment logged in both the initial and final equipment audit. For the initial equipment audit, this was a range of 0% up to a maximum 57.4% for pulse oximeters. For the final equipment audit, this was a range of 0% up to a maximum of 69.2% for oxygen pipelines (n=13); for (n>20) this was again pulse oximeters, where the proportion of "Yes" responses was 56.5%.

When criteria was applied to the dataset, such that equipment must have a "Yes" response rate for spare parts greater than 10% in both the initial and final equipment audit, the resulting data is shown in **Table 10**.

Only a few types of equipment met this criteria, including:

- Pulse Oximeter
- Surgical Diathermy/ESU
- Operating Table
- CPAP (Concentrator-Connected)
- Patient Monitor
- Anaesthetic Machine
- Suction Machine
- Oxygen Concentrator
- Endoscopy Equipment System (Scopes, Light, Video Display, Irrigation Pump)

It should be noted that (n<20) for Endoscopy Equipment System (Scopes, Light, Video Display, Irrigation Pump), where (n=15) for the initial equipment audit and (n=14) for the final equipment audit. This was also the case for the category of CPAP (Concentrator-Connected), (n=12) for both equipment audits.

The data shown in **Table 8**, **Table 9**, and **Table 10** is represented graphically in **Figure 58**, **Figure 59**, and **Figure 60**, respectively.

> *"By the way I managed to fix a blocked suction machine from my office… yesterday and am yet to fix another suction machine which has a broken drainage system by replacing it with other material I will get from hardware stores… [I] am also working together with engineers at our district hospital to familiarise myself with practical fixing of medical equipment. The course is life changing."*

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Table 8. Proportion of equipment with ALL spare parts needed for the device, matching entries meeting set criteria (see **Data Exclusions and Comments**) for both the initial and final equipment audit, data from potential outlier site (06GH) included. Descending order by proportion of "Yes" responses by participants to prompt "Do you have ALL the spare parts needed for this device?" in the initial equipment audit.

Equipment Type	Total Initial (Yes or No)	% Yes (Initial)	% No (Initial)
Pulse Oximeter	47	57.4%	42.6%
Surgical Diathermy/ESU	48	31.3%	68.8%
Operating Table	50	20.0%	80.0%
CPAP (Concentrator-Connected)	12	16.7%	83.3%
Patient Monitor	409	15.9%	84.1%
Oxygen Cylinder	82	15.9%	84.1%
Anaesthetic Machine	57	15.8%	84.2%
Infant Incubator	51	15.7%	84.3%
Suction Machine	137	13.9%	86.1%
Oxygen Concentrator	179	13.4%	86.6%
Endoscopy Equipment System (Scopes, Light, Video Display, Irrigation Pump)	15	13.3%	86.7%
Infant Radiant Warmer	51	11.8%	88.2%
Steriliser/Autoclave	54	9.3%	90.7%
Defibrillator	44	9.1%	90.9%
Ventilator	80	8.8%	91.3%
X-ray/C-arm	30	6.7%	93.3%
Ultrasound Scanner (Imaging Machine)	49	6.1%	93.9%
Dialysis Equipment	30	3.3%	96.7%
Infusion Pump/Syringe Driver	298	2.7%	97.3%
Blood Gas Analyser	6	0.0%	100.0%
CPAP (Pipeline/Cylinder Oxygen-Connected)	2	0.0%	100.0%
Electric or Air-Powered Bone Drill/Saw	2	0.0%	100.0%
Laparoscopy Equipment System (Scopes, Light, Video Display, Insufflator with Gas)	1	0.0%	100.0%
Oxygen Pipeline	13	0.0%	100.0%
Laryngoscope Handle (with Light)	3	0.0%	100.0%

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Table 9. Proportion of equipment with ALL spare parts needed for the device, matching entries meeting set criteria (see **Data Exclusions and Comments**) for both the initial and final equipment audit, data from potential outlier site (06GH) included. Descending order by proportion of "Yes" responses by participants to prompt "Do you have ALL the spare parts needed for this device?" in the final equipment audit.

Equipment Type	Total Initial (Yes or No)	% Yes (Initial)	% No (Initial)
Oxygen Pipeline	13	69.2%	30.8%
Pulse Oximeter	46	56.5%	43.5%
Surgical Diathermy/ESU	49	51.0%	49.0%
CPAP (Pipeline/Cylinder Oxygen-Connected)	2	50.0%	50.0%
Electric or Air-Powered Bone Drill/Saw	2	50.0%	50.0%
Laparoscopy Equipment System (Scopes, Light, Video Display, Insufflator with Gas)	2	50.0%	50.0%
X-ray/C-arm	31	35.5%	64.5%
Anaesthetic Machine	63	34.9%	65.1%
Operating Table	57	31.6%	68.4%
CPAP (Concentrator-Connected)	12	25.0%	75.0%
Defibrillator	41	24.4%	75.6%
Patient Monitor	411	21.7%	78.3%
Blood Gas Analyser	6	16.7%	83.3%
Ventilator	80	16.3%	83.8%
Suction Machine	140	15.0%	85.0%
Dialysis Equipment	47	14.9%	85.1%
Endoscopy Equipment System (Scopes, Light, Video Display, Irrigation Pump)	14	14.3%	85.7%
Oxygen Concentrator	180	11.7%	88.3%
Infusion Pump/Syringe Driver	300	10.7%	89.3%
Steriliser/Autoclave	56	8.9%	91.1%
Ultrasound Scanner (Imaging Machine)	49	8.2%	91.8%
Infant Radiant Warmer	50	8.0%	92.0%
Infant Incubator	52	7.7%	92.3%
Oxygen Cylinder	83	4.8%	95.2%
Laryngoscope Handle (with Light)	3	0.0%	100.0%

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Table 10. Proportion of equipment with ALL spare parts needed for the device, matching entries meeting set criteria (see **Data Exclusions and Comments**) for both the initial and final equipment audit, where proportion of "Yes" responses in both equipment audit was greater than 10%, data from potential outlier site (06GH) included. Descending order by proportion of "Yes" responses by participants to prompt "Do you have ALL the spare parts needed for this device?" in the initial equipment audit.

Equipment Type	Total Initial (Yes or No)	Total Final (Yes or No)	% Yes (Initial)	% Yes (Final)	% No (Initial)	% No (Final)	Both Above 10%
Pulse Oximeter	47	46	57.4%	56.5%	42.6%	43.5%	Yes
Surgical Diathermy/ESU	48	49	31.3%	51.0%	68.8%	49.0%	Yes
Operating Table	50	57	20.0%	31.6%	80.0%	68.4%	Yes
CPAP (Concentrator-Connected)	12	12	16.7%	25.0%	83.3%	75.0%	Yes
Patient Monitor	409	411	15.9%	21.7%	84.1%	78.3%	Yes
Anaesthetic Machine	57	63	15.8%	34.9%	84.2%	65.1%	Yes
Suction Machine	137	140	13.9%	15.0%	86.1%	85.0%	Yes
Oxygen Concentrator	179	180	13.4%	11.7%	86.6%	88.3%	Yes
Endoscopy Equipment System (Scopes, Light, Video Display, Irrigation Pump)	15	14	13.3%	14.3%	86.7%	85.7%	Yes

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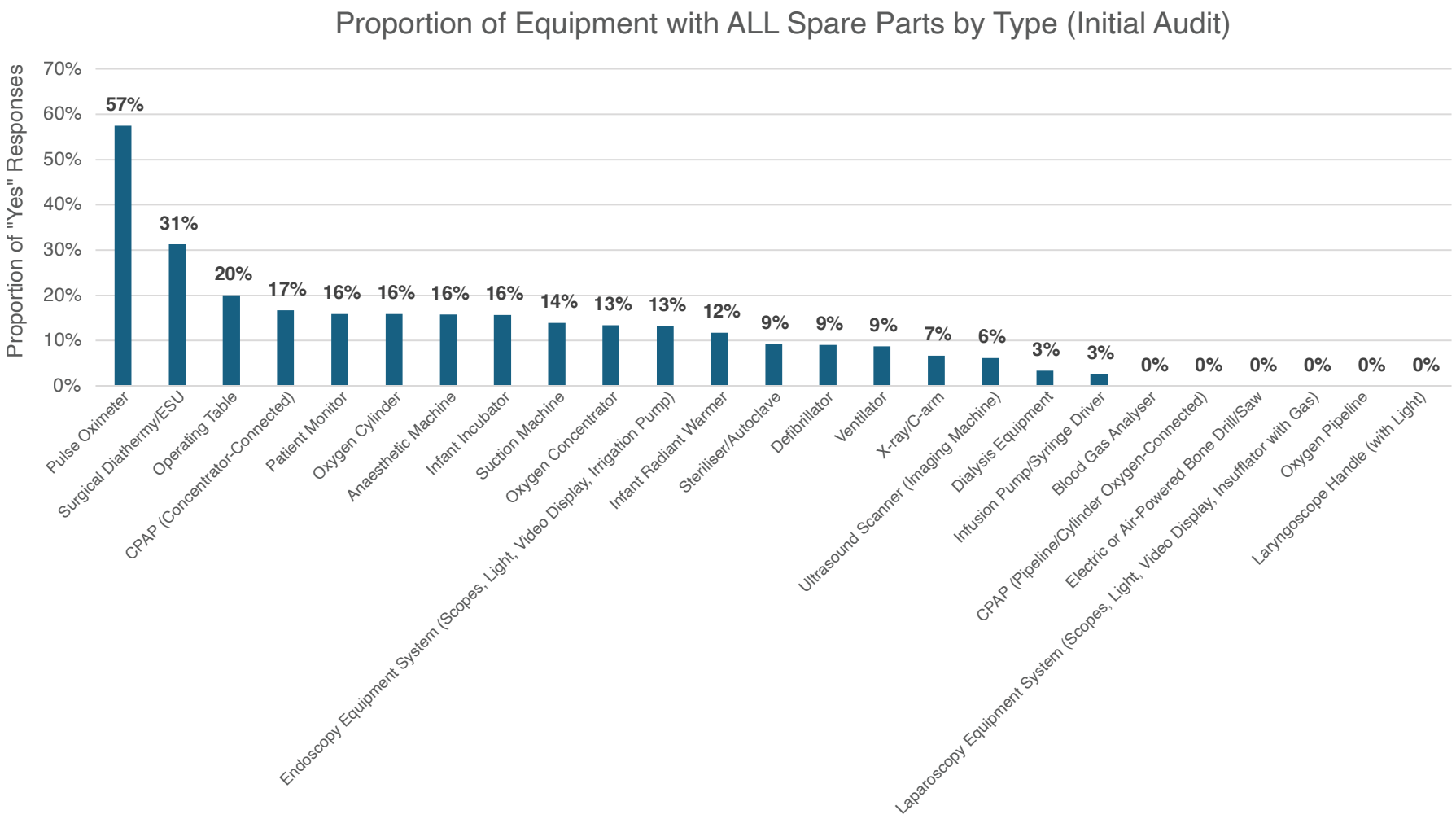


Figure 58. Proportion of equipment with ALL spare parts needed for the device in the initial equipment audit, matching entries meeting set criteria (see **Data Exclusions and Comments**) for both the initial and final equipment audit, data from potential outlier site (06GH) included. Descending order by proportion of "Yes" responses by participants to prompt "Do you have ALL the spare parts needed for this device?" in the initial equipment audit.

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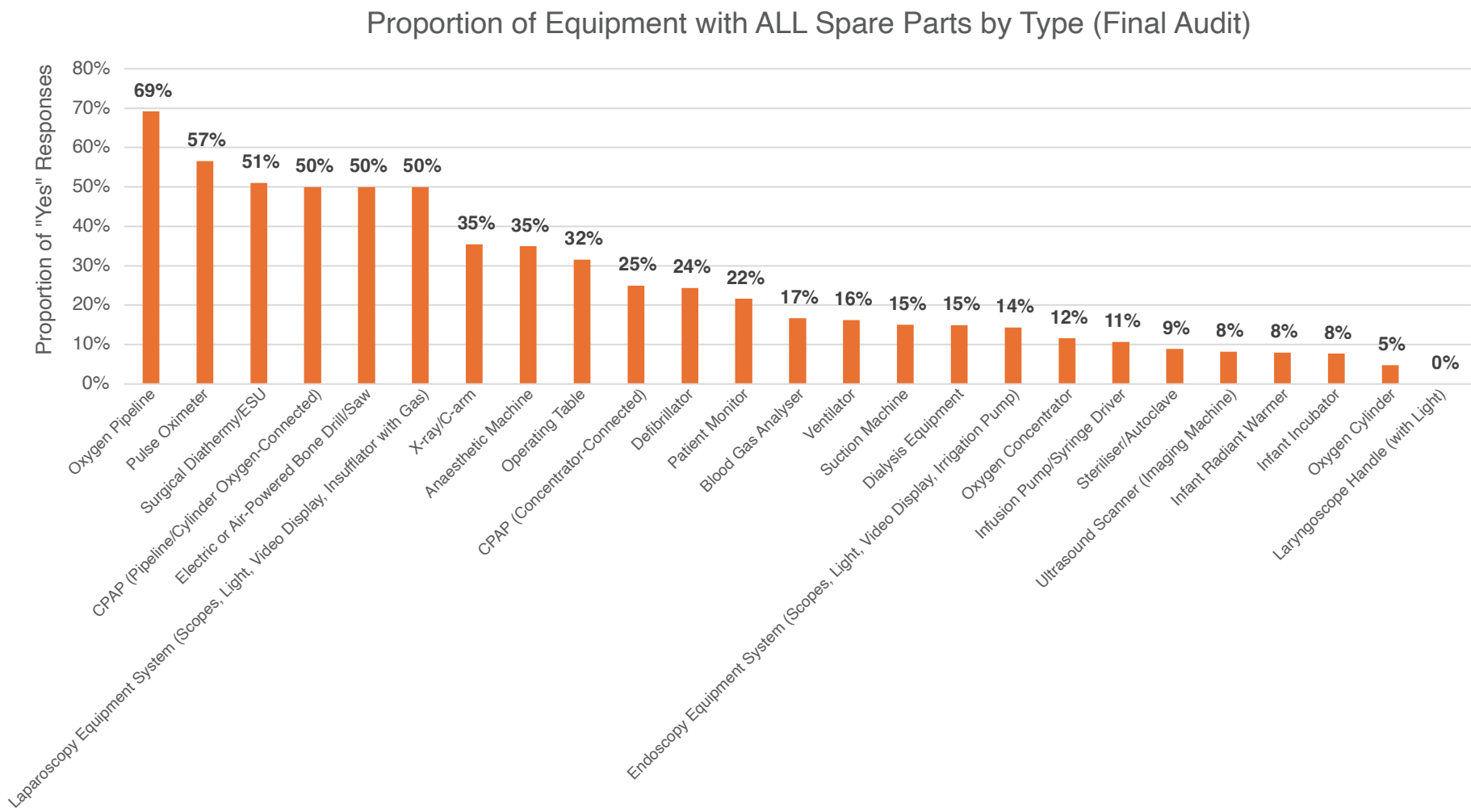


Figure 59. Proportion of equipment with ALL spare parts needed for the device in the final equipment audit, matching entries meeting set criteria (see **Data Exclusions and Comments**) for both the initial and final equipment audit, data from potential outlier site (06GH) included. Descending order by proportion of "Yes" responses by participants to prompt "Do you have ALL the spare parts needed for this device?" in the final equipment audit.

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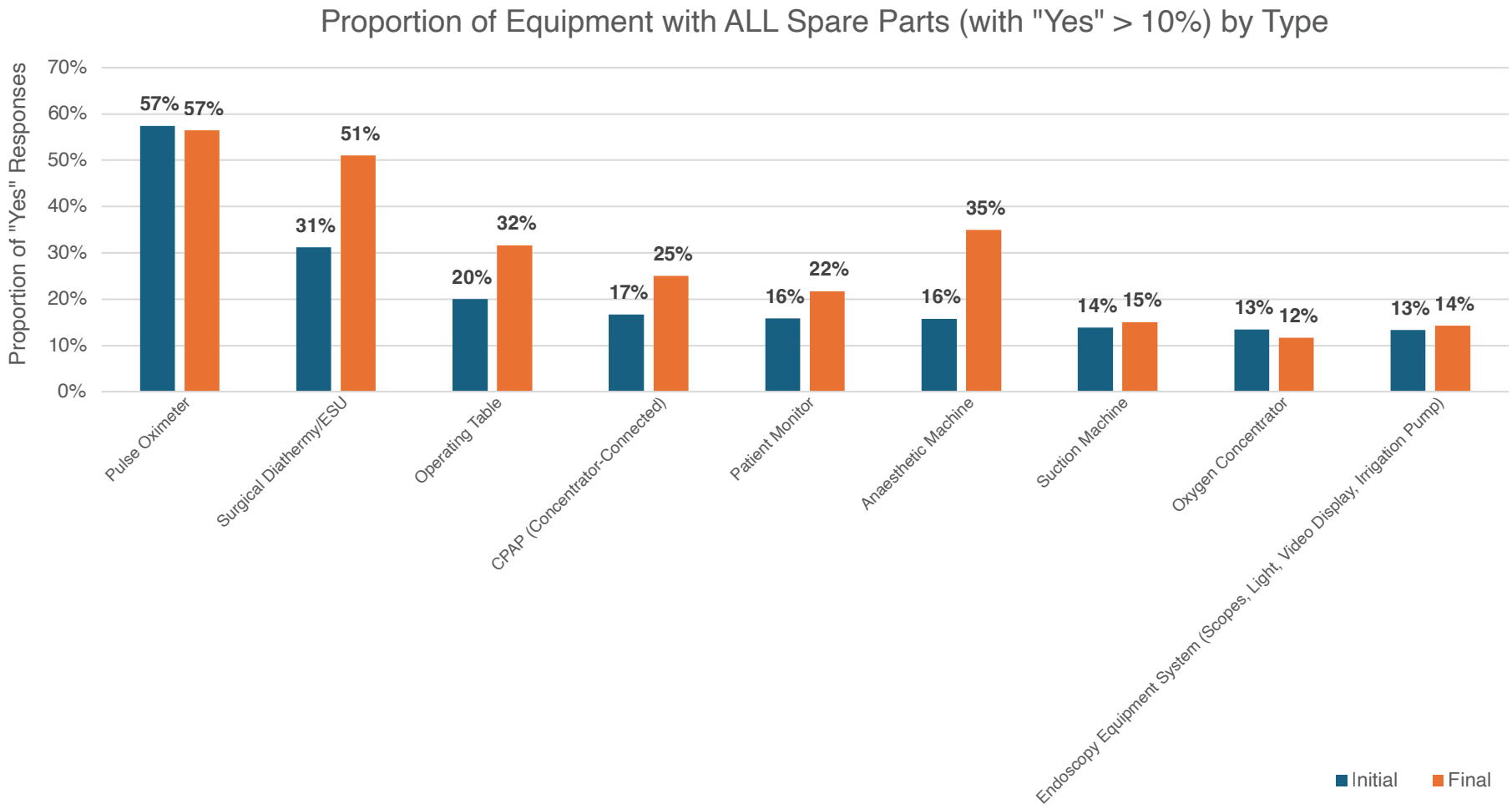


Figure 60. Proportion of equipment with ALL spare parts needed for the device, matching entries meeting set criteria (see **Data Exclusions and Comments**) for both the initial and final equipment audit, data from potential outlier site (06GH) included. Descending order by proportion of "Yes" responses by participants during initial equipment audit to prompt "Do you have ALL the spare parts needed for this device?", where "Yes" proportion was >10% for both initial and final equipment audit.

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One other initially significant change from the data was whether or not participants reported having all the necessary consumables for their equipment, **Figure 61**. The proportion of "Yes" responses fell sharply from 72% in the initial equipment audit to 53% in the final equipment audit. This resulted in a corresponding rise in "No" responses, up from 24% to 45% respectively.

However, the picture changed significantly with the removal of the data from site 06GH. While there was still a change in the availability of consumables (and in the same direction as before), the swing between the "Yes" and "No" responses decreased from about 20% to close to 5%, **Figure 62**. For completeness, the proportion of "Yes" responses fell from 59% to 54% between the two equipment audits, with the corresponding increase in "No" responses from 36% to 43%.

In either case, it was encouraging to see participants became more confident in their assessments, with the proportion of "Don't know" responses more than halving between the initial and final equipment audit (from 3.4% initially to 1.4% in the final equipment audit – a 58% reduction).

As 06GH did not record any "Don't know" responses, the reduction of 58% was identical regardless of whether or not this data was included. For reference, excluding the 06GH data yields a slightly increased share of "Don't know" responses, at 5.3% in the initial equipment audit, and 2.2% in the final equipment audit.

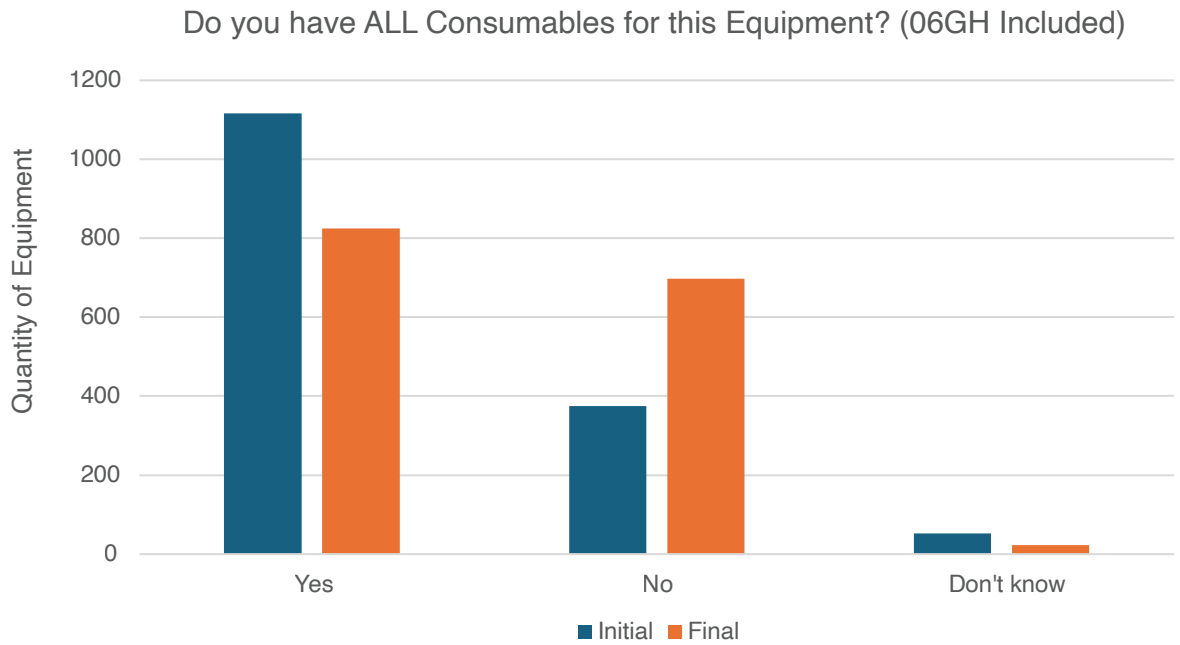


Figure 61. Quantity of equipment by response to the prompt "Do you have ALL the consumables needed for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1544 in both the initial and final equipment audit).

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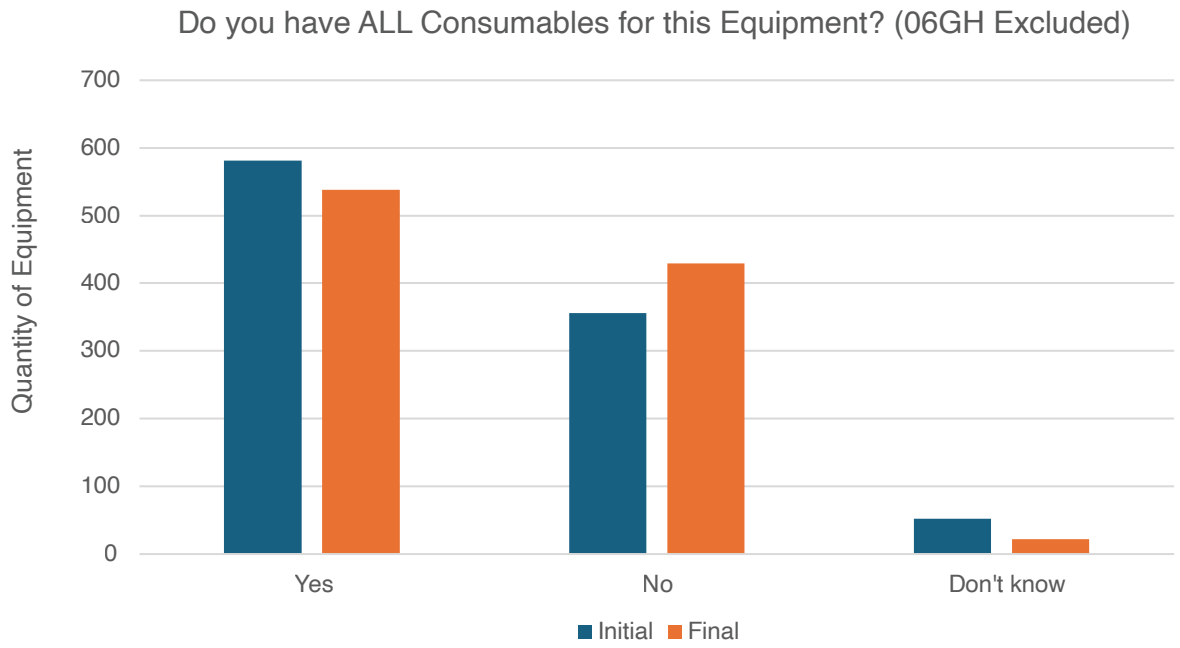


Figure 62. Quantity of equipment by response to the prompt "Do you have ALL the consumables needed for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=989 in both the initial and final equipment audit).

The pattern when looking at the availability of accessories for the equipment was more mixed, depending on how the data is broken down, and whether or not the data from site 06GH was included.

A very similar trend to the availability of consumables was observed when considering the prevalence of accessories for equipment in general terms, **Figure 63**. This pattern was manifest regardless of the inclusion or exclusion of data from site 06GH.

Again, there was a significant reduction in the proportion of "Yes" responses by participants between the initial and final equipment audit (from 57% to 49%), and a corresponding increase in "No" responses (from 39% to 51%).

As before, the reduction in "Don't know" responses was extreme, with an 83% reduction seen between the initial equipment audit (4.4%) and final equipment audit (0.7%).

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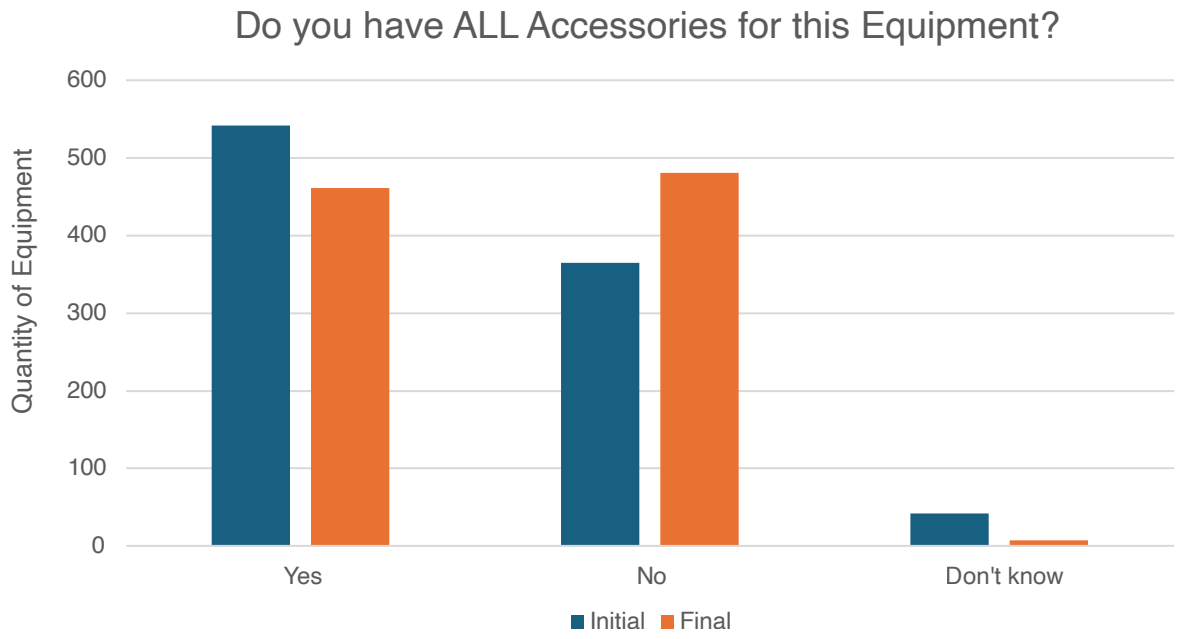


Figure 63. Quantity of equipment by response to the prompt "Do you have ALL the accessories needed for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=949 in both the initial and final equipment audit).

The differences arose on certain items of equipment when participants were asked to state if they had all relevant accessories in a specific patient size: adult, child, and neonate. For these breakdowns a more complex picture was observed, and the inclusion or exclusion the data from site 06GH dramatically changed the observed outcomes.

When the data from site 06GH was included, the proportion of "Yes" responses fell when considering adult accessories availability, **Figure 64**, but rose in terms of children and neonate accessories, **Figure 65** and **Figure 66**. The inverse pattern is shown when considering "No" responses, with the "Don't know" responses remaining consistently low (under 2.8% across all parameters for either equipment audit) and relatively flat.

However, these trends are almost exclusively down to the data from site 06GH. With this data removed, these trends disappear, with only a 2.3% change (at the very most) in either the "Yes" or "No" responses between the initial and final equipment audit for accessories for any sub-category of patient size, **Figure 67, Figure 68**, and **Figure 69**.

The relative availability of each type of accessory was interesting, with (as might be expected) adult sized accessories being the most prevalent (at about 68%), followed by child sized accessories (around 50%), and with neonate sized accessory availability falling to approximately 45%. These figures were relatively static between equipment audits, hence only a single figure was quoted for each parameter.

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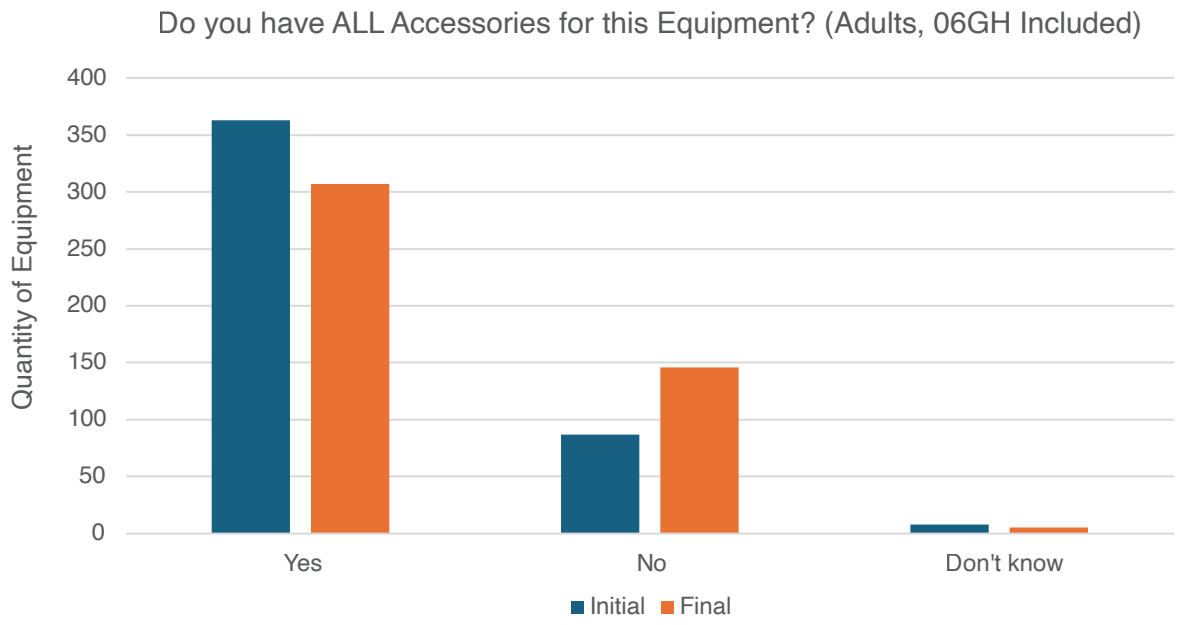


Figure 64. Quantity of equipment by response to the prompt "Do you have ALL the accessories for ADULTS for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=458 in both the initial and final equipment audit).

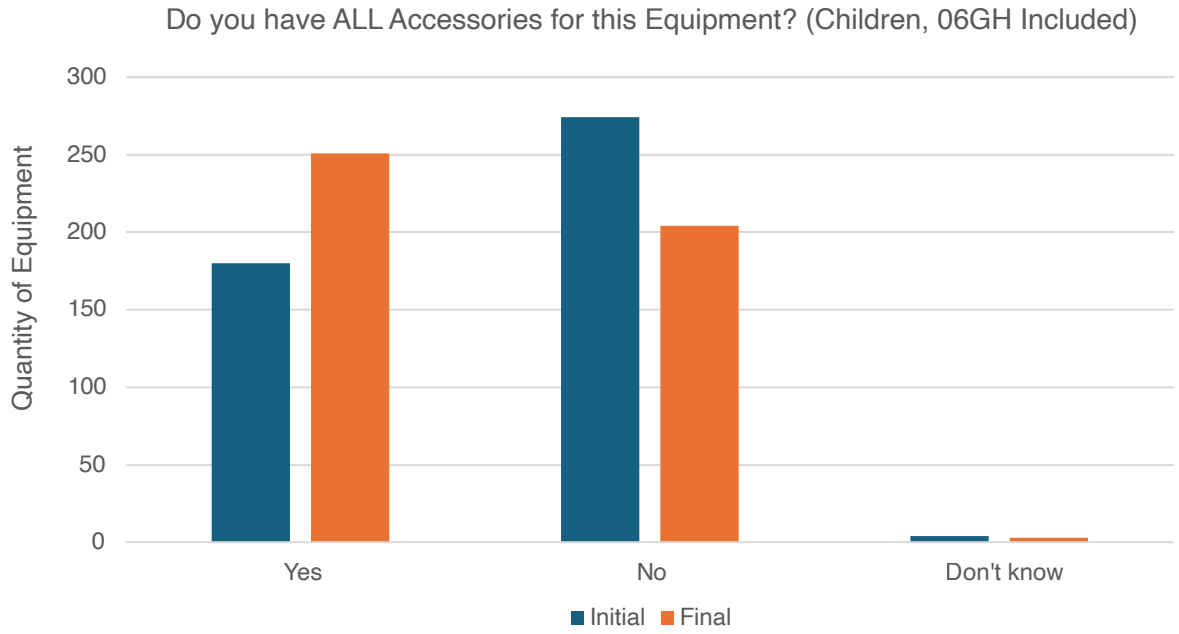


Figure 65. Quantity of equipment by response to the prompt "Do you have ALL the accessories for CHILDREN for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=458 in both the initial and final equipment audit).

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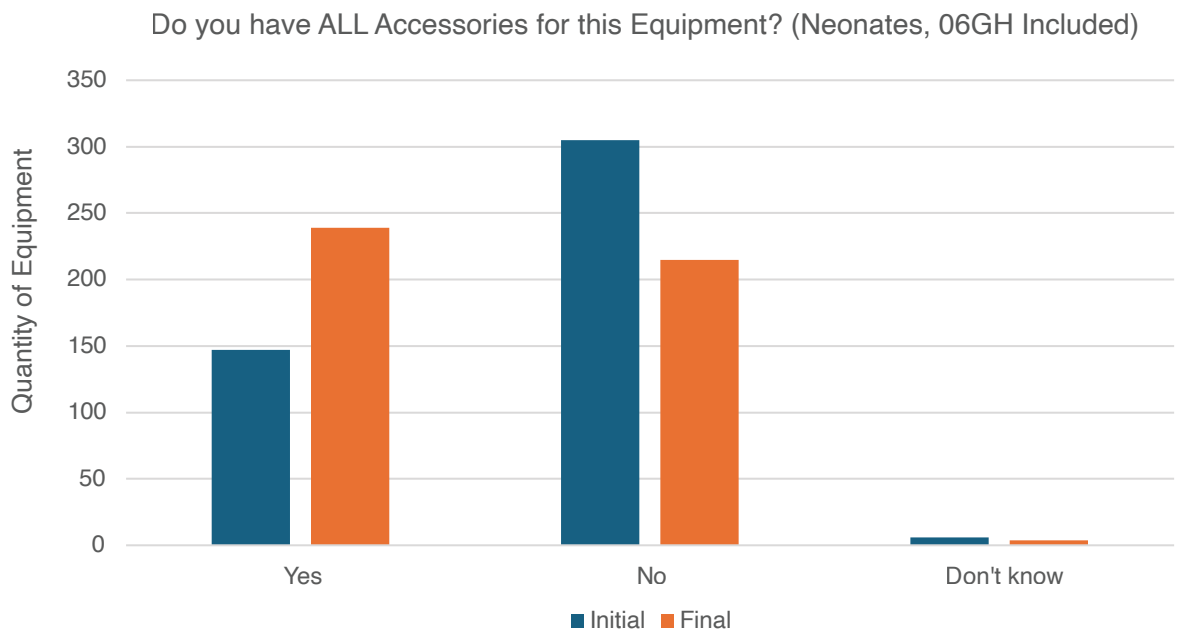


Figure 66. Quantity of equipment by response to the prompt "Do you have ALL the accessories for NEONATES for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=458 in both the initial and final equipment audit).

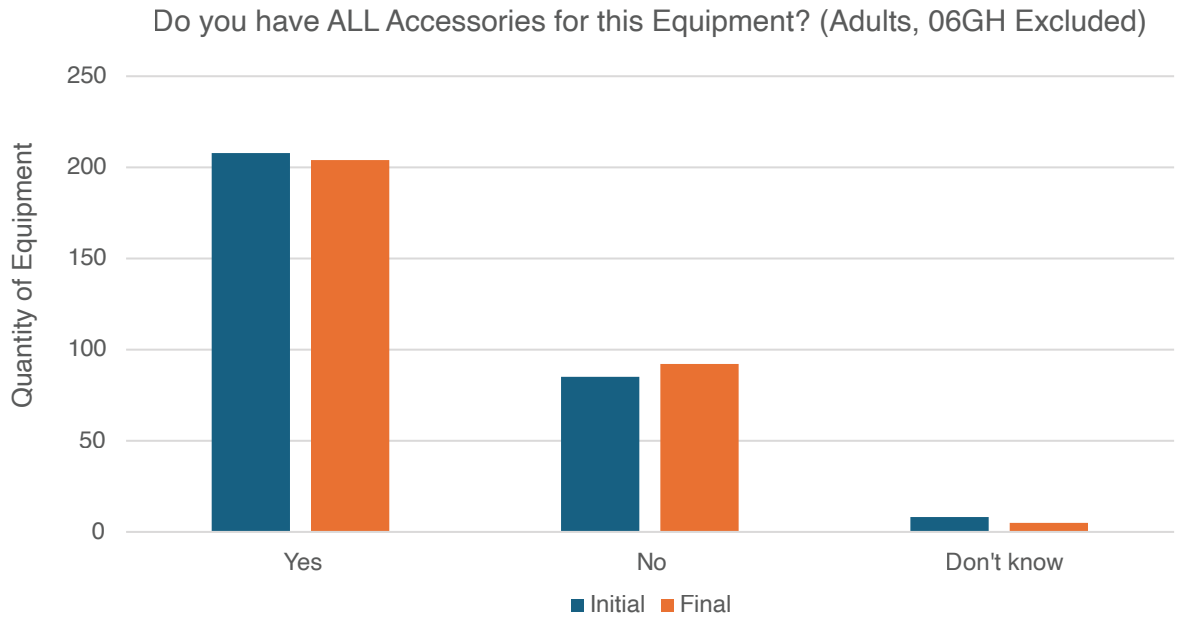


Figure 67. Quantity of equipment by response to the prompt "Do you have ALL the accessories for ADULTS for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=301 in both the initial and final equipment audit).

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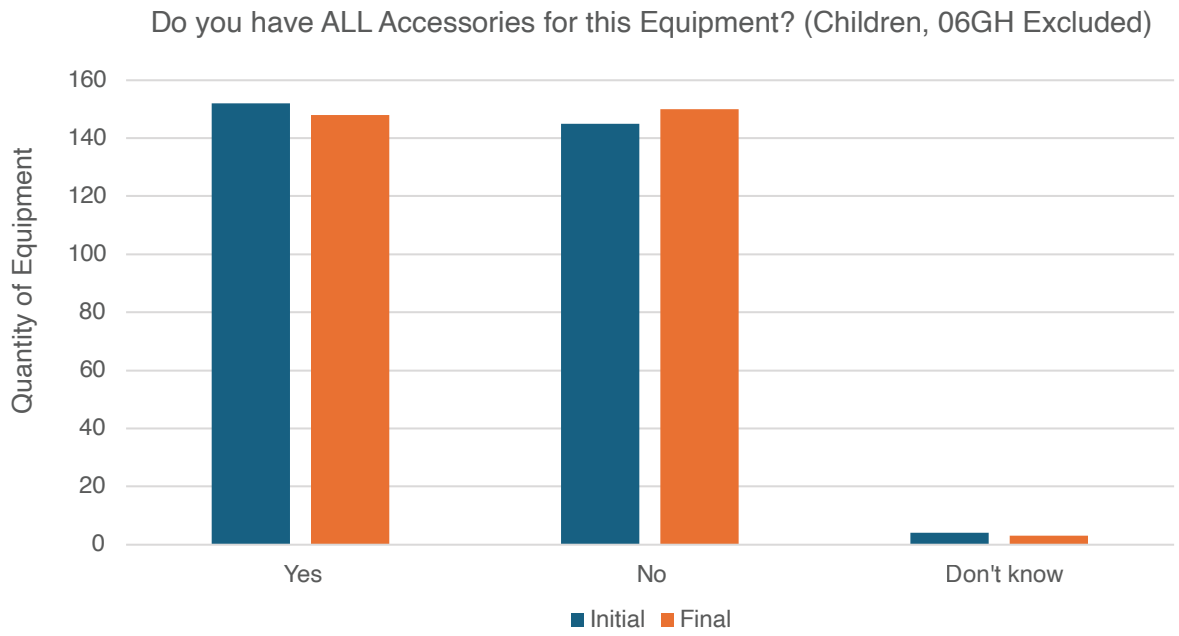


Figure 68. Quantity of equipment by response to the prompt "Do you have ALL the accessories for CHILDREN for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=301 in both the initial and final equipment audit).

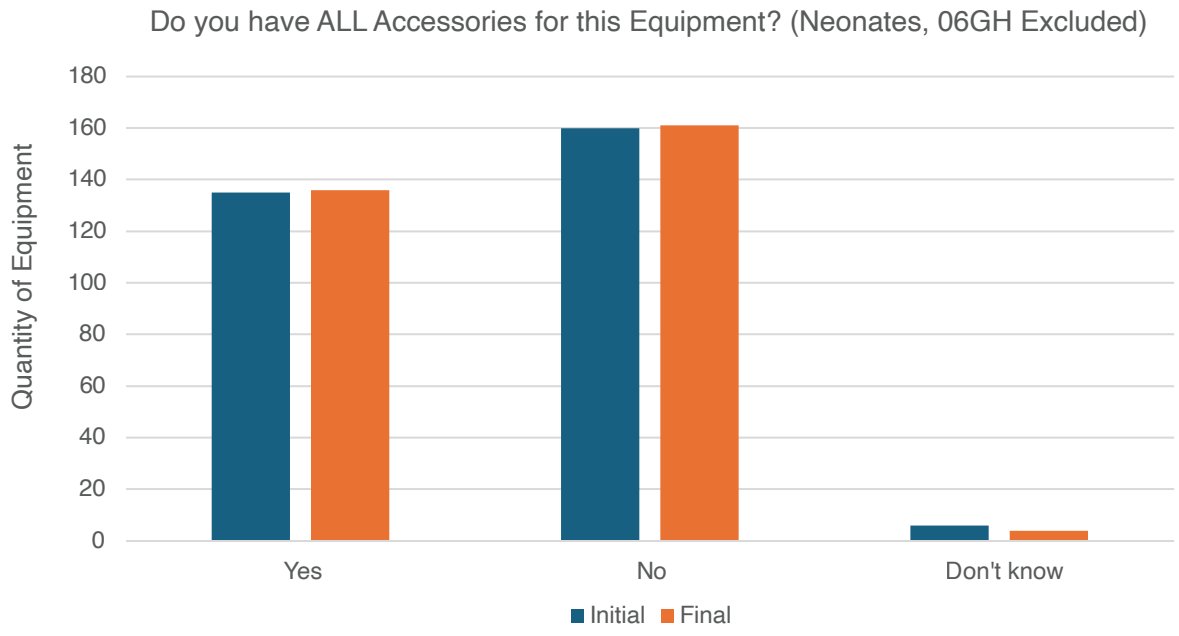


Figure 69. Quantity of equipment by response to the prompt "Do you have ALL the accessories for NEONATES for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=301 in both the initial and final equipment audit).

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One other factor which was considered to be a possible barrier to equipment repair and maintenance was the accessibility of repair manuals to the participants. This was investigated as part of the project, **Figure 70**.

An interesting element was the prevalence of physical (hard copy) repair manuals. This made up 44% of responses in the initial equipment audit, 39% in the final equipment audit. Overall, access to repair manuals was reasonable, with approximately 60% of equipment having a corresponding repair manual (either physical, digital, or online), **Figure 71** and **Figure 72**.

Access to a digital repair manual for equipment reportedly fell over the course of the project, from 9% in the initial equipment audit to 3% in the final equipment audit, while access to an online repair manual rose from 6% to 19% respectively.

Given participants were only able to select a single option for this, it is likely that either a reclassification occurred between "digital" and "online" manuals, or perhaps multiple methods to access equipment manuals were present (which accounted for a differing response between the two equipment audits). This is supported by the consistent overall "Yes" responses (total, of any kind) remaining at about 60%, with the proportion of "No" responses holding steady at around 35% (across both equipment audits).

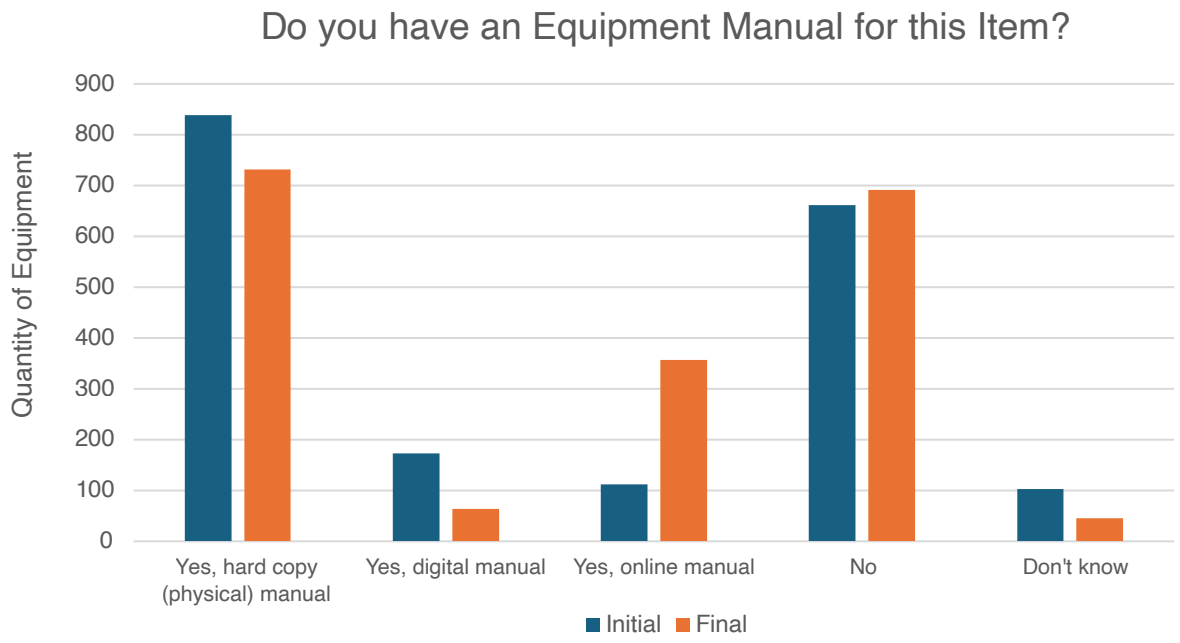


Figure 70. Quantity of equipment by response to the prompt "Do you have an equipment manual for this item?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1888 in both the initial and final equipment audit).

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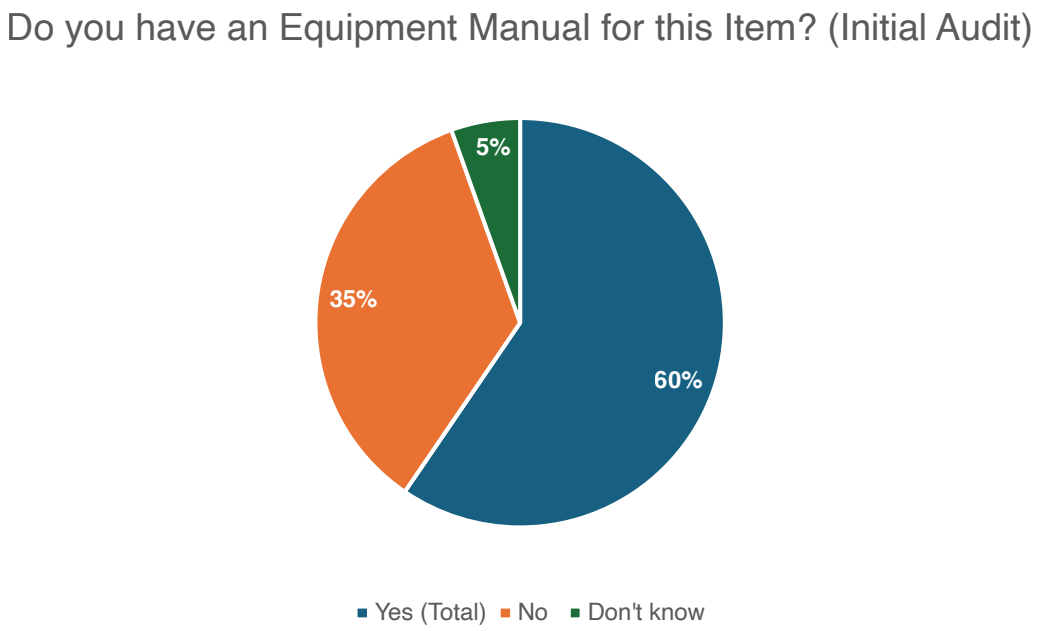


Figure 71. Proportion of equipment by response to the prompt "Do you have an equipment manual for this item?" in the initial equipment audit, with all "Yes" responses combined. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1888)

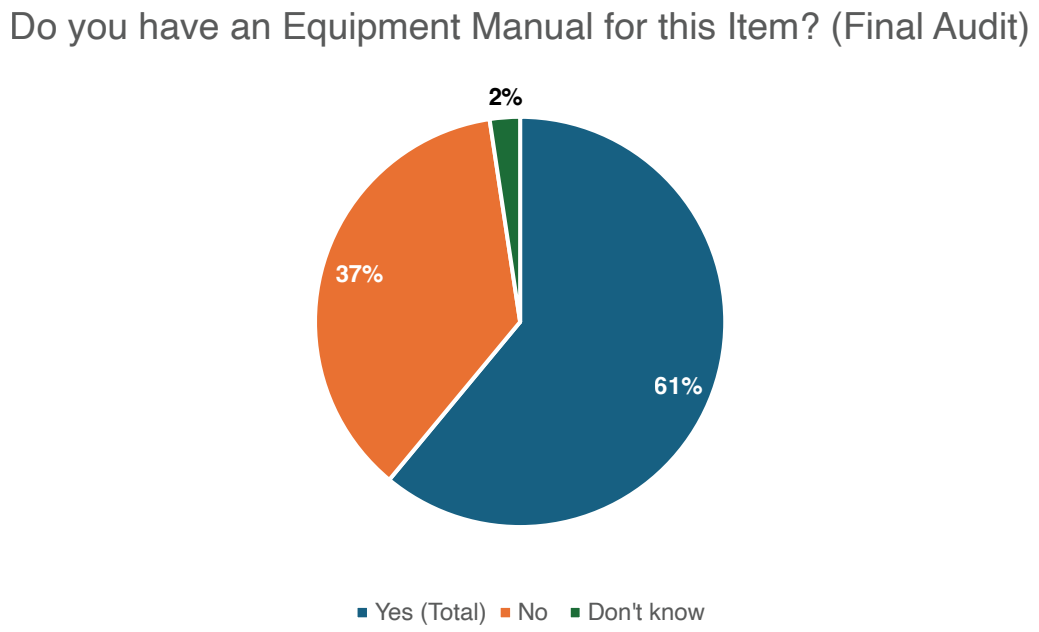


Figure 72. Proportion of equipment by response to the prompt "Do you have an equipment manual for this item?" in the final equipment audit, with all "Yes" responses combined. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=1888).

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One final notable trend observed when looking across all the topline summary graphs was a clear reduction in the quantity and proportion of “Don’t know” responses from participants when completing submissions for the final equipment audit compared to the initial equipment audit.

This reflects the increased confidence of the participants after completing the course, not only improving their ability to accurately access equipment, but also their self-belief as biomedical engineers.

In order to provide a graphical representation of this reduction, **Figure 63** has been rescaled showing only the “Don’t know” responses, **Figure 73**. This represents a reduction of 83.3% between the initial and final equipment audit. A modified vertical axis shows the same scaling but as the proportion of overall responses in the respective equipment audit, **Figure 74**. This pattern is consistently repeated across almost all measured parameters in the equipment audits, regardless of whether or not data from site 06GH is included or excluded, **Table 11**, and **Table 12**. These were then represented graphically, **Figure 75** and **Figure 76**.

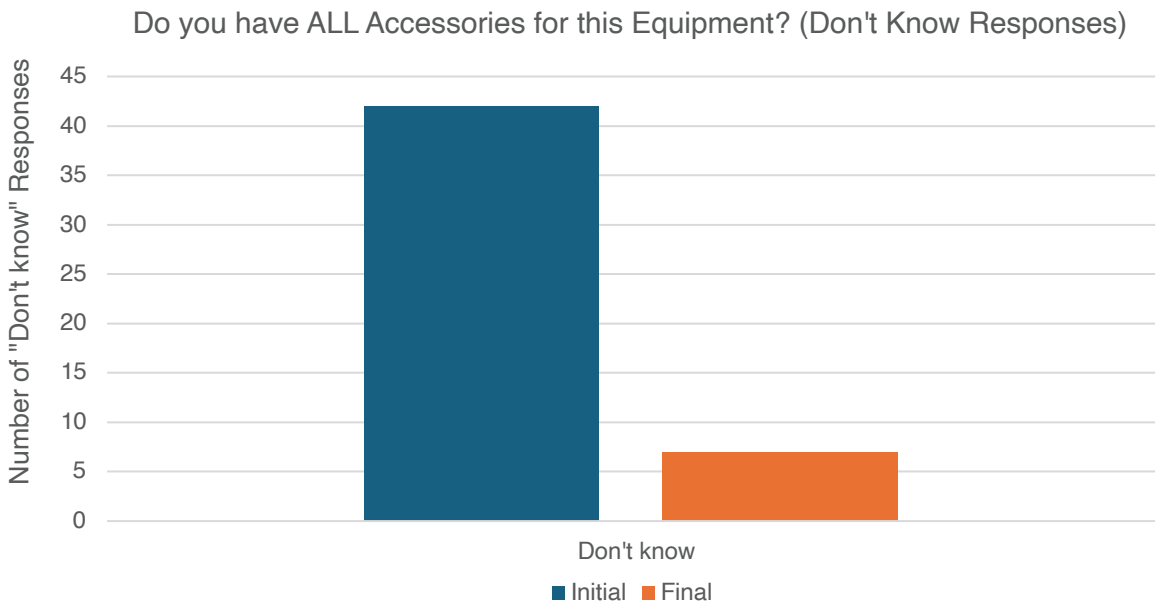


Figure 73. Number of “Don’t know” responses to the prompt “Do you have ALL the accessories needed for this device?” in both the initial and final equipment audit, only “Don’t know” responses shown. Data excluded as set out in the **Data Exclusions and Comments** section, no data collected for this question by potential outlier site (06GH), (n=949 total responses in both the initial and final equipment audit, only “Don’t know” responses shown).

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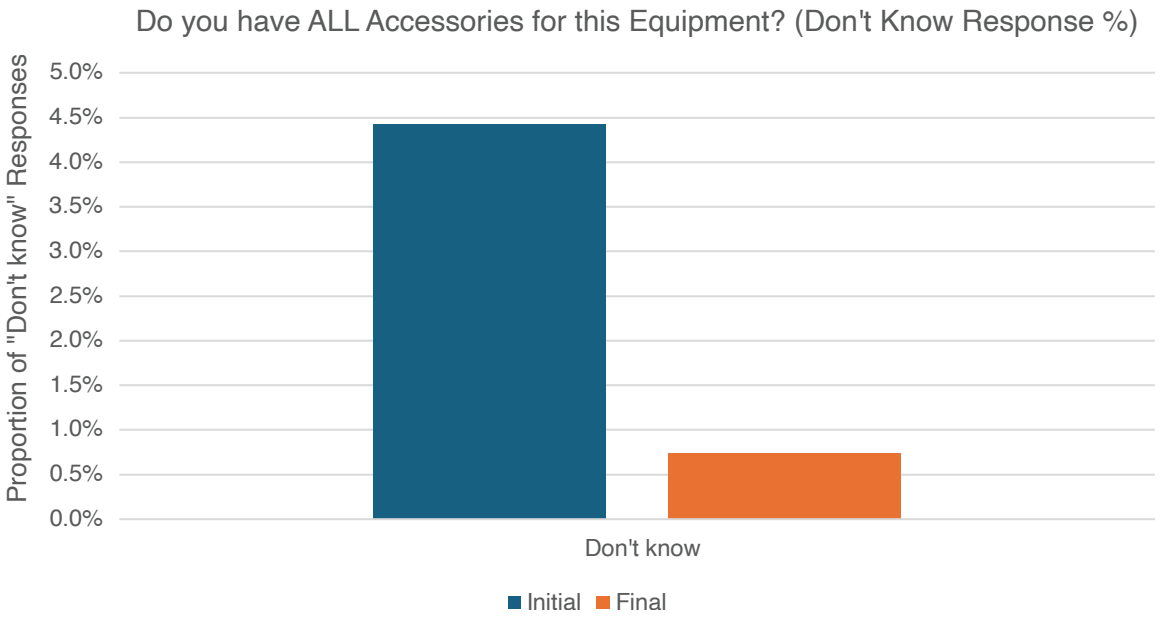


Figure 74. Proportion of "Don't know" responses (out of total responses on a per audit basis) to the prompt "Do you have ALL the accessories needed for this device?" in both the initial and final equipment audit, only "Don't know" responses shown. Data excluded as set out in the **Data Exclusions and Comments** section, no data collected for this question by potential outlier site (06GH), (n=949 total responses in both the initial and final equipment audit, only "Don't know" responses shown).

Table 11. Proportion of "Don't know" responses (on a per figure basis) from the overall number of responses within each equipment audit, as well as the corresponding proportionate change. Data from potential outlier site (06GH) included. Refer to referenced figures for sample size and participant prompt.

Figure	Initial % "Don't know"	Final % "Don't know"	Change in "Don't know"
Figure 42	4.8%	1.8%	-62.2%
Figure 44	2.4%	0.4%	-84.8%
Figure 45	2.4%	0.4%	-84.4%
Figure 52	2.5%	0.4%	-83.0%
Figure 53	1.4%	0.1%	-91.7%
Figure 54	5.0%	1.9%	-61.1%
Figure 55	2.7%	0.6%	-79.6%
Figure 61	3.4%	1.4%	-57.7%
Figure 63	4.4%	0.7%	-83.3%
Figure 64	1.7%	1.1%	-37.5%
Figure 65	0.9%	0.7%	-25.0%
Figure 66	1.3%	0.9%	-33.3%
Figure 70	5.5%	2.4%	-56.3%

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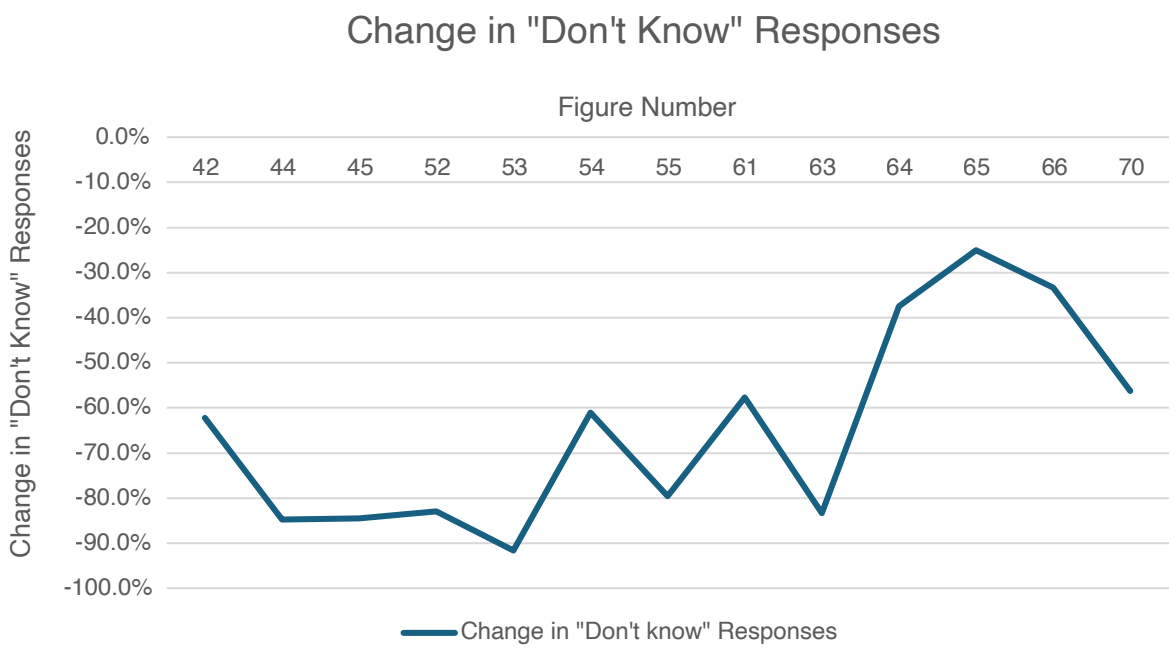


Figure 75. Proportionate change in "Don't know" responses (on a per figure basis) between the initial and final equipment audit. Data from potential outlier site (06GH) included. Refer to referenced figures for sample size and participant prompt.

Table 12. Proportion of "Don't know" responses (on a per figure basis) from the overall number of responses within each equipment audit, and the corresponding proportionate change, data from potential outlier site (06GH) excluded. Refer to referenced figures for sample size and participant prompt. Figure number refers to figure included in the report, or to the data from the corresponding figure but with data from site (06GH) excluded, where this figure has not been included in the report.

Figure	Initial % "Don't know"	Final % "Don't know"	Change in "Don't know"
Figure 43	7.0%	2.7%	-62.2%
Figure 44	3.6%	0.5%	-84.8%
Figure 48	3.6%	0.6%	-84.4%
Figure 52	3.7%	0.6%	-83.0%
Figure 53	2.1%	0.2%	-91.7%
Figure 54	6.6%	2.6%	-61.1%
Figure 55	4.1%	0.6%	-85.7%
Figure 62	5.3%	2.2%	-57.7%
Figure 63	5.4%	0.9%	-83.3%
Figure 67	2.7%	1.7%	-37.5%
Figure 68	1.3%	1.0%	-25.0%
Figure 69	2.0%	1.3%	-33.3%
Figure 70	8.1%	3.0%	-63.1%

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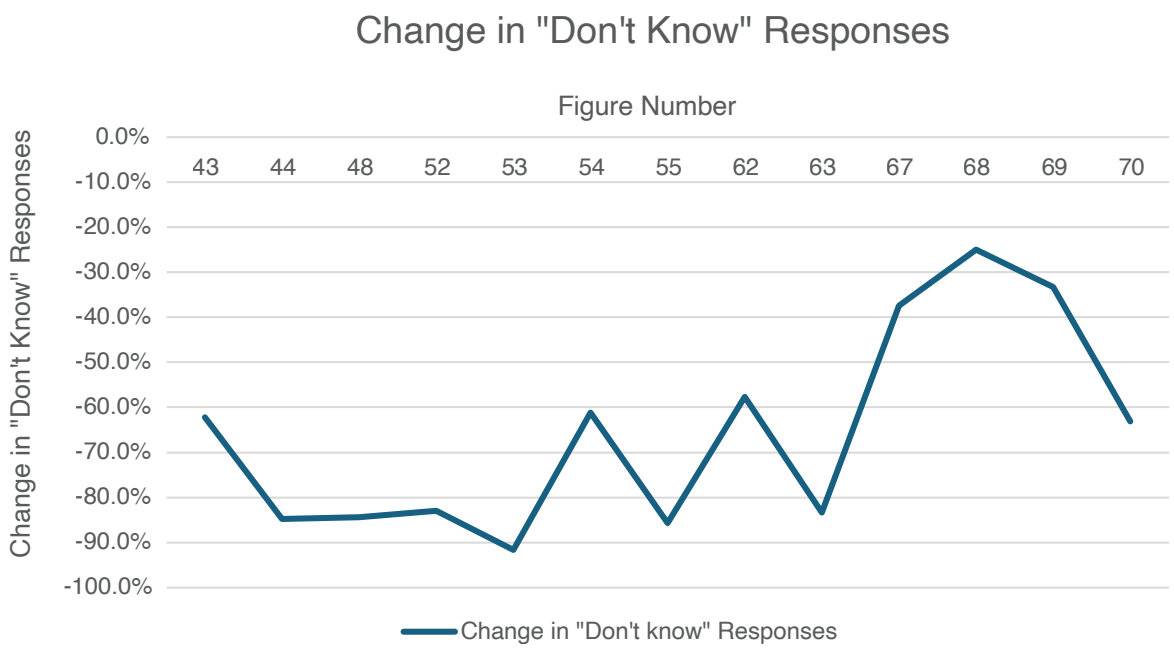


Figure 76. Proportionate change in "Don't know" responses (on a per figure basis) between the initial and final equipment audit. Data from potential outlier site (06GH) excluded. Refer to referenced figures for sample size and participant prompt. Figure number refers to figure included in the report, or to the data from the corresponding figure but with data from site (06GH) excluded, where this figure has not been included in the report.

"One practical lesson I have already applied is the structured approach to equipment maintenance taught in the Health and Safety unit. I now place greater emphasis on obtaining the equipment history, carrying out a thorough visual inspection, performing electrical safety tests before functional tests, and following a logical troubleshooting sequence. This approach has improved the safety, efficiency, and consistency of my maintenance work, and it has also influenced how I plan to organize my biomedical engineering workshop."

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Specific Equipment Findings

Anaesthetic Machines

One positive result which was reflected in a change in response between the equipment audits was that participants appeared to be more aware of the need for soda lime in their closed anaesthetic machines, or more able to prioritise its provision, **Figure 77**.

This is evidenced by an increase in the proportion of anaesthetic machines with soda lime in the final equipment audit (67%), when compared to the initial equipment audit (75%), **Figure 78** and **Figure 79**. However, it should be noted that the sample size is fairly small, and the absolute change is modest.

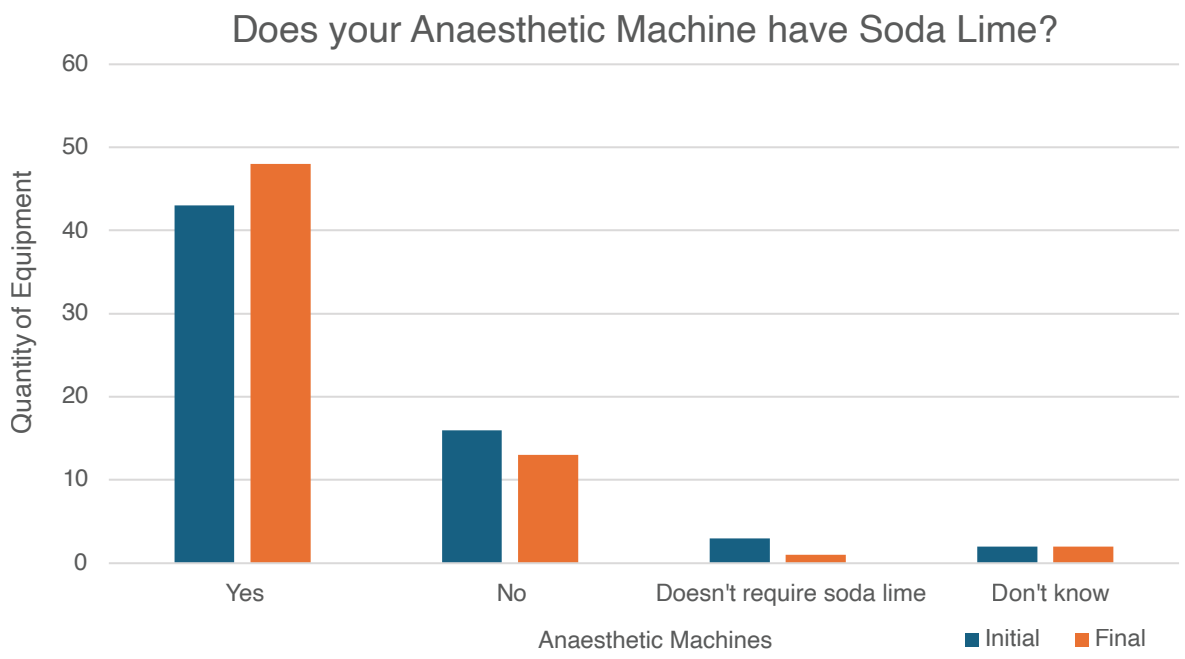


Figure 77. Quantity of anaesthetic machines by response to the prompt "Does it have soda lime?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=64 in both the initial and final equipment audit).

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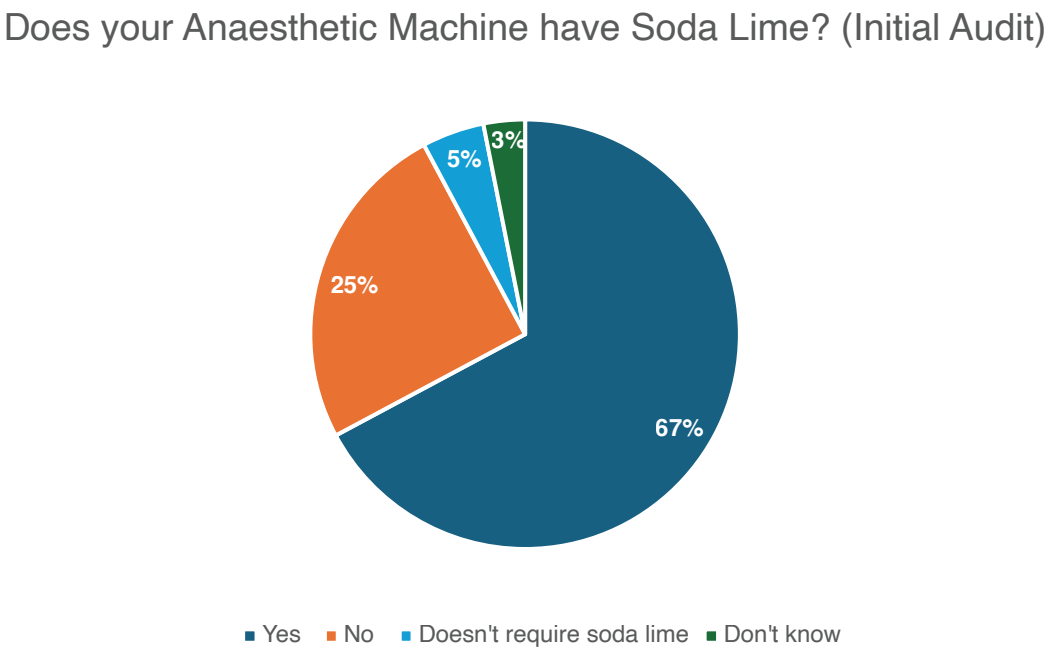


Figure 78. Proportion of anaesthetic machines by response to the prompt "Does it have soda lime?" in the initial equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=64).

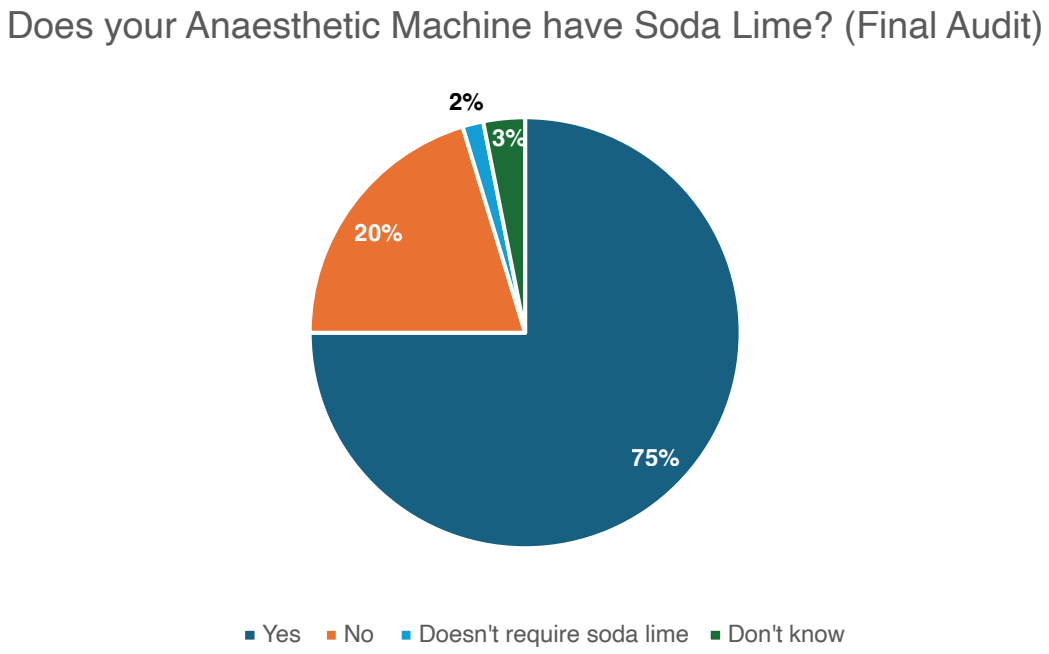


Figure 79. Proportion of anaesthetic machines by response to the prompt "Does it have soda lime?" in the final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=64).

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Infusion Pumps/Syringe Drivers

Upon initial analysis, when data from Site 06GH was included, it appeared that there was a dramatic change in the reported safety of infusion pump/syringe drivers between the two equipment audits, **Figure 80**. However, once the data from site 06GH was removed, this change disappeared, **Figure 81**.

As mentioned previously, it appears that the participants at site 06GH perhaps misunderstood the question, i.e., by reporting "Yes" they may have been attempting to signal that "Yes, our equipment is safe", whereas the question instead asked if they had any safety concerns about the equipment. This caused the opposite picture to be signalled in the data.

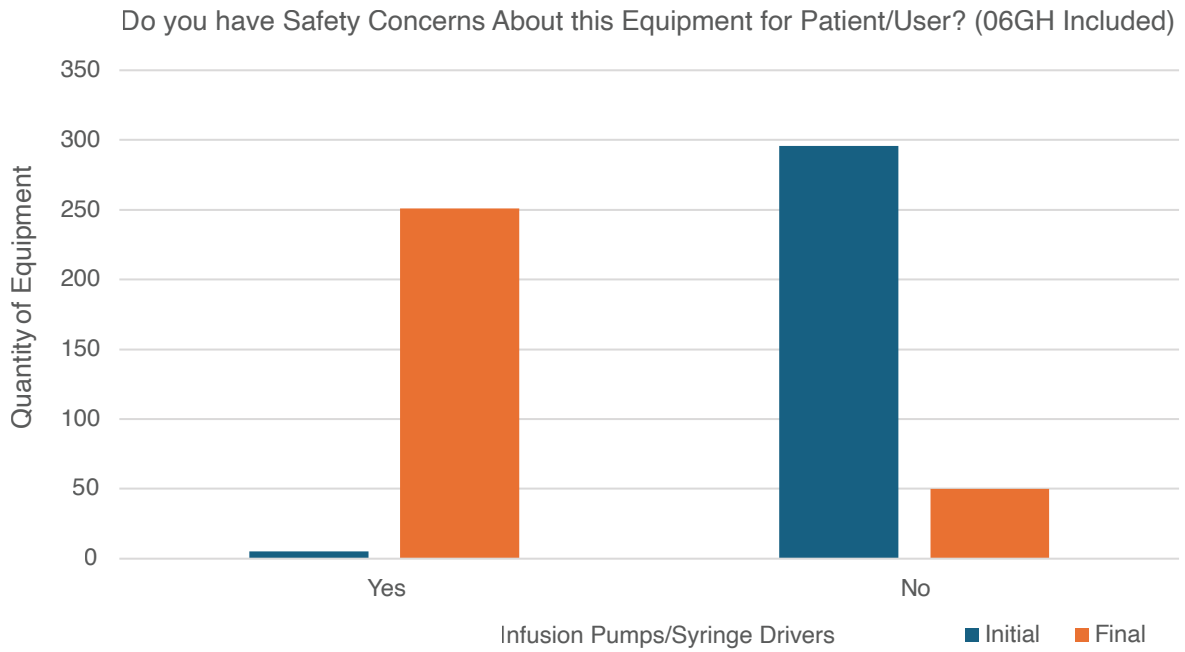


Figure 80. Quantity of infusion pumps/syringe drivers by response to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=301 in both the initial and final equipment audit).

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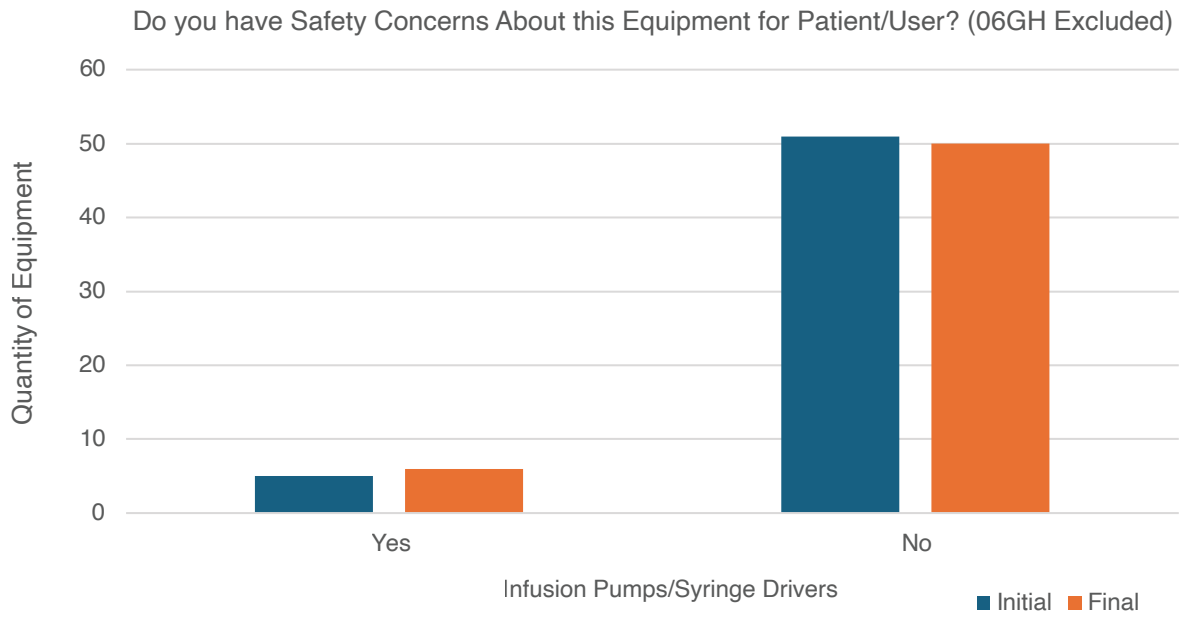


Figure 81. Quantity of infusion pumps/syringe drivers by response to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=56 in both the initial and final equipment audit).

> *"[The] health and safety [unit,] this will help me to work safe and maintain safety of others the knowledge obtained will help to reduce accidents."*

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Oxygen Cylinders

One specific health and safety aspect which was covered by the biomedical engineering course was the importance of securing or chaining up oxygen cylinders. Encouragingly, an improvement was reflected in the data when comparing between the two equipment audits, with a greater number of oxygen cylinders being reported as secured in the final equipment audit compared to the initial equipment audit, **Figure 82**.

The proportion of oxygen cylinders reported as being secured rose from 49% in the initial equipment audit, **Figure 83**, to 61% in the final equipment audit, **Figure 84**. The data was fairly consistent regardless of the inclusions of site 06GH.

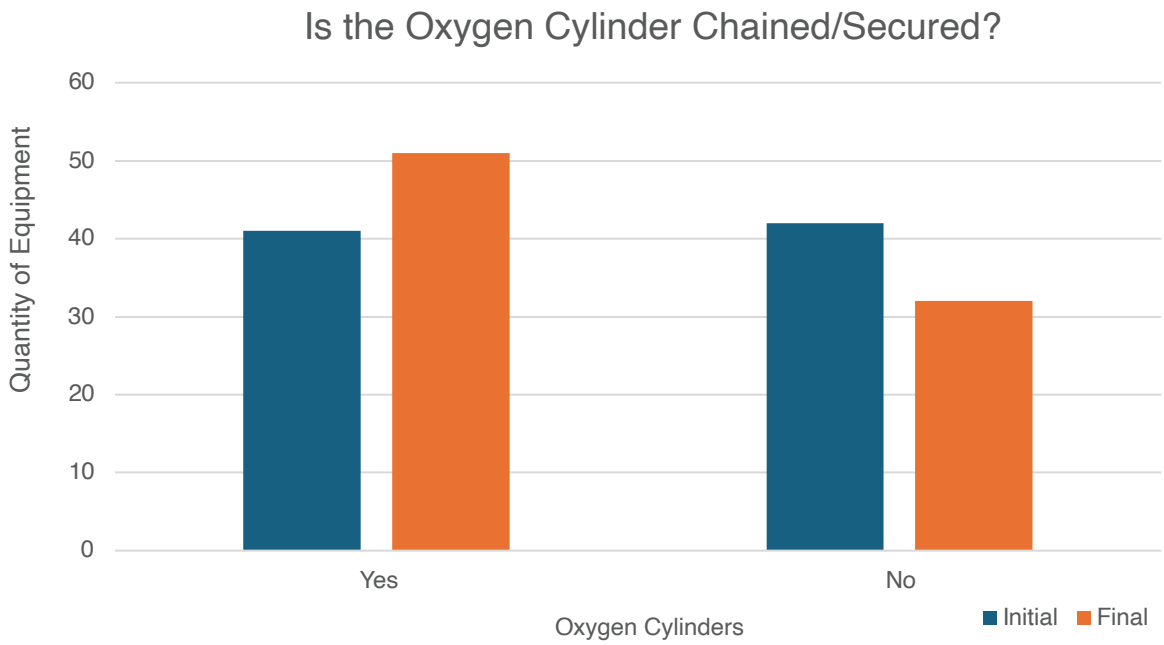


Figure 82. Quantity of oxygen cylinders by response to the prompt "Is the oxygen cylinder chained/secured?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=83 in both the initial and final equipment audit).

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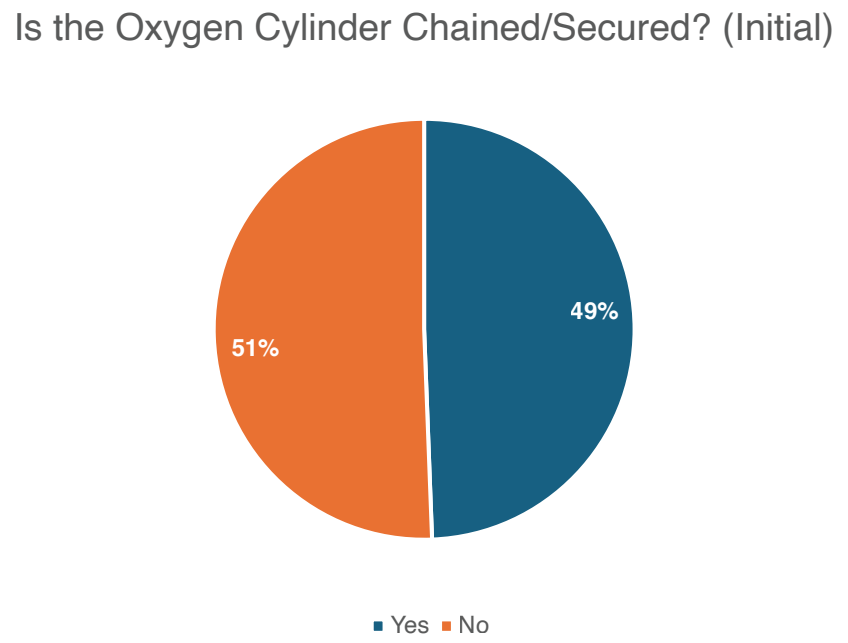


Figure 83. Proportion of oxygen cylinders by response to the prompt "Is the oxygen cylinder chained/secured?" in the initial equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=83).

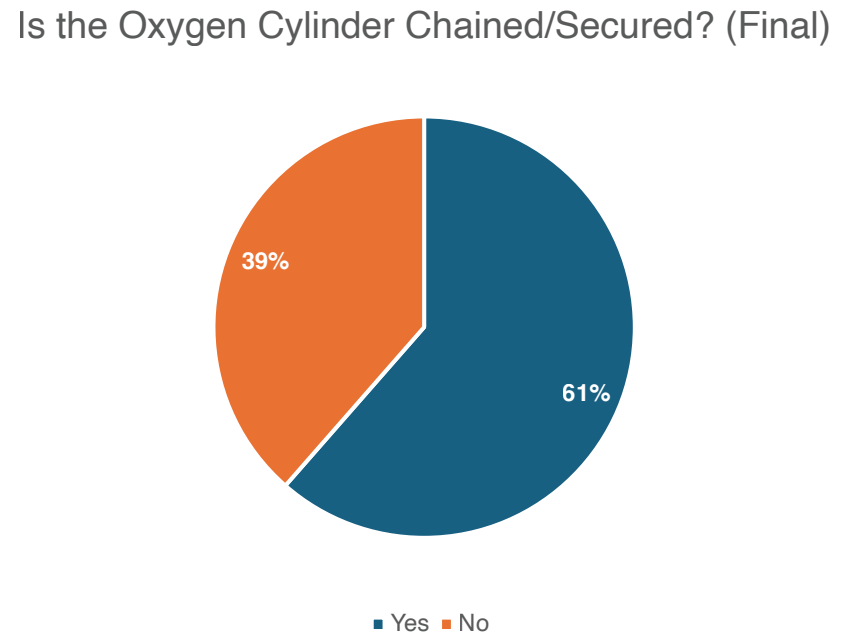


Figure 84. Proportion of oxygen cylinders by response to the prompt "Is the oxygen cylinder chained/secured?" in the final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=83).

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Patient Monitors

A similar pattern as for infusion pumps/syringe drivers was seen for patient monitors, whereby the removal of data from site 06GH dramatically altered the findings of the study. As mentioned previously, this appeared to be caused by the participants at site 06GH misinterpreting the question and believing that a "Yes" response represented equipment that was safe, rather than being equipment where there was a safety concern.

The initial findings showed a clear increase in safety concerns for the patient monitors surveyed when data from site 06GH was included, **Figure 85**. This trend was then negated once site 06GH was removed, **Figure 86**.

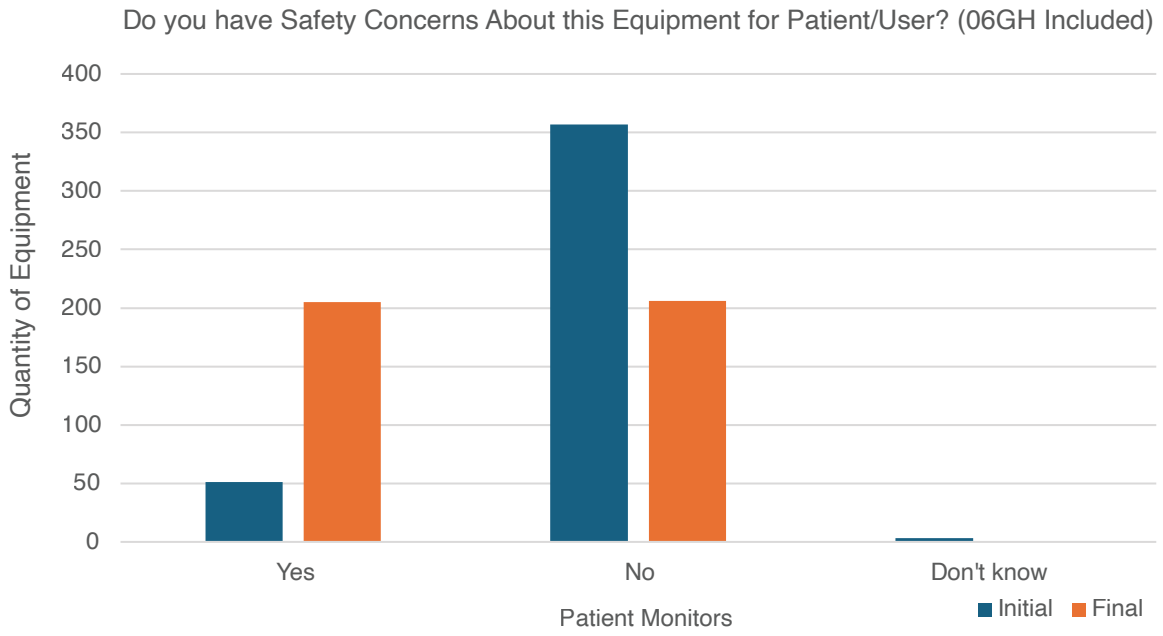


Figure 85. Quantity of patient monitors by response to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=411 in both the initial and final equipment audit).

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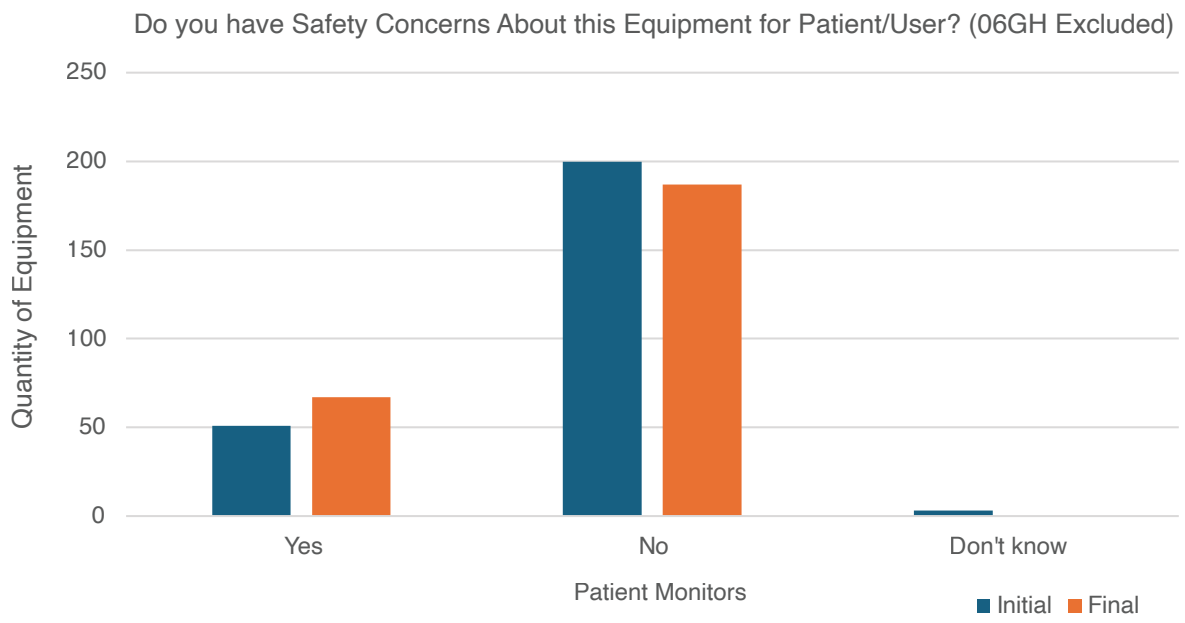


Figure 86. Quantity of patient monitors by response to the prompt "Do you have any concerns about the safety of this equipment, for either the patient or user?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=254 in both the initial and final equipment audit).

A similar pattern was also found when considering the availability of consumables for the patient monitors. When the data from site 06GH is included, there appears to be a significant change between the initial and final equipment audit, **Figure 87**. However, as before, this appears to have been caused primarily by data from site 06GH, which when removed revealed a fairly static picture, **Figure 88**.

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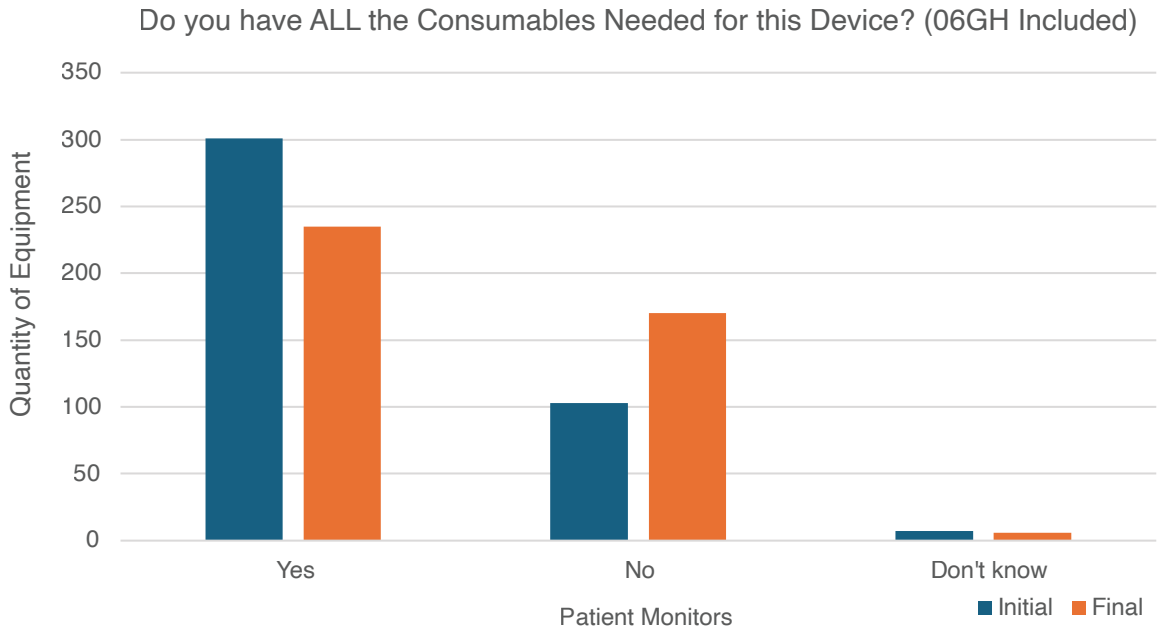


Figure 87. Quantity of patient monitors by response to the prompt "Do you have ALL the consumables needed for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=411 in both the initial and final equipment audit).

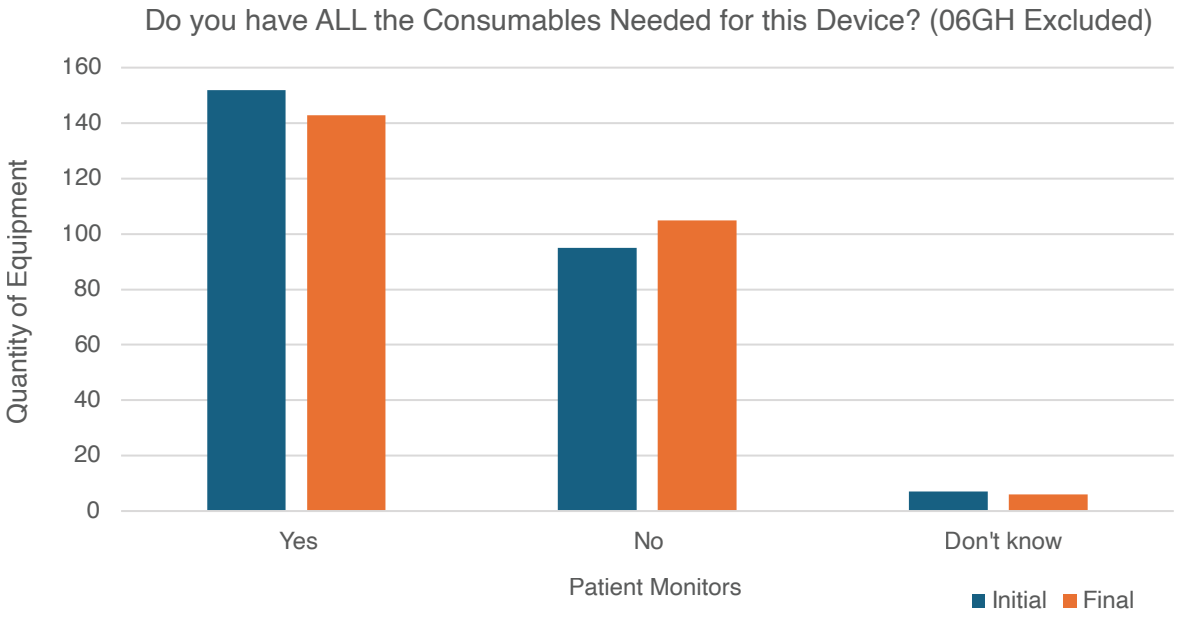


Figure 88. Quantity of patient monitors by response to the prompt "Do you have ALL the consumables needed for this device?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) excluded (n=254 in both the initial and final equipment audit).

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Equipment Battery Backups

One final aspect the equipment audits considered was the prevalence of battery backups across various types of equipment. Such questions were asked for the following equipment:

- Defibrillators (only asked if battery backup was working)
- Operating Lights
- Pulse Oximeters
- Suction Machines
- Ventilators

It was found that pulse oximeters and ventilators had a large proportion of equipment with a battery powered option, with both having around 90% prevalence. Operating lights, suction machines and ventilators rarely had a battery powered option, with each being between about 10-20%, **Figure 89.**

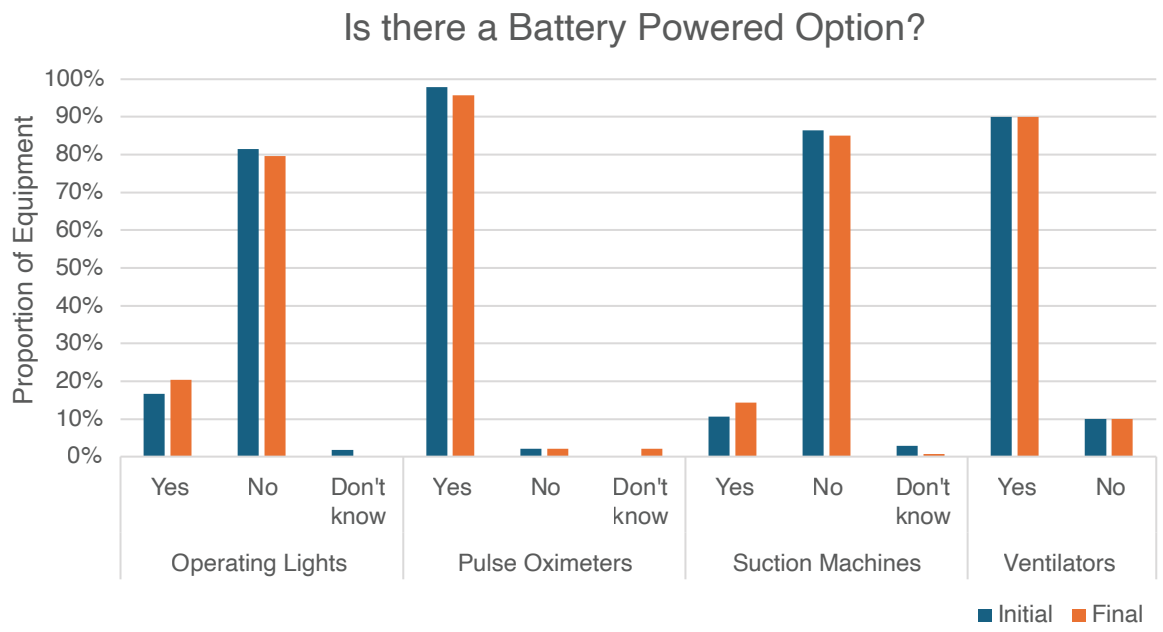


Figure 89. Proportion of equipment by response to the prompt "Is there a battery powered option?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=54 for operating lights in both the initial and final equipment audit, n=47 for pulse oximeters in both the initial and final equipment audit, n=140 for suction machines in both the initial and final equipment audit, and n=80 in both the initial and final equipment audit).

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When considering if the battery powered option worked, the pattern was broadly similar, with pulse oximeters and ventilators having a significant proportion of equipment with working battery backups, while suction machines and operating lights had a fairly limited proportion of working battery backups. As expected, defibrillators also had a high proportion of working battery backups, with the highest figure being recorded in the final equipment audit at 95%, **Figure 90**.

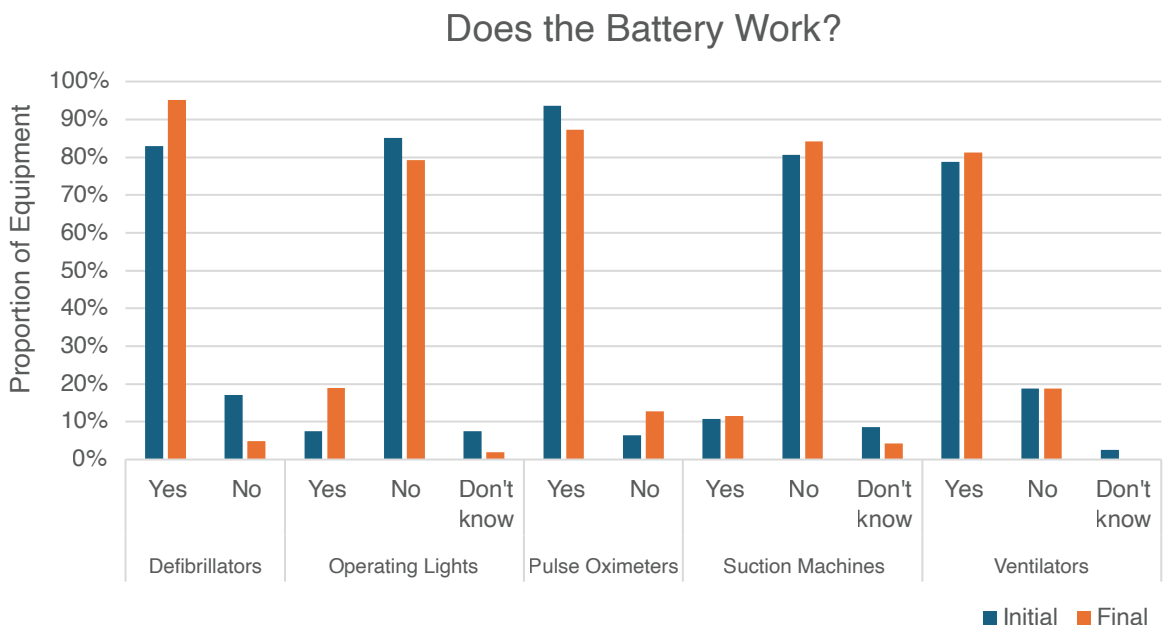


Figure 90. Proportion of equipment by response to the prompt "Does the battery work?" in both the initial and final equipment audit. Data excluded as set out in the **Data Exclusions and Comments** section, data from potential outlier site (06GH) included (n=41 for defibrillators in both the initial and final equipment audit, n=54 for operating lights in the initial equipment audit, n=53 for operating lights in the final equipment audit, n=47 for pulse oximeters in both the initial and final equipment audit, n=140 for suction machines in both the initial and final equipment audit, and n=80 in both the initial and final equipment audit). "Don't know" option shown only where data entries were recorded.

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Participant Course Feedback Survey

This data was expected to differ slightly from that collected during the onboarding and end of project surveys, primarily because each reflected a slightly different cohort of participants. As discussed in the **Data Exclusions and Comments** section, only participants who completed both the onboarding and end of project feedback survey were included in the analysis for that section (**Onboarding and End of Project Survey**). This represented a total of 60 participants.

Conversely, all participants who completed the course also completed the end of course feedback survey, the data from which is detailed in this section (**Participant Course Feedback Survey**). This represented 79 participants. Whilst there is significant overlap between both groups, the cohorts are not identical. For this reason, the responses from both cohorts were not expected to be identical, even though the questions were similarly worded in both the aforementioned sections. Where such relevant comparisons existed, these have been included in this section.

It should also be noted, as highlighted in the **Data Exclusions and Comments** section, that not all participants completed the same version of the course feedback survey. The number of participants included for each figure is clearly shown, and the full course feedback surveys can be found in **Appendix 3** and **Appendix 4**.

The first question of the course feedback survey asked about the education level of the participants, **Figure 91**. This data is approximately comparable to the data in the **Onboarding and End of Project Survey** section, **Figure 3**. Encouragingly for the consistency of the data, these values were found to be fairly similar.

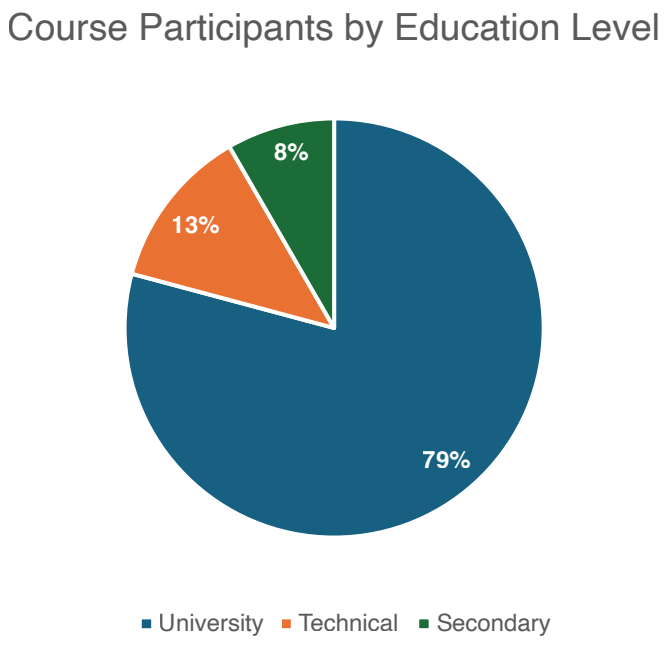


Figure 91. Proportion of participants by response to the prompt "What is your highest level of education?" reported in the updated course feedback survey (**Appendix 4**). Response options were "Secondary", "Technical College (1–2 years)", or "University Degree (3+ years)", (n=48).

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Previously, the prevalence of a university degree was found to be 68%, with 18% of participants holding a technical qualification, and 14% with no higher level education, **Figure 3**. These appear to be broadly in line with the data found from the course feedback survey, where 79% had a university degree, **Figure 91**. Almost all participants, 92%, had some form of higher level education, making this cohort comparatively well-educated. It should be noted that only participants who completed the updated version of the course feedback survey (**Appendix 4**) were asked this question.

As for the current level of education of the participants, their number of years of experience as a biomedical engineer was also fairly consistent between the onboarding and end of project survey, **Figure 2**, and the course feedback survey, **Figure 92**. Again, only participants who completed the updated version of the course feedback survey (**Appendix 4**) were asked this question.

The bulk of the participants had a significant amount of experience as a biomedical engineer, with 57% having between 3 and 10 years of experience, and 95% having at least one year of experience. This high level of experience also supports the fact that the data generated is expected to be both fairly accurate and reliable.

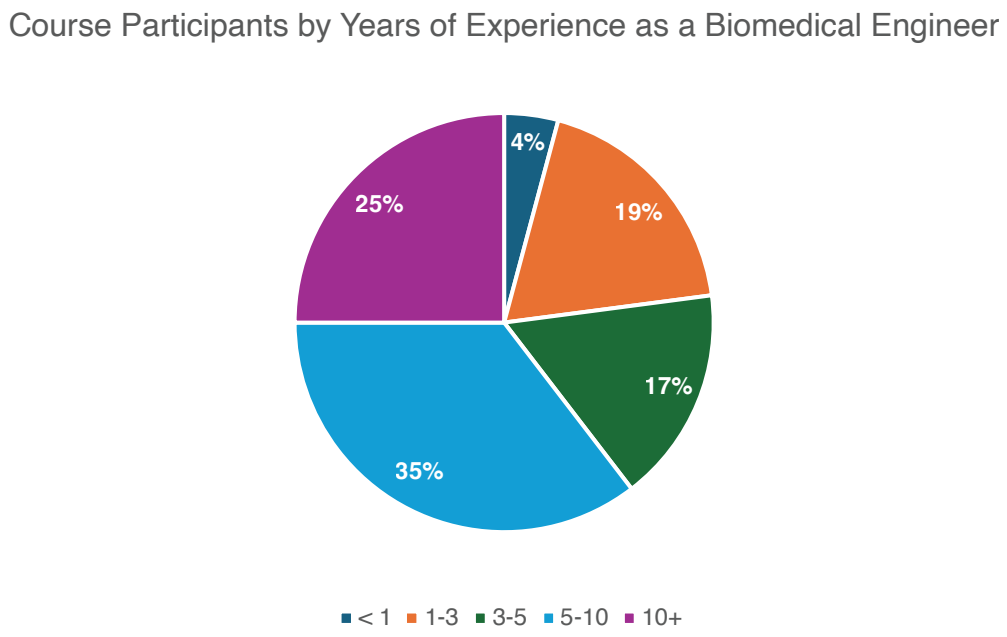


Figure 92. Proportion of participants by response to the prompt "How many years have you been working as a biomedical engineer/technician?" reported in the updated course feedback survey (**Appendix 4**). Responses were a free text answer, with the groupings above applied, responses on the boundaries being recorded in the upper applicable bracket (n=48).

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There was a very wide range in terms of the amount of time taken to complete the biomedical engineering course by the participants. Some completed the course in as little as 12 days, while the maximum amount of time to complete the course was 247 days. This does reflect a slight variation in the dedication to the training provided across some of the sites.

Approximately 18% of the participants completed the course in 10-20 days, a further 34% in 20-50 days, 32% in 50-100 days, and 16% after 100 days, **Figure 93**. Overall, just over 50% of participants completed the course in under 50 days, and over 80% by the 100 day mark, showing the high level of motivation for most participants.

This metric was available for all participants, regardless of the version of course feedback survey completed.

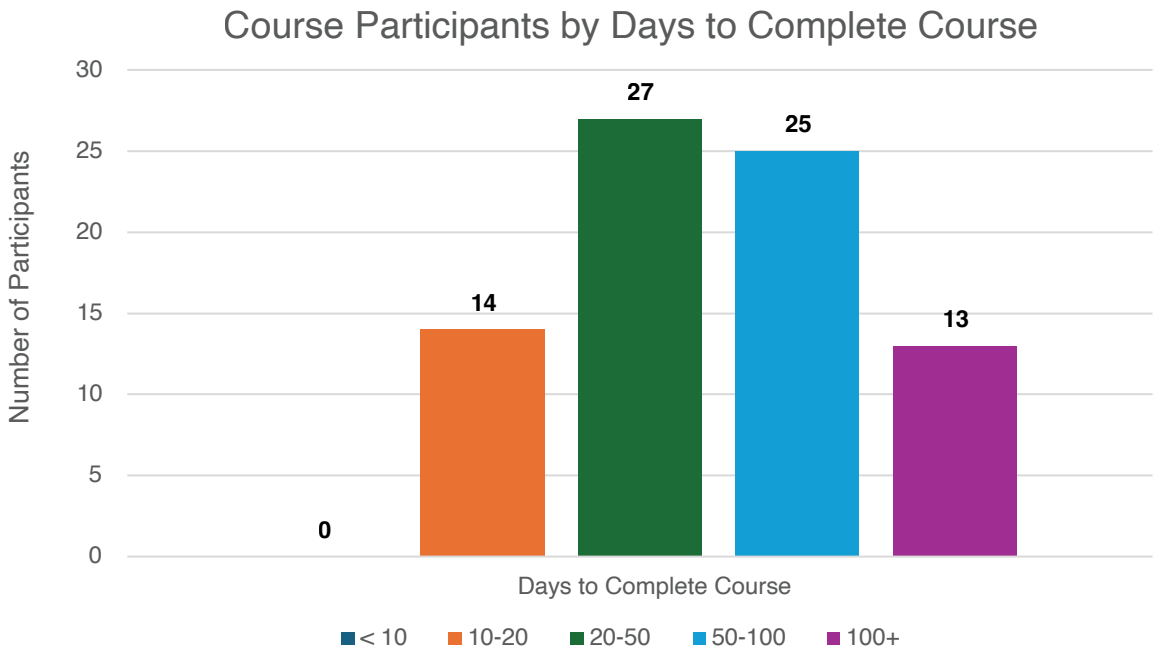


Figure 93. Number of participants by the amount of days taken to complete the biomedical engineering course. Count started when participant completed first MCQ test, and stopped when participant completed course feedback survey. Groupings above applied, responses on the boundaries being recorded in the upper applicable bracket (n=79).

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A very similar distribution is seen when the participants were grouped in terms of the amount of time taken to complete the course. Again, about half of the participants (45%) completed the course in a short number of hours (fewer than 20), while the bulk of the participants completing the course within a reasonable timeframe, 73% completed the course within 30 hours. This left a small minority of participants taking an extended time to complete the course, i.e. 8% of participants took over 50 hours to complete the course, **Figure 94**.

The range of course completion times was very large, spanning 4 hours 57 minutes, up to 132 hours 10 minutes, with the mean of 27 hours 39 minutes, and median of 22 hours and 43 minutes.

The time to complete the course for one participant was over 5 standard deviations away from the mean and so, as set out in the **Data Exclusions and Comments** section, this data was excluded from the data set.

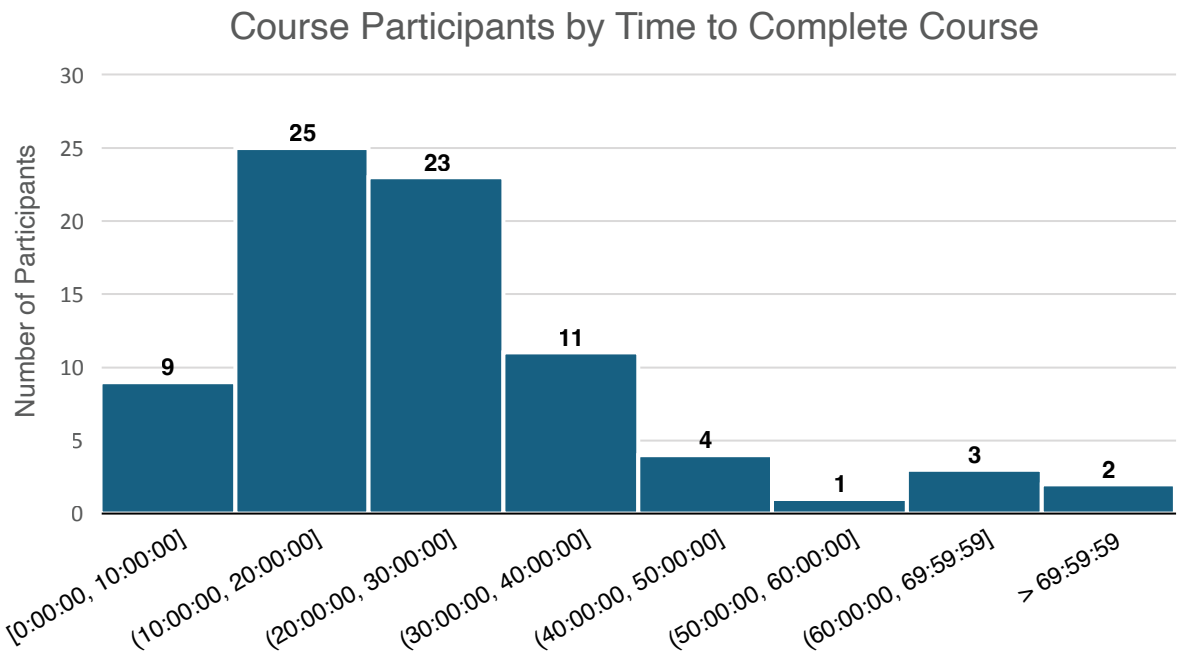


Figure 94. Number of participants by the amount of time taken to complete the biomedical engineering course. Counting all time spent with the account logged in, either watching course videos or completing MCQ tests. Groupings above applied, responses on the boundaries being recorded in the upper applicable bracket (n=78).

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The feedback received on the course by the participants was extremely positive, with the scores of the participants indicating that they are highly satisfied with the course (9.33/10), would recommend the course (9.52/10), and would take future courses from Medical Aid International (9.76/10), **Figure 95**.

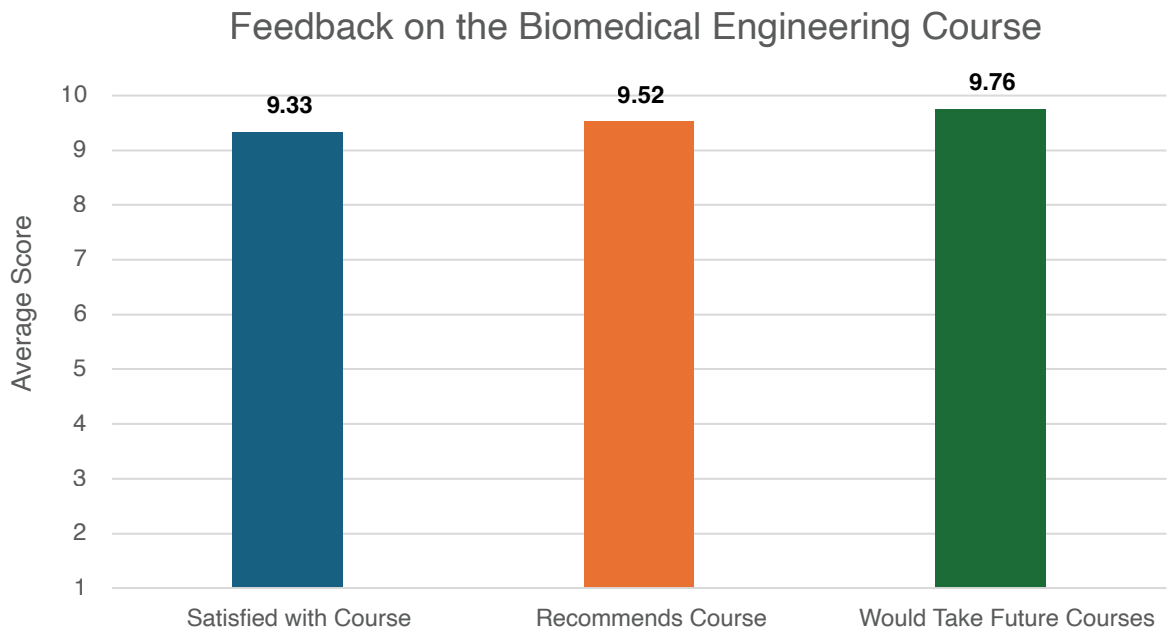


Figure 95. Average score of participants by response to each of the prompts: "Overall, how satisfied were you with the course and the learning material?", original, "On a scale of 1–10, how satisfied are you with the course and resources?", updated. "On a scale of 1-10, how likely are you to recommend the Programme?", original, "On a scale of 1–10, how likely are you to recommend the course?", updated. "On scale of 1-10, how likely are you to take any future Medical Aid International Programmes?", original, "On scale of 1–10, how likely are you to take any future Medical Aid International courses?", updated. Data from both the original course feedback survey (**Appendix 3**) and updated course feedback survey (**Appendix 4**), responses combined (n=79).

Participants completing the updated course feedback survey (**Appendix 4**) were then asked about how the course itself and the supplied programme resources had impacted their daily work. This was similar to the questions asked in **Figure 31**, with similar findings.

Encouragingly, the data shows that all aspects of the biomedical engineering programme were well received by the participants, having an impact on their daily work.

The toolkit was rated as having the greatest impact, with an average score of 9.50 (scored from 1-10), **Figure 96**. This data was supportive of Medical Aid International's approach of sending a toolkit with each place on the biomedical engineering programme, as often resources can be limited.

The course, textbooks, and digital library of service manuals were all rated fairly similarly, with each receiving an average score between 9.13-9.19/10.

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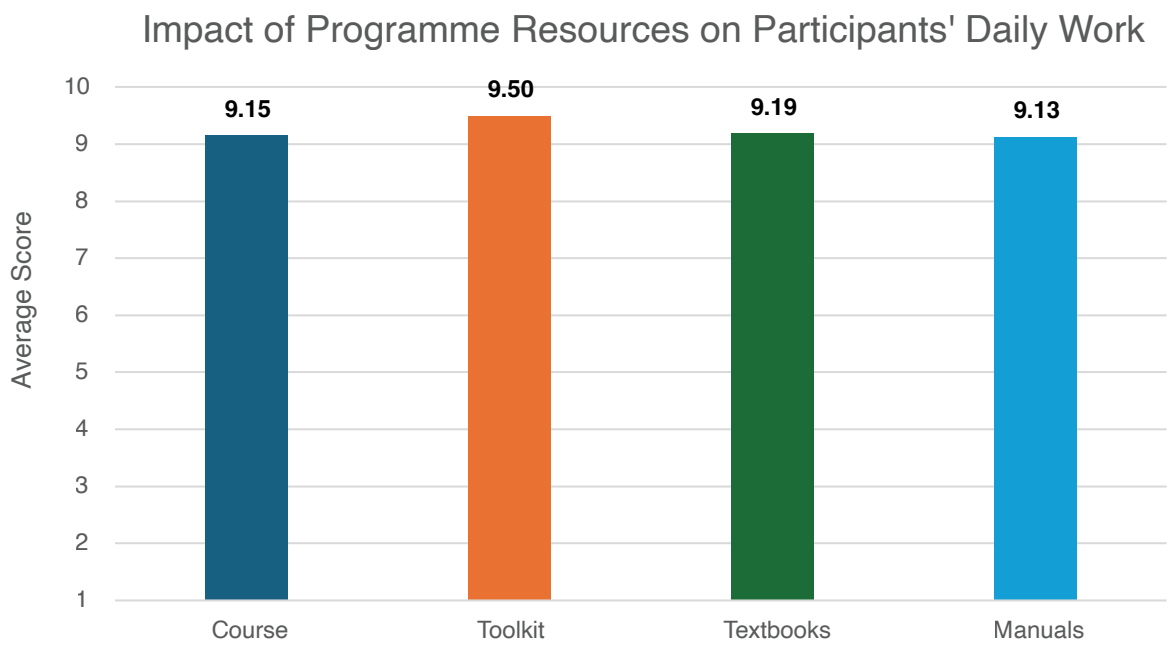


Figure 96. Average score of participants by response to the prompts "On a scale of 1–10, how much has the [**course**/**toolkit**/**textbooks**/**digital library of service manuals**] impacted your daily work?" reported in the updated course feedback survey (**Appendix 4**), each asked as a separate question (n=48).

The next section of the course feedback survey asked participants about the self-assessed improvements to their abilities across a variety of different metrics. Here the feedback collected was split depending on whether the participants completed the original course feedback survey (**Appendix 3**) or the updated course feedback survey (**Appendix 4**), with a different approach taken for each.

Participants who responded to the original course feedback survey (**Appendix 3**) were simply asked to rate their improvement for each of the metrics surveyed, Figure 97. In contrast, participants responding to the updated course feedback survey (**Appendix 4**) were asked to provide a self-assessed score of their ability both before and after completing the biomedical engineering course. From this data, the average improvement of the participants was calculated, **Figure 98**.

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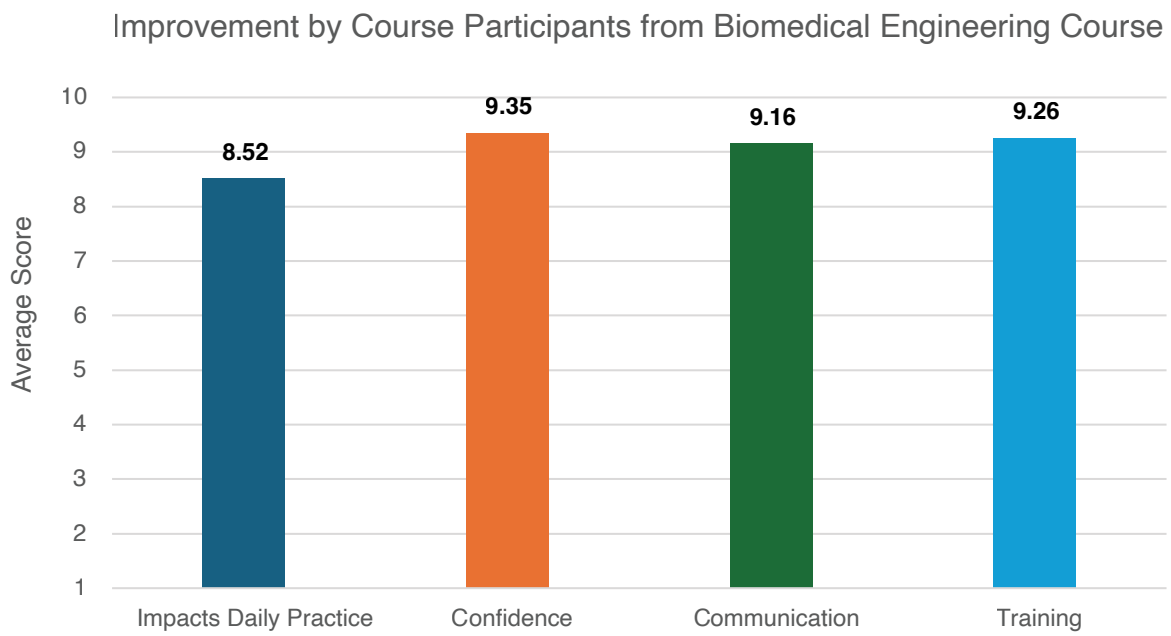


Figure 97. Average score of participants by response to each of the prompts: "On a scale of 1-10, how has the course in its entirety (including toolkits and textbooks) affected your practice on a day to day basis?", "How much has the course increased your motivation and confidence in the workplace?", "The course makes me better at communicating with my colleagues and the medical team.", and "The course has improved my ability to train others." Data reported in the original course feedback survey (**Appendix 3**), each asked as a separate question (n=31).

The participants reported very strong improvements in their self-assessed abilities across all measured metrics. This was clear evidence that the approach taken by Medical Aid International through the biomedical engineering course was highly effective.

There was clear evidence that the confidence shown by participants (rated improvement of 9.35/10) also fed into their improvement in daily practice (at 8.52/10). It was also encouraging to see that the content provided in Unit 13: Train the Trainer, also helped participants to communicate more effectively with the medical teams (scoring an improvement of 9.16), as well as train others (9.26/10). These were all clear benefits to participants of completing the biomedical engineering course.

> *"Unit 11a and 11b [were the most useful units]: because anaesthetics, suction devices, and operating department sterilisation are cornerstones of safe and effective surgical practice. Each plays a distinct role in ensuring patient safety, surgical precision, and infection control. I am feeling more confident after getting the knowledge."*

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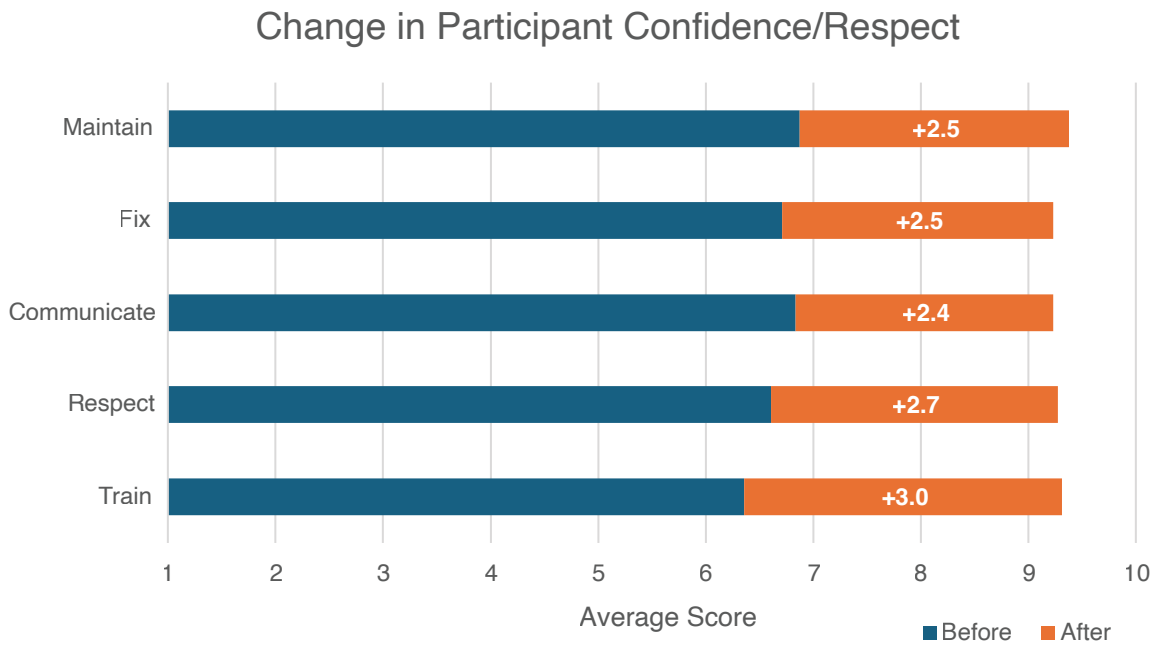


Figure 98. Average score of participants by response to each of the prompts: "On a scale of 1–10, how confident were you in your ability to **maintain** medical equipment [**BEFORE**/**AFTER**] the course?", "On a scale of 1–10, how confident were you in your ability to repair medical equipment [**BEFORE**/**AFTER**] the course?", "On a scale of 1–10, how confident were you in your ability to professionally **communicate** with medical personnel [**BEFORE**/**AFTER**] the course?", "On a scale of 1–10, how confident were you in your ability to **train** others [**BEFORE**/**AFTER**] the course?", and "On a scale of 1–10, how much do you think the medical personnel **respected** you as a biomedical engineer [**BEFORE**/**AFTER**] the course?". Questions for before and after were asked separately, in sequence for each prompt. Data reported in the updated course feedback survey (**Appendix 4**), each asked as a separate question (n=48).

Similarly to participants who responded to the original course feedback survey, the participants who took the updated course feedback survey also reported strong self-assessed improvements across all the metrics measured, with each metric's average score improving by at least 2.4, **Figure 98**.

Whist there was a slight disparity between the average scores initially (provided as the before the course ratings), with a range of 6.4 to 6.9, this range narrowed considerably when considering their self-assessed abilities after completing the course, from just 9.2 to 9.4.

The greatest improvements were found in participants' self-assessed abilities to communicate (up 3.0), and the respect they felt as biomedical engineers (up 2.7). This ties in with the view of Medical Aid International that one often under appreciated aspect of the biomedical engineering course is the confidence boost provided to participants. This confidence filters through into all other aspects of the programme.

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Again, Unit 13: Train the Trainer allowed participants to learn how to communicate more effectively (with an improvement in average score of 2.4). The core function of the biomedical engineering course, to help biomedical engineers to maintain and repair equipment, was also delivered, with participants gaining in these metrics significantly (at +2.5 for both categories).

The final scored question of the course feedback survey asked participants about the difficulty of the course, albeit with a slightly different wording between the original and updated course feedback surveys, **Figure 99**.

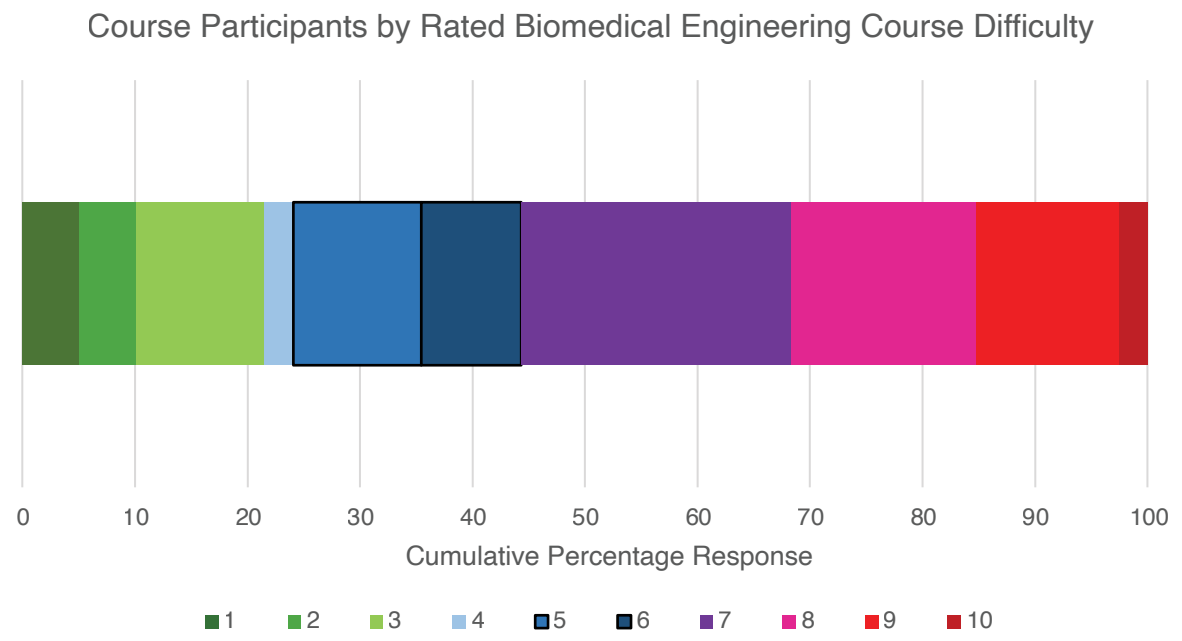


Figure 99. Cumulative proportion of participants by score in response to the prompt: "Was the information pitched at the right level; was it too easy or too difficult?", original, "On a scale of 1–10, how easy/difficult was the information in the course?", updated. Scale between 1-10, from 1 as "Too Easy", and 10 as "Too Difficult". Data from both the original course feedback survey (Appendix 3) and updated course feedback survey (**Appendix 4**), responses combined (n=79).

Ideally, the course would have been rated at a reasonable level of challenge for the participants so that the material was not too challenging to access, but not too easy (for example content they were already familiar with/knew). Given the scale was from 1-10, a middle score of either 5 or 6 would have been the ideal outcome; these scores were only reported by 20% of the participants, Figure 99.

However, considering scores with a range from 4-7 the proportion of participants covered is nearly half (47%). Overall, the course was rated as being on the more challenging side, with participants scoring the difficulty between 8-10 (inclusive) comprising 31.7% of the cohort, while those scoring it from 1-3 (inclusive) covered just 21.6% of the participants. Given a range of scores were reported by participants for the difficulty of the course, it appears the material was pitched at the correct level.

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The free text comments of the participants at the end of the survey were also analysed. Comments were subjectively graded into three categories: positive, neutral, and negative.

Comments which included feedback praising aspects of the course, or thanks were categorised as positive. This included participants saying that they had benefitted from the course, that the course was valuable/interesting, that they would love further opportunities to study with Medical Aid International, or thanks for the programme.

Neutral comments were graded as such if the participant provided a suggestion or improvement about the programme, or did not express a clear view on the course. This included requesting additional topics be covered, responses similar to "no comments", and suggestions on how the course could be improved.

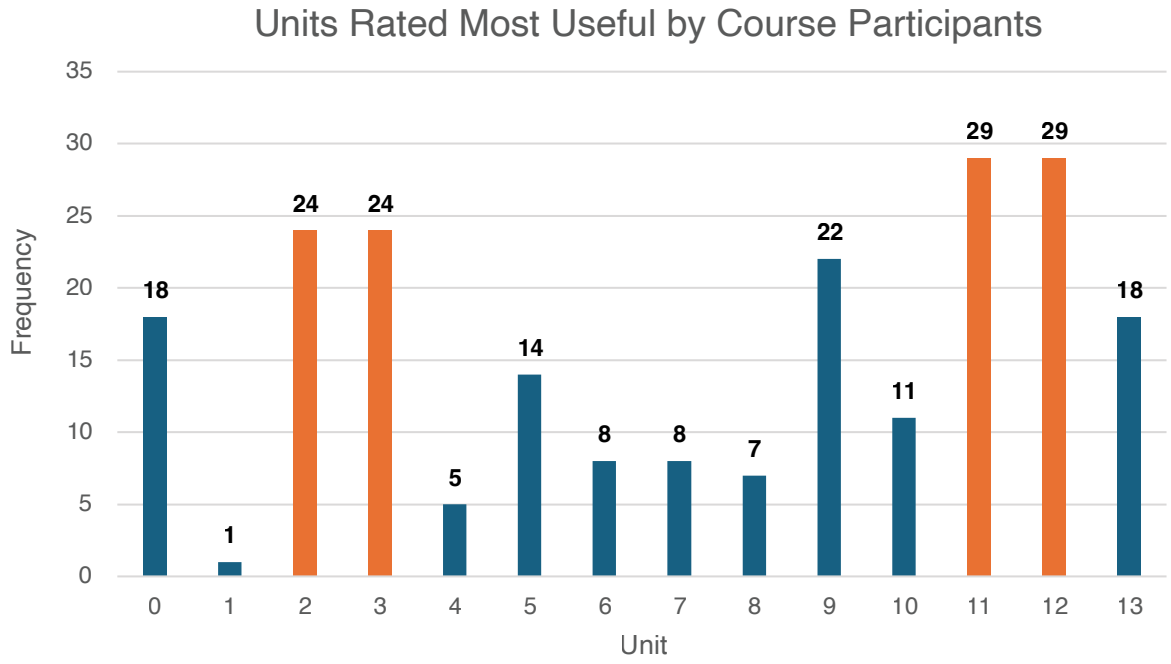
Negative comments were when the participant only suggested improvements or criticism. In the sole case this occurred, the participant requested an incentive be provided for having completed the course.

86% of the feedback was evaluated as positive, 13% as neutral, and only one comment (1%) was considered to be negative (as outlined above).

> *"Unit two is electrical safety. It is very important to me because it tough me how to handle medical equipment and most especially how to protect myself and also teach those I work with… Generally my mind and my work attitude has changed going through all the units."*

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As part of the course feedback survey, participants were also asked to select the units they found the most useful, **Figure 100**, and the most challenging, **Figure 101**.



Key of Unit Titles

Unit 0 – Health and Safety	Unit 7 – Premature Baby Incubators (PBIs)
Unit 1 – The Frequency Spectrum	Unit 8 – Ultrasound
Unit 2 – Electrical Safety	Unit 9 – Surgical Diathermy/ESU
Unit 3 – Electrocardiogram (ECG)	Unit 10 – Hygiene Guidelines
Unit 4 – Defibrillation	**Unit 11 – Anaesthetics and the Operating Room**
Unit 5 – Patient Monitoring	**Unit 12 – First Aid**
Unit 6 – Infusion Devices	Unit 13 – Train the Trainer

Figure 100. Number of participants by units chosen in response to the prompt: "Please identify the 3 units you found most beneficial and explain why?". Data from both the original course feedback survey (**Appendix 3**) and updated course feedback survey (**Appendix 4**), responses combined. Participant responses for up to 3 units recorded. Responses for Unit 11a (Anaesthetics, Oxygen and Suction Devices) and Unit 11b (The Operating Department and Sterilisation) merged into Unit 11 (Anaesthetics and the Operating Room), as these were originally a single unit, Unit 11, (n=218 recorded entries, 19 entries recorded as "null" where no response was provided – these entries are not shown and were not included as part of the 218 recorded entries).

> *"Unit 10, hygiene guidelines, teaches about good hygiene practices in the hospital, sources of infections and how we can safeguard ourselves from exposure to potential infection in the hospital as biomedical engineers."*

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One interesting finding was that there was a very high incidence of participants reporting units concerning health and safety as useful. For example, Unit 0 (Health and Safety), selected by 23% of participants, Unit 2 (Electrical Safety), selected by 30% of participants, and Unit 12 (First Aid), selected by 37% of participants. This underlines the importance of including these modules in the biomedical engineering course, as part of a holistic approach, as well indicating the relatively underserved provision in these areas.

One other finding was that there appeared to be a preference for practical, key equipment based units, such as Unit 11 (Anaesthetics and the Operating Room), selected by 37% of participants, Unit 3 (Electrocardiogram (ECG)), selected by 30% of participants, and Unit 9 (Surgical Diathermy/ESU), selected by 28% of participants.

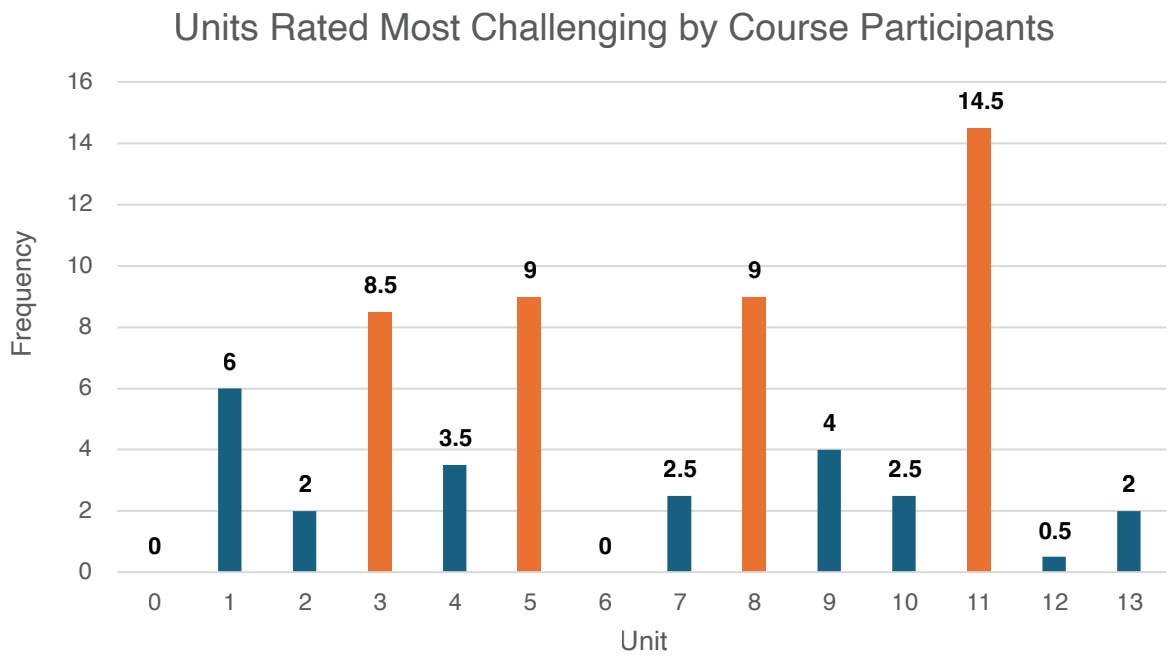
This is especially true for Unit 11, which covers equipment found in the operating room. One potential hypothesis is that biomedical engineers are asked to attend here often, or are asked to service these machines frequently. There was also a lot of equipment covered in this unit, making it relatively more useful to the participants, as biomedical engineers.

When considering which units the participants reported as most challenging, a different picture emerges, **Figure 101**. It appears to be the case that units with many questions in the multiple choice question (MCQ) test were rated as more challenging. The average number of questions per unit was 18, but the units rated as being relatively more challenging has more than this. For example, Unit 3 (Electrocardiogram (ECG)) had 25, Unit 5 (Patient Monitoring) had 34, Unit 8 (Ultrasound) had 23, and Unit 11 (Anaesthetics and the Operating Room) had 29 for sub Unit 11a, and 21 for sub Unit 11b. Given participants must score 100% to pass the MCQ test, the addition of more questions to the test make this more challenging.

This is partially supported by data when a linear regression is fitted to a scatter plot of the number of multiple choice questions for each unit in the corresponding end of unit test, against the frequency each unit was selected by participants as being the most challenging, Figure 102. Both appear to be positively correlated with moderate strength, with an R-squared value of 0.41, suggesting support for some relationship between the two.

It could also be the case that the equipment featured in these units was considered more complicated, or less familiar to the biomedical engineers, or that the content contained within these units was more complex.

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Key of Unit Titles

Unit 0 – Health and Safety
Unit 1 – The Frequency Spectrum
Unit 2 – Electrical Safety
Unit 3 – Electrocardiogram (ECG)
Unit 4 – Defibrillation
Unit 5 – Patient Monitoring
Unit 6 – Infusion Devices
Unit 7 – Premature Baby Incubators (PBIs)
Unit 8 – Ultrasound
Unit 9 – Surgical Diathermy/ESU
Unit 10 – Hygiene Guidelines
Unit 11 – Anaesthetics and the Operating Room
Unit 12 – First Aid
Unit 13 – Train the Trainer

Figure 101. Number of participants by units chosen in response to the prompt: "Please identify the unit you found the most challenging and explain why?". Data from both the original course feedback survey (**Appendix 3**) and updated course feedback survey (**Appendix 4**), responses combined. Participant responses for up to 2 units recorded, with half a point assigned to each unit if 2 provided. Responses for Unit 11a (Anaesthetics, Oxygen and Suction Devices) and Unit 11b (The Operating Department and Sterilisation) merged into Unit 11 (Anaesthetics and the Operating Room), as these were originally a single unit, Unit 11, (n=64 recorded entries, 2 additional entries recorded as "null" where no response was provided – these entries are not shown and were not included as part of the 64 recorded entries, 13 additional entries recorded as "All", not shown or included under the 64 recorded entries).

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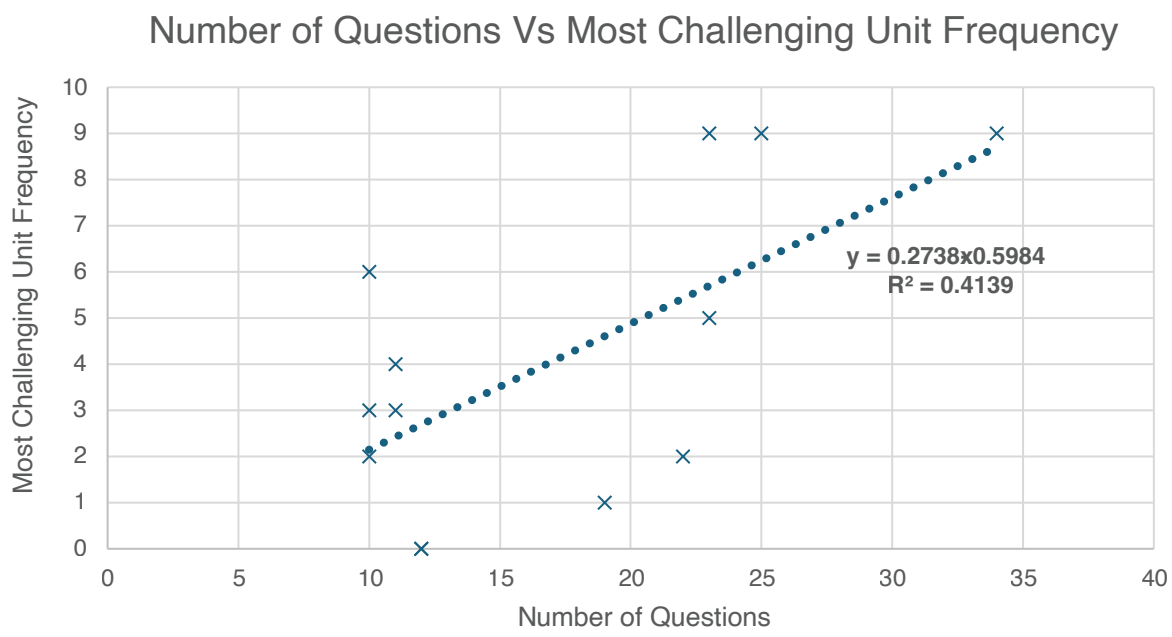


Figure 102. Plot of the number of multiple choice questions in the end of unit test against the frequency of each unit being rated as most challenging by participants. Unit 11/11a/11b excluded from the data (n=13).

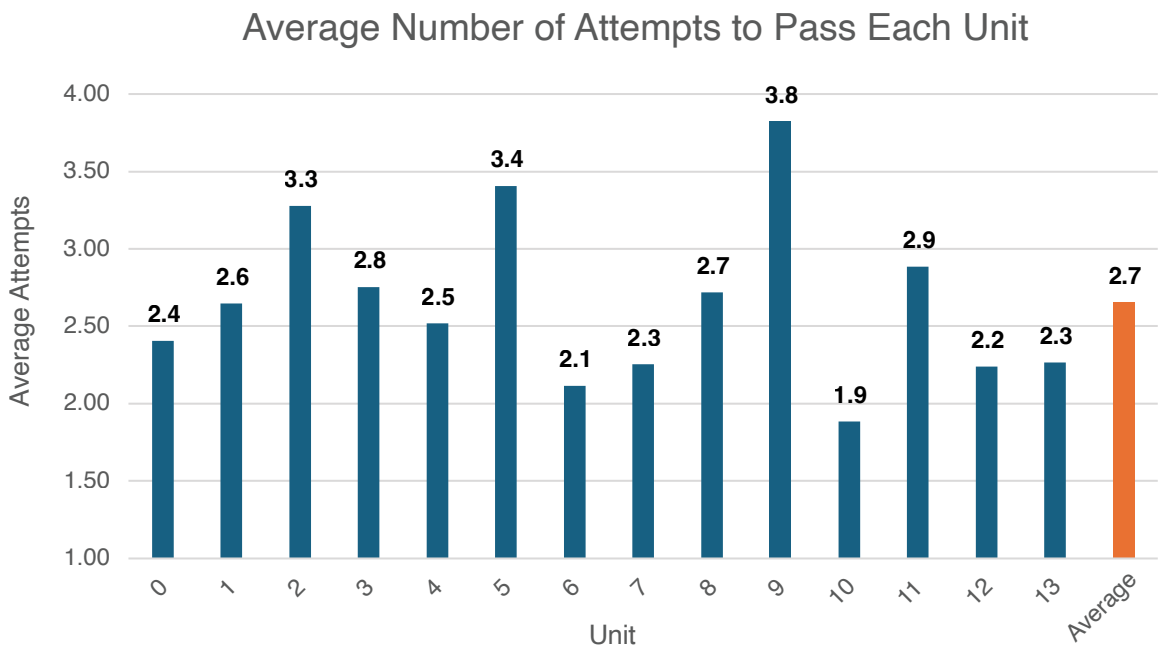
> *"I've always had reservations when working with defibrillators or training clinicians on their usage, but I've gained substantial knowledge. I have more confidence whenever I get the chance to handle them in the future."*

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The final section of data was collected using the metrics automatically generated by users completing the course. These included the average number of attempts needed to pass each unit, the average first attempt test score for each unit, and the average time taken to complete each unit on both the first, and the passing (scoring 100% for the first time) attempt.

There was a broad range of average attempts needed to complete the course, with Unit 10 (Hygiene Guidelines) being statistically the easiest unit by this measure, at 1.9 attempts, and Unit 9 (Surgical Diathermy/ESU) being statistically the most challenging, at 3.8 attempts, **Figure 103**.

It was interesting to note that the units which took the most attempts to pass were not necessarily those units which were rated as being most challenging by the participants. Unit 11 (Anaesthetics and the Operating Room) was rated as being the most challenging, but it was around the average (of 2.7) in terms of the number of attempts required to pass, at 2.9.



Key of Unit Titles

Unit 0 – Health and Safety	Unit 7 – Premature Baby Incubators (PBIs)
Unit 1 – The Frequency Spectrum	Unit 8 – Ultrasound
Unit 2 – Electrical Safety	Unit 9 – Surgical Diathermy/ESU
Unit 3 – Electrocardiogram (ECG)	Unit 10 – Hygiene Guidelines
Unit 4 – Defibrillation	Unit 11 – Anaesthetics and the Operating Room
Unit 5 – Patient Monitoring	Unit 12 – First Aid
Unit 6 – Infusion Devices	Unit 13 – Train the Trainer

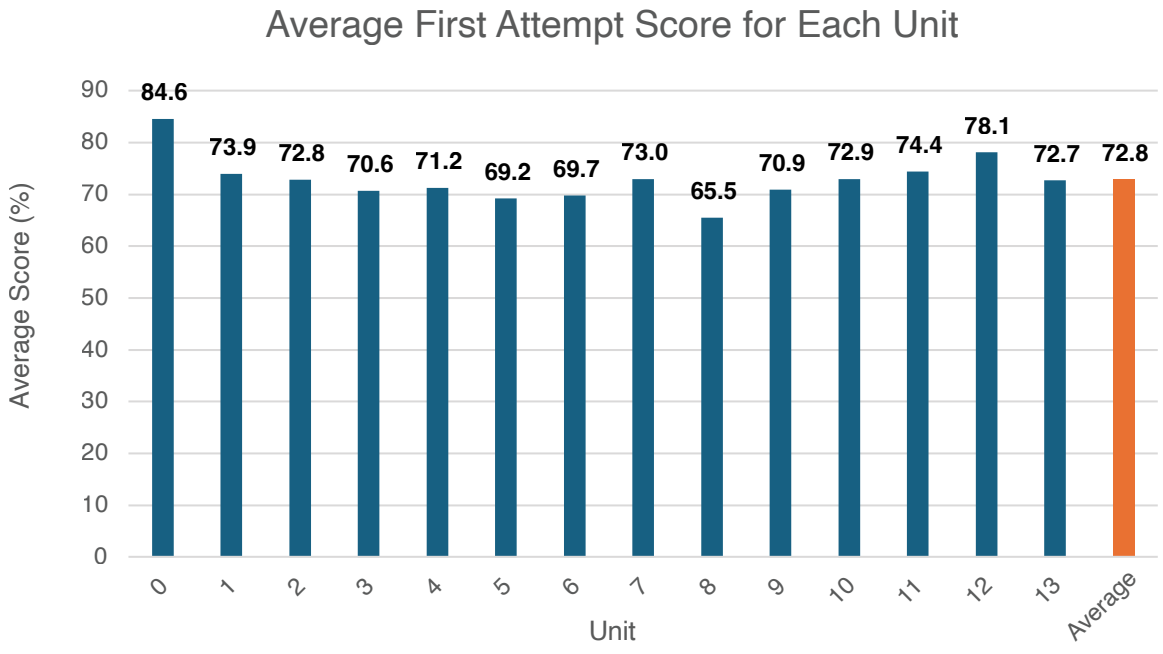
Figure 103. Average number of attempts required by participants to pass (score 100%) on each end of unit multiple choice question test. For Unit 11, the maximum number of attempts taken for either sub Unit 11a or sub Unit 11b for each participant was used and then averaged. Outlier data outside 5 standard deviations excluded (n=78 or 79 for each unit depending on exclusion of outliers).

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The range of average first attempt scores of the participants primarily fell into a narrow range of between 69% and 75%, with the average score being 72.8%. There were only three units which fell outside this range, Unit 0 (Health and Safety), Unit 8 (Ultrasound), and Unit 12 (First Aid), **Figure 104**.

Interestingly, the findings for these specific units appear to be reflected in terms of the relative challenge of the unit, as rated by the participants, **Figure 101**. Unit 0 (Health and Safety) and Unit 12 (First Aid) received relatively high first attempt scores, i.e., were easy to score well on, and were also seldom rated as the most challenging unit by participants (with a frequency of 0 and 1 respectively). Conversely, Unit 8 (Ultrasound) was the most difficult unit for participants to score highly on their first attempt, and this was also rated as the joint second most challenging unit by participants.

This trend, however, does not hold more broadly, as the range of first attempt scores is very narrow, meaning that it does not correlate well with the frequency of most challenging units from the participants (which cover a much wider range).



Key of Unit Titles

Unit 0 – Health and Safety	Unit 7 – Premature Baby Incubators (PBIs)
Unit 1 – The Frequency Spectrum	Unit 8 – Ultrasound
Unit 2 – Electrical Safety	Unit 9 – Surgical Diathermy/ESU
Unit 3 – Electrocardiogram (ECG)	Unit 10 – Hygiene Guidelines
Unit 4 – Defibrillation	Unit 11 – Anaesthetics and the Operating Room
Unit 5 – Patient Monitoring	Unit 12 – First Aid
Unit 6 – Infusion Devices	Unit 13 – Train the Trainer

Figure 104. Average score of participants during their first attempt on each end of unit multiple choice question test. For Unit 11, a weighted average of the scores obtained on sub Unit 11a and sub Unit 11b for each participant was used and then averaged. Outlier data outside 5 standard deviations excluded (n=78 or 79 for each unit depending on exclusion of outliers).

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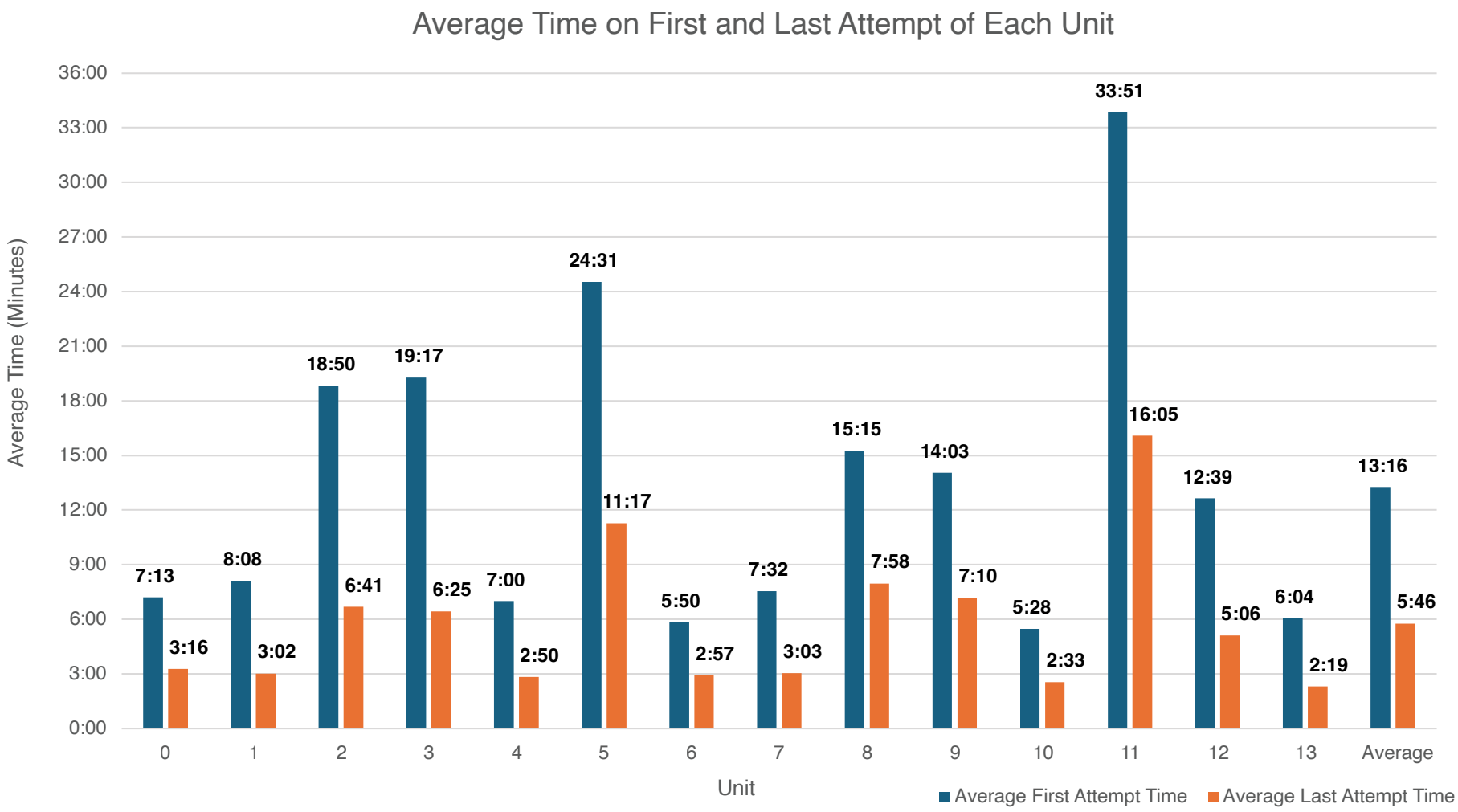


Figure 105. Average time taken by participants to complete their first and last (scoring 100%) attempt at the multiple choice question test for each unit. For Unit 11, the sum of the time taken for sub Unit 11a and sub Unit 11b for each participant was used and then averaged. Outlier data outside 5 standard deviations excluded (n=78 or 79 for each unit depending on exclusion of outliers).

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As expected, the average last attempt time for each of the units is considerably lower than for the average first attempt time, as the participants will have seen the questions before and will have known which questions they answered correctly and incorrectly during their previous attempt(s), **Figure 105**.

The average time taken by participants to complete both their first and last (passing, scoring 100%) attempts was almost entirely correlated with the number of questions in the end of unit multiple choice question test, **Figure 106** and **Figure 107**.

In both cases there was an extremely strong positive correlation, with an R-squared value of 0.96 when considering the average first attempt time, and an R-squared value of 0.98 when considering the average last (passing, scoring 100%) attempt time.

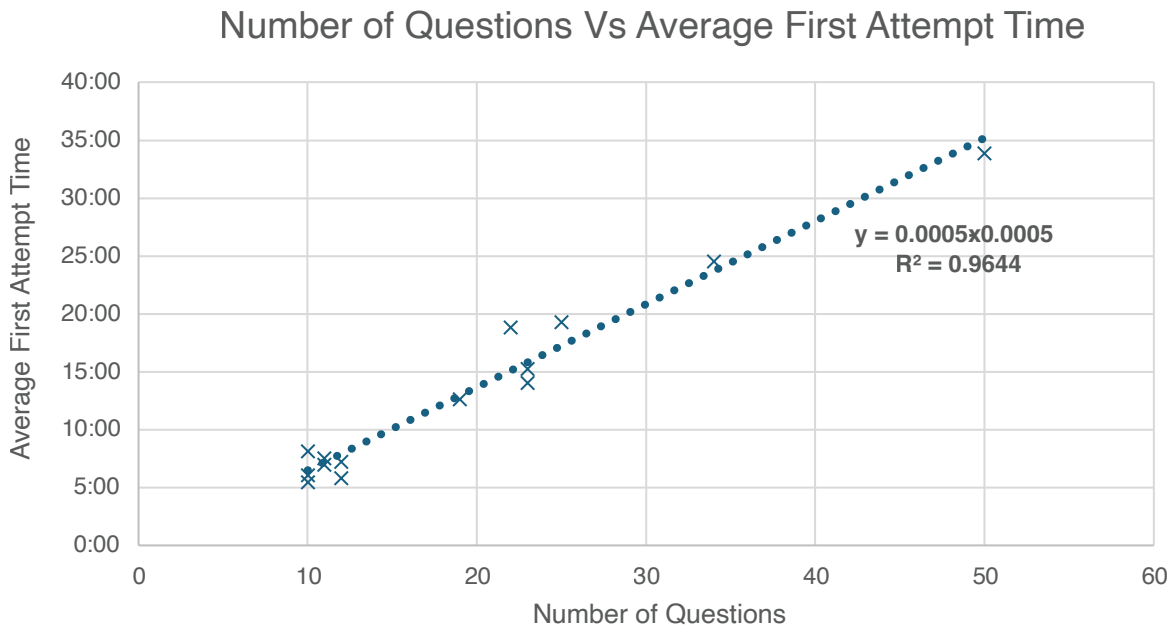


Figure 106. Plot of the number of multiple choice questions in the end of unit test against the average amount to time taken by the participants to complete their first attempt at each test. Unit 11 considered as the sum of the times taken to complete the sub Unit 11a and sub Unit 11b tests (as these were originally a single unit), (n=14).

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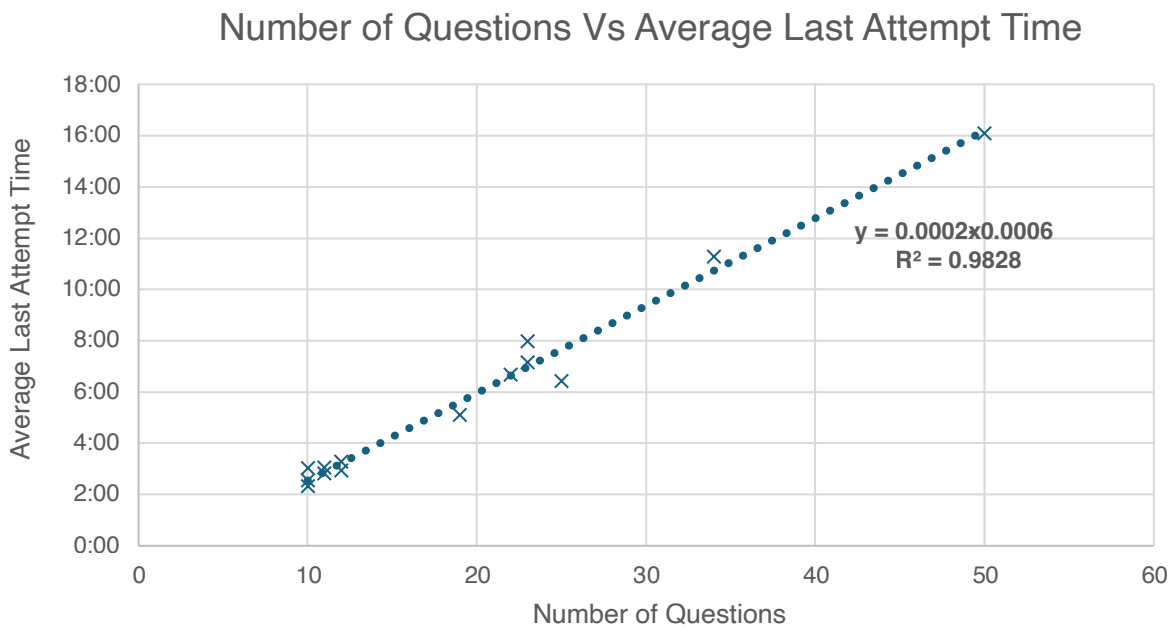


Figure 107. Plot of the number of multiple choice questions in the end of unit test against the average amount to time taken by the participants to complete their last (passing, scoring 100%) attempt at each test. Unit 11 considered as the sum of the times taken to complete the sub Unit 11a and sub Unit 11b tests (as these were originally a single unit), (n=14).

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Discussion and Conclusion

The report was set out in such a way that each source of data could be evaluated and the findings measured against the aims of the project. These were to upskill biomedical engineers across a number of healthcare facilities, and additionally to assess the effectiveness of the biomedical engineering course offered by Medical Aid International, which was used to bring about this upskilling, all with the aim of improving patient care.

Each of the three sections: **Onboarding and End of Project Survey**, **Initial and Final Equipment Audit Data**, and **Participant Course Feedback Survey** provided evidence of upskilled biomedical engineers from the training course provided, and hence the effectiveness of the course.

Overall, the picture is one where the effectiveness of the biomedical engineering course from Medical Aid International is extremely effective and impactful, which is set out in detail in the sub-sections below.

Onboarding and End of Project Survey Conclusions

The onboarding and end of project survey data showed that the biomedical engineers showed an improvement across all measured metrics (maintaining equipment, fixing equipment, communicating with medical personnel, training others, and feeling respected as an engineer), **Table 2**. A Wilcoxon signed-rank test was applied to this data and all of the changes were found to be statistically significant, **Table 3**.

Additionally, these improvements reported by the participants were (in almost all cases) realised regardless of the educational level of the participant, **Figure 11**, **Figure 12**, and **Figure 13**. Those with a university level of education appeared to benefit most from the course (experiencing the greatest increase in their self-assessed abilities), while those who had a college/polytechnic level of education consistently ranked their self-assessed abilities as being the strongest, **Table 4**.

There was also an increase in self-assessed abilities of the participants regardless of their level of experience as a biomedical engineer, **Table 5**. It was encouraging to see that the course was of benefit to almost all participants, regardless of their education or experience level.

The onboarding and end of project surveys also highlighted the severe lack of spare parts in LMIC environments, with this reason being responsible for approximately 75% of all non-operational equipment, **Figure 24** and **Figure 25**. However, after completing the course, there was a reduction in equipment reported as non-operational due to a lack of knowledge by the biomedical engineers/medical personnel – a positive from undertaking the online training.

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One other key aspect of the programme was the provision of a variety of resources to assist the biomedical engineers to carry out their duties more effectively. This is one area which is often a limiting factor in LMICs. The project sought to address this by providing a professional toolkit to each biomedical engineer (amongst other resources), which all but eradicated this problem. Initially, only 30% of participants had an adequate complement of tools, Figure 26, but after the programme, this rose to 93%, **Figure 27**. The proportion of participants with each tool, all of which we supplied, also rose significantly during the project, **Figure 28**.

Additionally, a variety of other resources were supplied as part of the project, such as textbooks, digital service manuals, and a laptop. Alongside the toolkit, all of these resources were received extremely favourably, **Figure 31**.

From this data, it was clear that the impact of the biomedical engineering course was very positive, yielding upskilled biomedical engineers. Aside from this, further positive feedback was received from the participants in terms of the successful management of the project by Medical Aid International.

95% of participants reported that the communication by Medical Aid International throughout the project was either a score of 9 or 10/10, **Figure 36**. The same was true for how well supported they felt, **Figure 37**. 92% of participants would also fully recommend the project (scoring this metric a 10/10), with no participant giving a score lower than 7/10, **Figure 38**.

Initial and Final Equipment Audit Data Conclusions

Here there were fewer findings in terms of the changes between the two equipment audits. However, a good amount of data was logged by the participants, with 1888 matching entries being logged in each of the initial and final equipment audit (making 3776 in total).

Moreover, a relatively static picture between the initial and final audits showed that the participants were able to consistently record information about the medical equipment at their healthcare facilities. The fact that only a few significant changes in this area were found highlights that the project was completed thoroughly and accurately. If changes had been found across all areas of the project, this may have been a cause for concern, as some areas (which the course did not cover) would be expected to hold to a consistent pattern. The fact that a fairly consistent pattern was observed lends evidence to the fact that the data collected by the participants was done so carefully, accurately, and reliably.

As set out in the **Data Exclusions and Comments** section, one site (06GH) was excluded from the dataset in certain areas.

Unrelated to the impact from the biomedical engineering course, it was found that equipment at the hospitals was largely donated, but with a lot of equipment also being purchased new, **Figure 43**. Most of the equipment was used within the last 7 days, **Figure 44**, and participants had safety concerns about 20% of equipment, **Figure 49**.

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The equipment surveyed also performed its job to the satisfaction of participants in most cases, **Figure 52**, and successfully switched on, **Figure 53**.

Spare parts were lacking for almost all of the equipment surveyed, **Figure 55**, with only 13-19% of equipment having all spare parts available, **Figure 57**. There was a wide range of spare parts availability by equipment type, with pulse oximeters having particularly good availably (above 50%), but with most equipment types having under 20%, **Figure 58**.

The availability of both consumables and accessories was slightly better, although the pattern was mixed and varied by patient type (adult, child, or neonate), **Figure 62**, **Figure 64**, **Figure 65**, and **Figure 66**. The availability of repair manuals was relatively more favourable, at about 60%, **Figure 72**.

The key finding from this section was the increased confidence of the biomedical engineers from completing the course. This is reflected in the very sizable reduction in "Don't know" responses when comparing participant responses to the initial equipment audit to the final equipment audit. The range of these reductions primarily spans from 60% to 90% across the questions asked, **Figure 75**. The greatest reduction was 91.7%, with the lowest being 25.0%, **Table 12**.

There were a few findings relating to changes in responses for specific items of equipment, for which training was provided in the online course. This suggests that these findings were caused by the improved knowledge provided by the course.

One such example of this was an increase in the proportion of anaesthetic machines with soda lime during the final equipment audit compared to the initial equipment audit. This increase was from 67%, **Figure 78**, to 75%, **Figure 79**.



A MedAid biomedical engineer receiving her programme resources before the start of the course.

There was also an increase in the proportion of oxygen cylinders being secured/chained. There was an increase from 49% in the initial equipment audit, **Figure 83**, to 61% in the final equipment audit, **Figure 84**.

The prevalence and condition of battery backups was also considered, **Figure 90**, with defibrillators, pulse oximeters, and ventilators for the most part having functioning battery backups, while operating lights and suction machines did not.

> *"I am so grateful for this course, my course coordinator, my sponsor and all the medical Aid international team for this experience. I am also grateful for the toolkit it makes work easy and enjoyable. I will intentionally put all of what I've learned to practice."*

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Participant Course Feedback Survey Conclusions

The vast majority of participants reported to have a university level of education (79%), **Figure 91**, with all but 5% having at least one year of experience as a biomedical engineer, and 39% having 5-10 years of experience, **Figure 92**.

There was a wide spread in terms of both the days taken, and time taken to complete the biomedical engineering course. 52% of the participants completed the course in under 50 days, with 16% taking over 100 days, **Figure 93**. Similarly, 45% of participants completed the course in under 20 hours, while 8% too over 50 hours to complete the course, **Figure 94**.

In terms of the impact of the biomedical engineering course on participants, the average scores received by participants were all very positive in terms of whether or not they were satisfied with the course, would recommend the course, or would take future courses with Medical Aid International. Each of these scores (on a scale of 1-10) was rated as over 9.3, **Figure 95**.

The impact of the course and the resources on participants was also evidence in **Figure 96**, where the impact of all aspects of the programme (course, toolkit, textbooks, and manuals) were reported to be at 9.1 or above (on a scale of 1-10).

Participants were then asked about the impact the course had on their daily practice, confidence, communication ability, and their ability to train others. All of these metrics were well received, with an average score of 8.52-9.35 (on a scale of 1-10), **Figure 97**.

Other key metrics for biomedical engineers were also measured, using an updated course feedback survey for some participants (about half the cohort), who measured notable increases in their self-assessed abilities to maintain and fix equipment, communicate with and train others, as well as their perceived respect level as biomedical engineers, **Figure 98**. The scale was again 1-10, with each metric increasing by a minimum of 2.4 points.

The difficulty of the course was also at a reasonable level, with a range of difficulty scores provided by the participants. On balance, participants perceived the course to be slightly more challenging than it was easy, **Figure 99**.

A broad mix of units were selected as being the most useful, with Unit 2 (Electrical Safety), Unit 3 (Electrocardiogram (ECG)), Unit 11 (Anaesthetics and the Operating Room), Unit 12 (First Aid) being the four most frequently selected units, **Figure 100**.

The most challenging units selected by participants were the following: Unit 3 (Electrocardiogram (ECG)), Unit 5 (Patient Monitoring), Unit 8 (Ultrasound), and Unit 11 (Anaesthetics and the Operating Room), **Figure 101**. There was a slight positive correlation between the number of multiple choice questions in each end of unit test and how frequently that unit was rated as most challenging by the participants, **Figure 102**.

It was also interesting, although rather expected, that there was very strong (almost perfect, R-squared of 0.96) correlation between the number of multiple choice questions in each end of unit test and the average amount of time taken by participants to complete the corresponding test, **Figure 106**.

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Appendices

Appendix 1. Onboarding Survey Questions

a) Email

b) Name

c) Age

d) Hospital Name

1. How many years have you been working as an engineer/technician

2a. Did you go to university for engineering?

- Yes
- No
- Other: _____

2b. If you went to university for engineering, which university did you attend? If you did not attend university, skip this question.

3. Have you received any biomedical engineering training outside of formal education (for example: supplier led trainings, online courses)

- Yes
- No
- Other: _____

4. On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to **maintain** the equipment at your facility?
Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

5. On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to **fix** the equipment at your facility?
Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

6. On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to professionally communicate with medical personnel (doctors, nurses, surgeons, etc.)?
Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

7. On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to train medical personnel (doctors, nurses, surgeons, etc.) on how to use the medical equipment at your healthcare facility?
Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

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8. On a scale of 1-10 (1 being not at all, 10 being highly respect) how much do you think the medical personnel (doctors, nurses, surgeons, etc.) at your healthcare facility respect you as an engineer?
   Not at all respected 1 2 3 4 5 6 7 8 9 10 Very respected

9. In your best estimate, how many pieces of medical equipment does your facility have?

10. In your best guess, what percentage of the equipment on-site is non-operational?

11. In your opinion, what is the number one reason medical equipment at your healthcare facility is non- operational?
    - ○ Broken beyond repair
    - ○ No spare parts available to fix equipment
    - ○ Engineers/Medical personnel do not know how to use the equipment
    - ○ No consumables available to run the equipment
    - ○ Equipment never worked even when it first arrived
    - ○ Other: _____

12. Do you have the tools needed to maintain and fix the equipment?
    - ○ Yes
    - ○ No
    - ○ Other: _____

13. Do you have the following tools (select all that apply)?
    - ☐ Full set of spanners
    - ☐ Full set of screw drivers
    - ☐ Multi-meter
    - ☐ Soldering iron
    - ☐ Allen keys
    - ☐ Pliers (combination and long nose)
    - ☐ Wire cutters (regular and precise)
    - ☐ Set of needle files
    - ☐ High quality torch/flashlight
    - ☐ Spare fuses

14. Do you consent to the use of your anonymized data in future research?
    - ○ Yes
    - ○ No

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Appendix 2. End of Project Survey Questions

a) Email

b) Name

c) Age

d) Hospital Name

1. How many years have you been working as an engineer/technician

2a. Did you go to university for engineering?

- Yes
- No
- Other: _____

2b. If you went to university for engineering, which university did you attend? If you did not attend university, skip this question.

3. Have you received any biomedical engineering training outside of formal education (for example: supplier led trainings, online courses)

- Yes
- No
- Other: _____

4. On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to **maintain** the equipment at your facility?
Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

5. On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to **fix** the equipment at your facility?
Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

6. On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to professionally communicate with medical personnel (doctors, nurses, surgeons, etc.)?
Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

7. On a scale of 1-10 (1 being not at all, 10 being very confident) how confident are you in your ability to train medical personnel (doctors, nurses, surgeons, etc.) on how to use the medical equipment at your healthcare facility?
Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

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8. On a scale of 1-10 (1 being not at all, 10 being highly respect) how much do you think the medical personnel (doctors, nurses, surgeons, etc.) at your healthcare facility respect you as an engineer?
   Not at all respected 1 2 3 4 5 6 7 8 9 10 Very respected

9. In your best estimate, how many pieces of medical equipment does your facility have?

10. In your best guess, what percentage of the equipment on-site is non-operational?

11. In your opinion, what is the number one reason medical equipment at your healthcare facility is non-operational?
    - ○ Broken beyond repair
    - ○ No spare parts available to fix equipment
    - ○ Engineers/Medical personnel do not know how to use the equipment
    - ○ No consumables available to run the equipment
    - ○ Equipment never worked even when it first arrived
    - ○ Other: _____

12. Do you have the tools needed to maintain and fix the equipment?
    - ○ Yes
    - ○ No
    - ○ Other: _____

13. Do you have the following tools (select all that apply)?
    - ☐ Full set of spanners
    - ☐ Full set of screw drivers
    - ☐ Multi-meter
    - ☐ Soldering iron
    - ☐ Allen keys
    - ☐ Pliers (combination and long nose)
    - ☐ Wire cutters (regular and precise)
    - ☐ Set of needle files
    - ☐ High quality torch/flashlight
    - ☐ Spare fuses

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14. Please rate how useful you found the following items:
    Toolkit:
    - Not Useful
    - Somewhat Useful
    - Very Useful

    Textbooks:
    - Not Useful
    - Somewhat Useful
    - Very Useful

    Digital Service Manuals:
    - Not Useful
    - Somewhat Useful
    - Very Useful

    Laptop:
    - Not Useful
    - Somewhat Useful
    - Very Useful

15. On a scale of 1-10 (1 being poor communication, 10 being excellent communication) how would you rate the communication from Medical Aid International throughout the project?
    Poor communication 1 2 3 4 5 6 7 8 9 10 Excellent communication

16. On a scale of 1-10 (1 poorly supported, 10 being well supported) how would you rate the level of support from Medical Aid International throughout the project?
    Poorly supported 1 2 3 4 5 6 7 8 9 10 Well supported

17. On a scale of 1-10 (1 would not recommend, 10 being strongly recommend) how strongly, if at all, would you recommend this project to others?
    Wound not recommend 1 2 3 4 5 6 7 8 9 10 Strongly recommend

18. What is one thing that would make your job easier or more rewarding?

19. What is one thing we could have supplied that would have made the project easier?

20. What is one thing we could have changed about the project to improve it?

21. Do you consent to the use of your anonymised data in future research?
    - Yes
    - No

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Appendix 3. Participant Course Feedback Survey – Original

1. Overall, how satisfied were you with the course and the learning material?
   Least Satisfied 1 2 3 4 5 6 7 8 9 10 Most Satisfied

2. Please identify the 3 units you found most beneficial and explain why?

3. Please identify the unit/s you found the most challenging and explain why?

4. What could be improved on the course?

5. On a scale of 1-10, how likely are you to recommend the Programme?
   Very Unlikely 1 2 3 4 5 6 7 8 9 10 Very Likely

6. On scale of 1-10, how likely are you to take any future Medical Aid International Programmes?
   Very Unlikely 1 2 3 4 5 6 7 8 9 10 Very Likely

7. On a scale of 1-10, how has the course in its entirety (including toolkits and textbooks) affected your practice on a day to day basis?
   Not at All 1 2 3 4 5 6 7 8 9 10 Drastically

8. Describe a specific example where you applied something you learnt form the training.

9. How much has the course increased your motivation and confidence in the workplace?
   Not at All 1 2 3 4 5 6 7 8 9 10 Drastically

10. The course makes me better at communicating with my colleagues and the medical team.
    Not at All 1 2 3 4 5 6 7 8 9 10 Drastically

11. The course has improved my ability to train others.
    Not at All 1 2 3 4 5 6 7 8 9 10 Drastically

12. Was the information pitched at the right level, was it too easy or too difficult?
    Too Easy 1 2 3 4 5 6 7 8 9 10 Too Difficult

13. Please comment further details.

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Appendix 4. Participant Course Feedback Survey – Updated

1. How many years have you been working as a biomedical engineer/technician?

2. What is your highest level of education?
   - Secondary
   - Technical College (1–2 years)
   - University Degree (3+ years)

3. On a scale of 1–10, how satisfied are you with the course and resources?
   Least Satisfied 1 2 3 4 5 6 7 8 9 10 Most Satisfied

4. Please identify the 3 units you found most beneficial and explain why?

5. Please identify the unit you found the most challenging and explain why?

6. What could be improved on the course?

7. On a scale of 1–10, how likely are you to recommend the course?
   Very Unlikely 1 2 3 4 5 6 7 8 9 10 Very Likely

8. On scale of 1–10, how likely are you to take any future Medical Aid International courses?
   Very Unlikely 1 2 3 4 5 6 7 8 9 10 Very Likely

9. On a scale of 1–10, how much has the **course** impacted your daily work?
   No Impact 1 2 3 4 5 6 7 8 9 10 Significant Impact

10. On a scale of 1–10, how much has the **toolkit** impacted your daily work?
    No Impact 1 2 3 4 5 6 7 8 9 10 Significant Impact

11. On a scale of 1–10, how much have the **textbooks** impacted your daily work?
    No Impact 1 2 3 4 5 6 7 8 9 10 Significant Impact

12. On a scale of 1–10, how much has the **digital library of service manuals** impacted your daily work?
    No Impact 1 2 3 4 5 6 7 8 9 10 Significant Impact

13. Describe a specific example where you applied something you learnt from the training.

14. On a scale of 1–10, how confident were you in your ability to **maintain** medical equipment **BEFORE** the course?
    Not at All Confident 1 2 3 4 5 6 7 8 9 10 Very Confident

15. On a scale of 1–10, how confident are you in your ability to **maintain** medical equipment **AFTER** the course?
    Not at All Confident 1 2 3 4 5 6 7 8 9 10 Very Confident

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16. On a scale of 1–10, how confident were you in your ability to **repair** medical equipment **BEFORE** the course?
    Not at All Confident 1 2 3 4 5 6 7 8 9 10 Very Confident

17. On a scale of 1–10, how confident are you in your ability to **repair** medical equipment **AFTER** the course?
    Not at All Confident 1 2 3 4 5 6 7 8 9 10 Very Confident

18. On a scale of 1–10, how confident were you in your ability to professionally **communicate** with medical personnel **BEFORE** the course?
    Not at All Confident 1 2 3 4 5 6 7 8 9 10 Very Confident

19. On a scale of 1–10, how confident are you in your ability to professionally **communicate** with medical personnel **AFTER** the course?
    Not at All Confident 1 2 3 4 5 6 7 8 9 10 Very Confident

20. On a scale of 1–10, how confident were you in your ability to **train** others **BEFORE** the course?
    Not at All Confident 1 2 3 4 5 6 7 8 9 10 Very Confident

21. On a scale of 1–10, how confident are you in your ability to **train** others **AFTER** the course?
    Not at All Confident 1 2 3 4 5 6 7 8 9 10 Very Confident

22. On a scale of 1–10, how much do you think the medical personnel **respected** you as a biomedical engineer **BEFORE** the course?
    Not at All Respected 1 2 3 4 5 6 7 8 9 10 Very Respected

23. On a scale of 1–10, how much do you think the medical personnel **respect** you as a biomedical engineer **AFTER** the course?
    Not at All Respected 1 2 3 4 5 6 7 8 9 10 Very Respected

24. On a scale of 1–10, how easy/difficult was the information in the course?
    Too Easy 1 2 3 4 5 6 7 8 9 10 Too Difficult

25. Please provide any further comments.

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