Creation of E-Learning about ABO Grouping for Transfusion Scientists

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DClinSci 2023

Creation of E-Learning about ABO Grouping for Transfusion Scientists

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A thesis submitted in partial fulfilment of the requirements of Manchester Metropolitan University for the degree of Doctor of Clinical Science

Department of Life Science

Manchester Metropolitan University

in collaboration with NHS Blood and Transplant

2023

Contents

Abstract

Introduction:

Review of the SHOT data indicated that there is a deficiency in knowledge with the ABO blood grouping system which is in part associated with mistakes and errors. These errors have the potential to be life threatening and have been attributed to the laboratory staff. It is thought one of the reasons this has occurred is there is no available resource for staff to learn and develop the knowledge required to prevent knowledge-based errors occurring. This resulted in the creation of an easily accessible e-learning package which included interactive learning. This aimed to determine if this satisfies the users and results in both knowledge improvement and confidence of the scientist in the ABO blood grouping system.

Project Aims:

The project aimed to design an educational package which was able to run on the internet in real-time using a learning management system (LMS) platform to enable scientists to improve both their knowledge and confidence in a single topic of transfusion science (ABO Blood grouping).

Methods:

A user engagement survey was performed to ascertain the requirements from users in the Southwest of England which alongside the heamovigilance data supported the focus topic of ABO. The content of the learning was created by the author and designed into a e-learning package by a package designer. The material was trialled by student volunteers (50 participants

were invited, 19 commenced the e-learning and eight completed the project) within transfusion laboratories with knowledge assessments at predefined time points to determine the success of the final product.

Results:

An e-learning package was developed on Articulate Storyline® which allowed for interactive case studies allowing users to apply knowledge learnt through the package which students found enjoyable. As a result of the package, it was noted there was a 1.3-point increase in actual knowledge and a 1.8-point increase in perceived knowledge. A power analysis demonstrated that the actual knowledge gave a power result of 0.65 using a one-tail calculation which would demonstrate the results seen may not be replicable; however, the power calculation using a two-tail of the perceived knowledge was 0.82 which shows significant power.

Conclusion:

The project allowed for the development of an interactive e-learning project which has been shown by this feasibility study to have a benefit to knowledge and confidence in participants. The resource of the package can be used for future studies and learning opportunities both within NHSBT and externally. There were limitations with the package development and participation numbers however these can be overcome in future developments of the package.

Acknowledgements:

I want to thank NHSBT and NSHCS for all their support and opportunities with my training and my colleagues within the RCI laboratories and together with the clinical team for all their support through my training and my project.

I would also like to thank the students who completed this project, which would not have been possible without their time. When they participated, this was a trying time for the NHS as COVID-19 had taken hold, and I can never thank the BMS staff enough for finding time to look at the e-learning.

I would also like to thank both my academic workplace supervisor and my university workplace supervisor, whom, without their support and guidance, I would not have achieved a completed research project and thesis.

Finally, I would like to thank my family. My mum and sister who have always believed I had it in me to complete a doctorate. My husband, who has supported me countless times on the journey to completing the DClinSci. I would also love to thank Evelyn and Isabel, whilst they have not helped; they have been my shining light throughout my doctorate and ensured I have always kept a smile on my face despite things not always going to plan.

Glossary Document:

Academy of Healthcare Science – **AHCS**

Bachelor of Science - **BSc**

Biomedical Scientist - **BMS**

Blood Safety and Quality Regulations - **BSQR**

Blood Transfusion Laboratory Practice – **BTLP**

Bristol Online Surveys - **BOS**

British Blood Transfusion Society – **BBTS**

British Society for Haematology - **BSH**

Chief Scientific Officer - **CSO**

Clinical Scientist – **CS**

Consultant Clinical Scientists - **CCS**

Continuing Professional Development - **CPD**

Department of Health - **DoH**

Doctor of Clinical Science – **DClinSci**

Food and Drug Administration - **FDA**

Fresh Frozen Plasma - **FFP**

Good Manufacturing Practice - **GMP**

Haemoglobin – **Hb**

Health Education England - **HEE**

Healthcare and Professions Council - **HCPC**

High Titre - **HT**

Higher Specialist Scientific Training - **HSST**

Hospital Transfusion Committee - **HTC**

Information Technology - **IT**

Institute of Biomedical Science - **IBMS**

Intensive Therapy Unit – **ITU**

Internal Proficiency Exercises - **IPEx**

Joint United Kingdom Blood Transfusion and Tissue Transplantation Services Professional Advisory Committee - **JPAC**

Laboratory Manager – **LM**

Learning Content Management System – **LCMS**

Learning Management System - **LMS**

Major Haemorrhage - **MH**

Manchester Academy for Healthcare Science Education - **MAHSE**

Master of Science - **MSc**

Medicines and Healthcare products Regulatory Agency – **MHRA**

Modernising Scientific Careers - **MSC**

Myelodysplastic Syndrome - **MDS**

National Blood Transfusion Committee - **NBTC**

National Comparative Audit – **NCA**

National External Quality Assurance Scheme - **NEQAS**

National Health Service – **NHS**

National Health Service Blood and Transplant - **NHSBT**

National Institute for Health and Care Excellence - **NICE**

National School of Healthcare Science – **NSHCS**

National Transfusion Laboratory Managers - **NTLM**

Patient Blood Management – **PBM**

Practitioner Training Programme - **PTP**

Problem Based Learning - **PBL**

Quality Management System - **QMS**

Red Cell ImmunoHaematology – **RCI**

Regional Transfusion Committee - **RTC**

Research and Development - **R&D**

Royal College of Pathologists – **RCPath**

Scientist Training Programme - **STP**

Serious Adverse Blood Reaction and Events - **SABRE**

Serious Hazards of Transfusion - **SHOT**

Southwest – **SW**

Specialist Registrars – **SpRs**

Transfusion Associated Circulatory Overload - **TACO**

Transfusion Laboratory Manager - **TLM**

Transfusion Practitioners - **TP**

United Kingdom - **UK**

United Kingdom Transfusion Laboratory Collaborative - **UKTLC**

User Requirement Specification – **URS**

World Health Organisation - **WHO**

Wrong Component Transfused – **WCT**

1. Introduction:

1.1 Introduction to project:

This project was designed to look at educational practices within England in transfusion education for scientists and to develop an intervention which could be used to train Biomedical Scientists (BMS) and other healthcare professionals. The project looked at existing training platforms available to BMS staff within England and the methods of training used within these examples. The learning methods from these packages were then reviewed based on knowledge of learning styles and adapted for this project to include two methods of assessment; both knowledge expansion using a traditional e-learning package, whilst also allowing students to apply their knowledge using gamification or interactive case study scenarios. The project took a single topic of ABO blood grouping and was first of its kind in England taking both lecture style e-learning which had been seen by other groups such as the Scottish Blood Service Anti-D modules (E-learning for Health, 2020), whilst allowing for the interactive learning style seen in the BTLP TACT® modules available from UK NEQAS allowing staff to apply transfusion knowledge (UKNEQAS, 2021; Bond et al., 2017; Blakely et al., 2009). The learning was then assessed using a formative knowledge assessment.

The topic for this project was selected as ABO this was reported in the most recent Serious Hazards of Transfusion (SHOT) report as a topic in which there are a number of reported errors (n=7 in 2020 and n=3 in 2021) as well as a number of near misses (2016-2021 n=1778) which were detected but had the potential to result in patient harm (Narayan et al., 2022:25). This data is reflective of the other SHOT reports which have highlighted a deficiency both in the process of administering blood but also in the knowledge of blood

groups both in the clinical area as well as the laboratory. In the 2017 report, SHOT recommends that training and education is essential for all staff involved in the transfusion pathway with a particular focus on ABO as the impact this can have on the patient if a transfusion of the wrong blood group is administered (Narayan et al., 2018:20). The clinical context of the error was also considered which looked at the severity of the potential incident to the patient.

The risk of mortality and morbidity to a patient receiving an ABO-incompatible transfusion was the highest-scoring in clinical significance to the patient. SHOT defines major morbidity as intensive care admission, an induced coagulopathy, acute intravascular haemolysis, acute reaction which can be defined as life threatening, persistent viral infection, sensitisation to the D/K antigen in women of childbearing potential and a reaction which results in a haemoglobin which can cause a risk to life (Narayan et al., 2021:17). The literature suggests an ABO-incompatible transfusion has approximately a 30% chance of causing a significant reaction (Bolton-Maggs et al., 2016) which may potentially result in death. It should be noted out of all the reporting categories in SHOT, ABO-incompatible transfusion is described as a Department of Health (DoH) never event, regardless of the outcome to the patient (NHS Improvements, 2018). All data presented in this thesis is the authors interpretation and is not necessarily a reflection on all transfusion professionals.

The author of the project led the development of the content and the direction the e-learning package took in regards to the interaction and layout. The author created all the content for the electronic storyboards, and this can be seen in appendix 4 & 5. The author designed

the content for the media such as the videos used throughout the package and relied on a professional to create the videos (storyboards can be seen in appendix 17). The author then participated in all the editing of both the packages and also the videos ensuring the content and delivery was as the author had intended. The author also created the question bank which can be seen in appendix 6. The package designer was employed to create the visual as directed by the author as their area of expertise was not development of e-learning using the software. The package designer confirmed with the author at every step of development and all design was approved before being signed off.

1.2 Pathology within the NHS:

The National Health Service (NHS) pathology services are split into three key domains: Blood Science (Biochemistry, Haematology and Transfusion etc), Infection Science (Microbiology and Virology), and Physical/ Cellular Science (Reproductive Medicine and Histology etc). These areas are staffed by BMS, Clinical Scientists (CS) and Consultant Medical Doctors or Consultant Clinical Scientist (CCS) support (NHS England, 2020). Currently, all NHS trusts within England will have some or all the disciplines within pathology to provide results for the trust patients on site. Pathology services provide 80% of diagnoses to the clinical areas, providing an essential service to the NHS and its patients to ensure patients are managed appropriately (NHS England, 2021). The formation of pathology networks between trusts is underway and will result in a change in laboratories' locations having a hub and spoke model but will not affect the staff required to work in them (Satta and Edmonstone, 2018).

Staff working within pathology undergo specialist training both at university to obtain a Bachelor of Science (BSc) degree in Biomedical Science and complete a registration portfolio assessed by the Institute of Biomedical Scientists (IBMS). Once BMS staff have completed their training, they can register with the Health and Professions Council (HCPC) (IBMS a, 2021, HCPC, 2014). Upon registration, they can gain employment as a BMS and receive local training within their department. There are then further opportunities to gain additional qualifications, which allow for additional development within the profession.

Scientific staff are graded in bands that were created under Agenda for Change within the NHS. These bands are graded based on the job and the qualifications required for the role

(Williamson and Williams, 2011). The bands and examples of their job roles can be seen in table one below (NHS Employers, 2020).

Table 1 Agenda for Change Bandings and Job Roles within the NHS:

Band	**Example Job Roles**
4	Associate Practitioner, Senior Medical Laboratory Assistant
5	Trainee BMS, newly qualified BMS
6	Specialist BMS, CS Trainee
7	Senior BMS, newly qualified CS, CCS Trainee
8a and above	Laboratory Managers (LMs), Senior CS, CCS

1.3.1 Pathology Training Modernisation:

Training at the postgraduate and undergraduate level has been redesigned within England. The reorganisation of pathology training was introduced in 2011 when Modernising Scientific Careers (MSC) was launched; initially with the Scientist Training Programme (STP) designed for training CS within pathology disciplines and other areas of the NHS (Hill, 2010).

The STP programme is a three-year training course in which postgraduate students rotate within four areas of pathology, including their specialist discipline, for the first year before spending the final two years specialising (NSHCS a, 2021). The STP training in transfusion involved both work-based training with the completion of a portfolio and a master's degree (MSc) provided by Manchester Academy of Healthcare Science Education (MAHSE) (NSHCS b, 2021). These students must complete both the academic and work-based components before completing an exit exam, which required a pass before being eligible to apply to the HCPC as a CS.

MSC was then extended to BMS training with the Practitioner Training Programme (PTP). Implementation of MSC changed how Biomedical Science degrees were operated and how the students gained the practical experience required to complete the IBMS registration portfolio to obtain registration with the HCPC as a BMS. Students were released throughout the three-year degree to complete short laboratory-based placements within their chosen domain (e.g., Blood Science, Infection Science or Cellular Science). The placements varied in length throughout the course and allowed the students to complete both the PTP portfolio and the IBMS portfolio (NSHCS c, 2021). Once the academic course and the work-based assessments

were complete, trainees could then apply to the HCPC for registration as a BMS. These courses have operated alongside the traditional BMS courses where students enrolled for four years, which included a placement year within a laboratory to complete their registration portfolio (The Biomedical Scientist, 2018). Universities and laboratories have found the PTP degree hard to manage, and found the students were not getting sufficient time either in the laboratory or the university to complete their training (The Biomedical Scientist, 2018). Therefore, recently there has been a return of students to the more traditional co-terminus degree course (Pitt and Cunningham, 2011) to educate the future BMS staff.

The final stage of the training revolution as part of MSC was the Higher Scientific Specialist Training (HSST) programme to train CCS within pathology disciplines. HSST provided a new level of scientist previously covered by consultant clinicians and not historically seen in all pathology disciplines. The HSST training programme is a five-year training programme that involves three components for blood science students. These are: the completion of the Doctor of Clinical Science (DClinSci), completion of a work-based assessment portfolio on OneFile and the completion of the Royal College of Pathologists (RCPath) fellowship exams (NSHCS d, 2021). The HSST training programme was created to provide the student with the clinical knowledge required of a CCS and the leadership and management skills required of a clinical lead (Allard and Ferry, 2021).

There is work ongoing to develop other career framework levels, such as Healthcare Scientist Associates (Band four) which is an evolving role due to the increase in automation used in pathology laboratories. They require work-based training to create a highly specialised

workforce. These staff can register on a voluntary register provided by the Academy of Healthcare Science (AHCS) (National School of Healthcare Science, 2022).

As part of MSC, the expansion of knowledge around other areas of pathology as well as leadership (Hill, 2010) was crucial and specialist knowledge in the practitioner discipline was achieved by rotations, leading to a workforce that can appreciate other areas of pathology. An example of this includes all Healthcare Scientists working within blood science have experience in genomics, an increasing field continually evolving and expanding its remit within pathology. This increase in training in other departments has reduced the time spent in the specialist area. For example, in haematology and transfusion at the CS level, only a quarter of the first year is spent within the two departments. The second and third year are spilt between haematology and transfusion. These two departments are referred to as a single discipline; however, there is a workforce requirement to make these individual training pathways. This is further diluting the specialist knowledge of this staff group who may have historically specialised in either transfusion or haematology. This has been acknowledged at the HSST level, where there is a course for haematology and a course for transfusion allowing CCS to specialise within their chosen field.

1.3.2 Medical Training within Pathology:

Medical professionals' training within pathology has decreased and there are fewer pathology lectures provided during their degree courses, resulting in a reduction in the baseline knowledge of newly qualified doctors (Marsdin and Biswas, 2013; Duguid and Copplestone, 2008). This is then further impacted by reducing the clinical time allocated for laboratory rotations both as medical students and junior doctors (British Society for Haematology, 2020). This is seen in transfusion, for example, where Specialist Registrars (SpRs) historically spent time in the laboratory to understand the techniques used and how to interpret their patients' results (Marsdin and Biswas, 2013). They are then expected to support the clinical transfusion laboratory as part of their rotations (British Society for Haematology, 2020; RCPath a, 2021; NSHCS HWWG, 2020).

There is also an increase in the clinical workload for SpRs; for example, a Haematology SpR is often responsible for Haemato-Oncology, General Haematology, Thrombosis, and Anticoagulation, as well as laboratory Haematology/Transfusion (British Society for Haematology, 2020). The increase in the workload of a haematology SpR directly impacts on their ability to spend time in the laboratory as the clinical need outweighs the requirement for the learning of laboratory techniques (British Society for Haematology, 2020).

Reduction in clinical leadership was highlighted in the workforce review conducted by the BSH of all Haematologists (British Society for Haematology, 2020) showing there is insufficient clinical leadership and is being combatted in part by introducing CCS. These scientists can provide leadership and excellent clinical and laboratory knowledge bridging the

gap between the laboratory and the clinical environment and there are some success stories within NHS Trusts in England (NSHCS HWWG, 2020). CCS are being used within NHSBT due to the loss of experienced Consultant Haematologists retiring. Therefore, CCS can support the remaining Haematology Consultants with their expertise within the Red Cell ImmunoHaematology (RCI) laboratory (Williams, 2016)

1.3.3 Transfusion Scientific Workforce:

Transfusion has always been traditionally paired with haematology, with most scientific staff covering both disciplines whilst falling under the broader remit of blood science encompassing biochemistry and immunology. Staff need to have vast specialist knowledge of two disciplines (haematology and transfusion) to maintain competency and demonstrate an appropriate level of knowledge currently required by a BMS. This is demonstrated by the IBMS specialist portfolio, which requires specialist knowledge of both haematology and transfusion for one of the two specialist portfolios resulting in knowledge being spread too thinly. There are advantages to have a scientist trained in both haematology and transfusion. There needs to be a fundamental understanding of full blood count results and coagulation results to allow for appropriate use of blood for patients. Furthermore, this allows for a scientist to be able to work as part of a multidisciplinary team to ensure best care possible and allow for flexibility in the workforce (Pearse and Scott, 2023). It does however come at a disadvantage of having knowledge spread across two or more disciplines which may reduce expertise in a single discipline and prevent specialist level of knowledge being obtained for scientific staff. This may result in mistakes which have an impact on patients (Osaro and Chima, 2014). This is not replicated in other disciplines which have historically been paired together, such as histology and cytology (IBMS b, 2021) which are no longer training scientists as multidisciplinary but are creating individual training paths to ensure expertise and the demands on the service increased (Dudding, 2016).

Some laboratories have further expanded their BMS staff's remit to include covering the whole of blood science, e.g., immunology, biochemistry, haematology, and transfusion, expanding

their required knowledge further. This is further supported by the United Kingdom Transfusion Laboratory Collaborative (UKTLC) surveys and has shown an increase in the number of multidisciplinary staff working within transfusion (Bark et al., 2016). BMS staff are required to maintain both knowledge and competency within all these disciplines, meaning there is a reduction in specialist knowledge (NSHCS HWWG, 2020). The Pathology networks has also increased the requirement for multidisciplinary staff at the smaller automated laboratories (Beastall, 2008; Bolton-Maggs et al., 2019) with no colleagues to discuss results with onsite. The increase in service demand and the use of multidisciplinary and junior staff (Bolton-Maggs et al., 2019; Narayan et al., 2019) due to an increase the automation available has led to a reduction in the ability to deal with minor problems with samples and increase the need for remote specialist advice (Hill, 2010).

The UKTLC recommended that staff working within transfusion as a lone worker must have a specialist level qualification in transfusion such as the British Blood Transfusion Society (BBTS) specialist certificate or an IBMS specialist diploma equivalent (Chaffe et al., 2014) and it is noted this is not always achieved (Bolton-Maggs et al.,2019). It is recognised in most trusts BMS staff may be covering both haematology and transfusion overnight and this was demonstrated in the 2019 UKTLC survey (Bolton-Maggs et al., 2019), which increases the burden on the member of staff.

1.3.4 Demand on the Scientific Workforce:

Over the last 20 years, there has been an increase in the demand for haematology services, with more patients presenting with haematological issues which historically had a poor prognosis; however, this has improved with better treatments being researched and available, leading to a better outcome for patients (Hallworth et al., 2002). There is also an ageing and diverse population within the United Kingdom (UK) (Andah et al., 2018), which increases haematological conditions associated with older patients, such as Myelodysplastic Syndrome (MDS) as wells as haemoglobinopathy disorders which require management by a Haematologist and laboratory requiring transfusion therapy (PHE Gov.UK., 2018; Trompeter et al., 2020). Increases in haemoglobinopathies are reported due to increased neonatal and prenatal testing (Ryan et al., 2010) as well as improved management of these patients due to specific guidelines (Davis et al., 2017).

The diversity of conditions being seen in the haematology patient cohort results in an increase in the volume of work and requires a specialist level of knowledge (Bolton-Maggs et al., 2019; Hill, 2010; RCPath, 2017). There are also developments in the technologies requiring expanding knowledge, such as the routine use of red cell genotyping for some patient cohorts (Belsito et al., 2017) such as patients with haemoglobinopathies (Trompeter et al., 2020).

A BMS working in haematology in a large teaching hospital could be expected to know all of these areas: general haematology, morphology, coagulation, haemoglobinopathy screening, flow cytometry for immunophenotyping, molecular haematology and transfusion (NHS Jobs, 2023) this can be seen by looking at a BMS job description for a haematology and transfusion

BMS as this is not available in the literature. Historically BMS staff would have specialised in one area of haematology and transfusion, which is not the case now (NSHCS HWWG, 2020). Whilst some of this is alleviated by the introduction of more automation, it can cause issues where complex patients results cannot be resolved using automated techniques alone (RCPath, 2017). It can also cause problem-solving problems if an investigation fails, as automated technologies are seen as a black box and scientific staff do not always understand the methods they use (Bark et al., 2016).

1.4 What Evidence is there for Issues with the Transfusion Workforce:

The combination of a reduction in medical knowledge and scientific knowledge in the clinical and laboratory workforce has led to an increasing number of errors that may directly impact patient outcomes as seen in the most recent SHOT report with 81.6% of all reports received being related to errors although not all of these errors are directly attributed to training and education (Narayan et al., 2021:14) this can be seen in figure one. It has been acknowledged this needed addressing to ensure there is adequate laboratory support to prevent some of the errors through learning from incidents and near misses (Narayan et al., 2021:23).

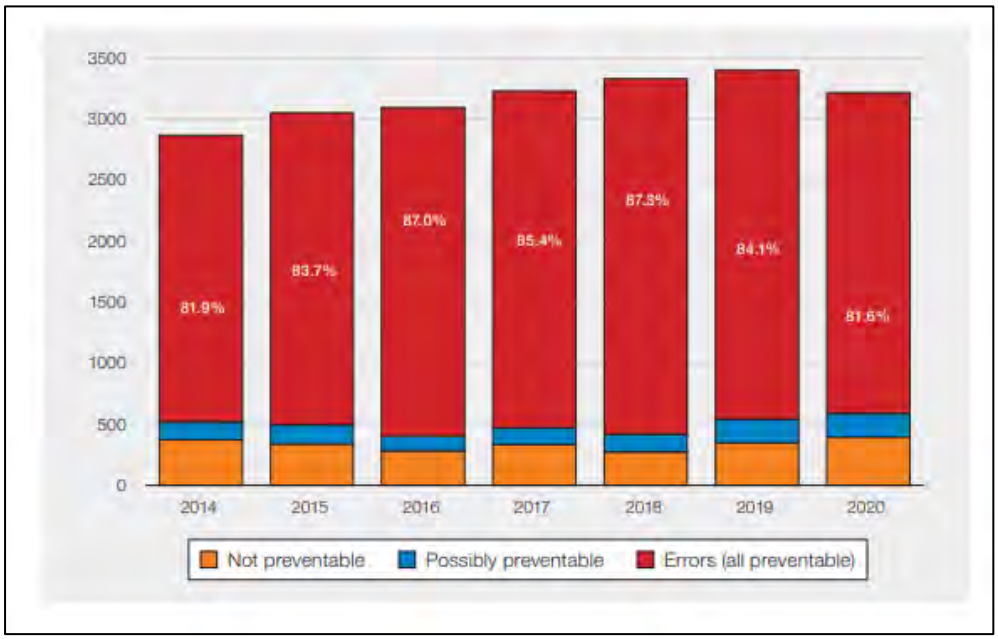


Figure 1 – Errors as a percentage of reports 2014-2021 (Narayan et al., 2021:15)

Transfusion has two haemovigilance systems, SHOT and the Medicines and Healthcare products Regulatory Agency (MHRA) who both report through the electronic reporting site 'SABRE' (Serious Adverse Blood Reaction and Events) (MHRA, 2013; SHOT, 2021). The

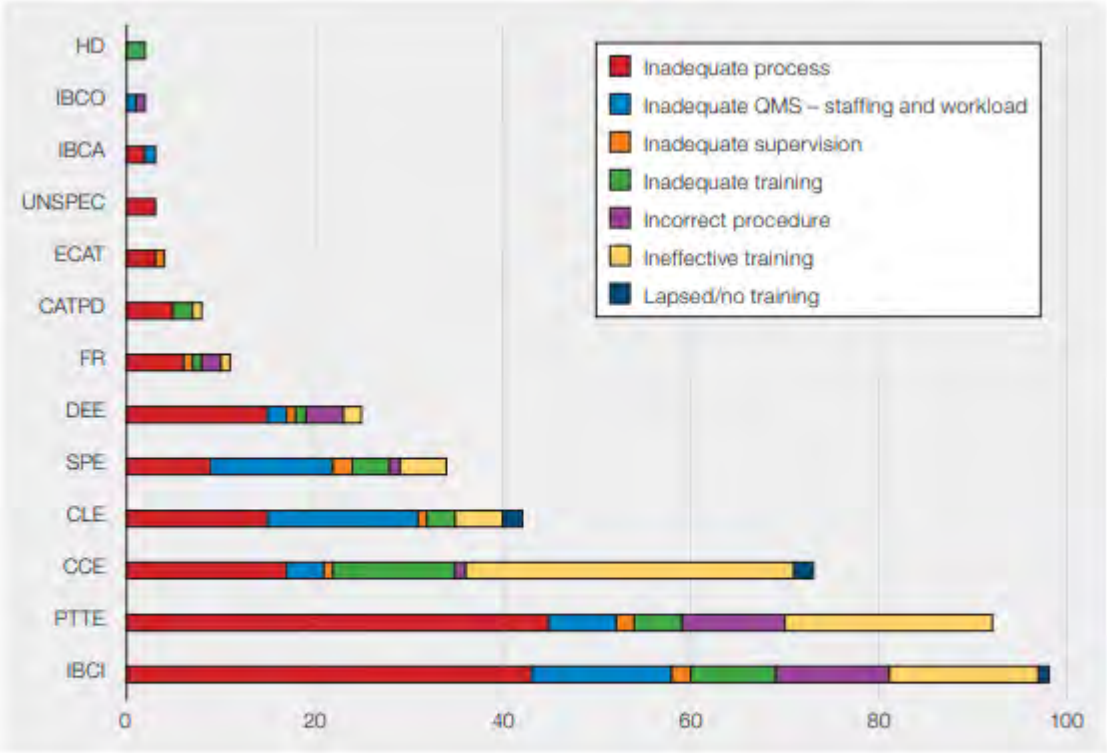
MHRA is the competent authority to ensure compliance with the Blood Safety and Quality Regulations (BSQR) for transfusion (Narayan et al., 2020) from the EU directive 2005. Together they have shown there has been a noted increase in the number of reports within transfusion.

The decrease in knowledge and expertise has been highlighted within transfusion with an increase in the number of errors reported both internally within hospital or National Health Service Blood and Transplant (NHSBT) via their local Quality Management System (QMS) and externally to the two national haemovigilance schemes (SHOT and MHRA). However, a reduction of knowledge and training is not the only cause of errors. Transfusion errors can be eliminated in part by taking a particular focus on human factors such as the environment and cognitive biases (Bolton-Maggs and Watts, 2020). Whilst addressing education within the workforce may address some errors, additional interventions need to occur to further minimise risk (Narayan et al. b, 2021) and prevent some of the slip errors seen (Dzik, 2006).

The MHRA focuses on laboratory-based errors and adverse reactions in patients and is responsible for ensuring the safety of transfusion practice and have noted a reduction in the knowledge of the staff currently working within transfusion which has led to some of the reports received. These errors have been steadily increasing over the past few years with a slight decrease in 2020 which may be explained by external factors such as the COVID-19 pandemic reducing reporting (Narayan et al., 2021:15). The increase in errors seen may have coincided with the introduction of the MSC courses in 2011. These courses have increased the BMS staff's training, requiring staff to rotate through blood science (NSHCS, 2020c; The Biomedical Scientist, 2018). This expansion of knowledge has resulted in qualified staff

entering the workforce with a greater breadth but less depth of knowledge than historical newly qualified BMS / CS staff. It has been noted in the 2018 SHOT report that 19.9% of the errors can be attributed to the laboratory (reported to be lower due to COVID-19) (Narayan et al., 2021:130).

Inadequate training has also been highlighted as an issue in a chapter of the 2016 SHOT report written by the MHRA. It describes the root causes for errors reported to SABRE and demonstrated that insufficient staff, both absolute numbers and appropriately qualified, alongside inadequate training could be a cause of errors reported to SABRE (Bolton-Maggs et al., 2017:216). This is supported by 25.4% of errors occurring during lone working which would indicate that staffing and training are resulting in errors amongst other causes (Narayan et al., 2022:141). These data can be seen from the 2020 SHOT report in figures 2 and 3 and is reflective of the picture seen in previous years reports (Narayan et al., 2021:233). Figure 3 also highlights the other causes for error seen in the SHOT reports which contribute a considerable proportion of the errors made. The author has taken a focus on ineffective or inadequate training as a cause of error for this thesis but acknowledges there are other causes. Errors are usually attributed to multiple causes referred to as the 'Swiss Cheese effect' (Narayan et al., 2022:77).



HD = handling damage; IBCO = incorrect blood component ordered; IBCA = incorrect blood component accepted; UNSPEC = unspecified; ECAT = expired component available for transfusion; CATPD; component available for transfusion past de-reservation; FR = failed recall; DEE = data entry error; SPE = sample processing error; CLE = component labelling error; CCE = component collection error; PTTE = pre-transfusion testing error; IBCI = incorrect blood component issued

Figure 2: National Data – The reporting event subcategory and the root cause for the serious adverse event. (Narayan et al., 2021:233)

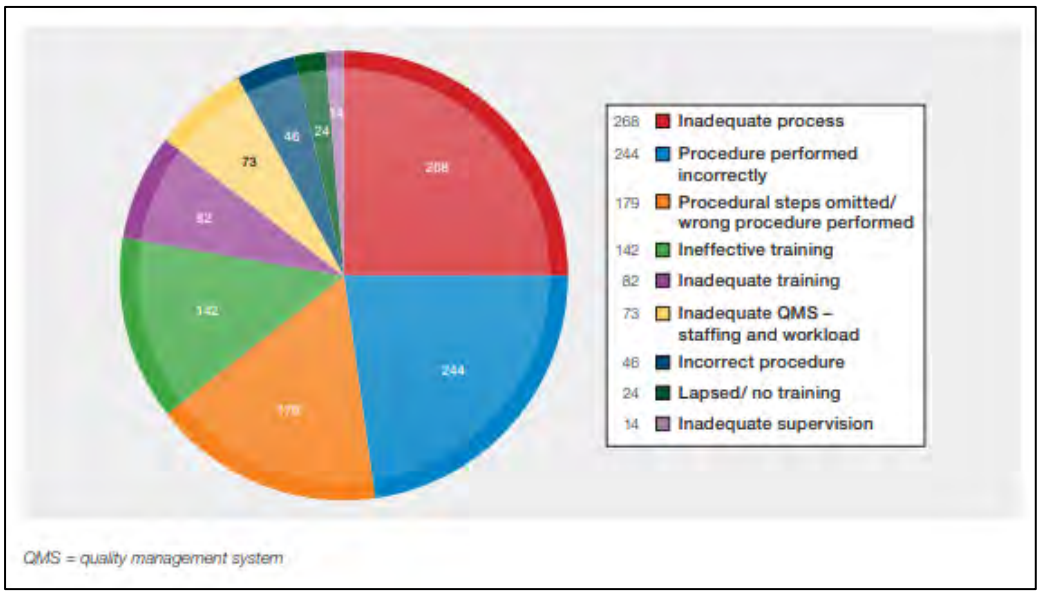


Figure 3 – Human error subcategory for reports received in 2020 – National Data (Narayan et al., 2021:230)

Figure three is taken from the SABRE chapter in the 2020 SHOT report (Narayan et al., 2021:230) and provides the national data, highlighting how training or knowledge was the cause of many of the laboratory errors (n=248), providing further evidence that unless there is a change in education and training, patient safety may continue to be compromised. There is evidence in the literature that shows access to educational interventions improves patient safety and reduces knowledge-based errors (Gallagher-Swann et al., 2011; Sahmoud et al., 2021).

Figure four below highlights the error rate reported to SHOT in the years 2016-2020 for laboratory errors. This figure demonstrates a decrease in numbers for some of the reporting categories. This may be due to a downward trend for the total number of reports received from external organisations although it should be noted there has not been a noted decrease in overall reports received (Narayan et al., 2021:6). It is noted that not all errors are reported to SHOT for many reasons including staff workload, indicating there has not necessarily been an improvement in the quality, just insufficient reporting (Narayan et al., 2020:5). Whilst the total numbers of reports received attributed to the laboratory scientists remains low these should not be occurring and are often because of human factors such as distraction, workload etc. and poor training which is often attributed as a root cause in the incidents reported in the SABRE data (Narayan et al., 2021:233).

Figure 4 – Laboratory errors 2016-2020 categorised by the step where the error occurred (Narayan et al., 2021:130)

Most of the errors which have the most risk of serious morbidity or mortality seen in the SHOT reports historically, including ABO-incompatible transfusions, were made in the clinical areas e.g., on the wards by clinical staff. However, recently, there has been an increase in these errors occurring in the laboratory, which can be attributed to insufficient knowledge and understanding of basic transfusion concepts. This was seen in the 2019 report where three of the six errors occurred in the laboratory (Narayan et al.,2020:19,105). The SHOT report also highlights other causes for errors which include staff shortages, automation / IT failures, wrong blood in tube and communication although this is not an exhaustive list (Narayan et al., 2022:78, 88,91).

An example can be seen in the 2019 SHOT report, a BMS released an ABO incompatible unit of Fresh Frozen Plasma (FFP) due to a lack of understanding of blood groups and guidelines

(Narayan et al., 2020:61). The patient had the major haemorrhage (MH) protocol activated for a bleed, and the BMS in the laboratory selected group O FFP as part of the MH pack. They had applied the theory that group O is a universal product, and whilst this applies to red cell products, it is not the universal product for plasma. Joint United Kingdom Blood Transfusion and Tissue Transplantation Services Professional Advisory Committee (JPAC) define the universal plasma product as group A High Titre (HT) negative due to being unable to get sufficient AB donors which is truly universal due to no ABO antibodies present. Although this patient unfortunately died, this was not attributed to the transfusion (Narayan et al., 2020:61). There have unfortunately been further examples of this in other SHOT reports where laboratory-based errors have resulted in ABO-incompatible blood products being issued to patients (Bolton-Maggs et al., 2019:112; Narayan et al., 2021:20). While this example can be attributed to a lack of understanding of the essential blood group concepts, some of these errors can also be attributed to reduced staffing levels and experience in the departments with an increase in service demand as well as IT failures (Bolton-Maggs et al., 2019; Narayan et al, 2020:19,21). SHOT has recognised the importance of knowledge gaps in the cause for errors and human factors such as staff shortages, time pressure, and other distractions leading to significant errors (Bolton-Maggs et al., 2019; Narayan et al., 2021:137). There has been work from SHOT since 2016 promoting the importance of human factors (Narayan et al., 2021:23) and also providing training resources such as a PowerPoint® to all staff in transfusion to reduce the impact of these on the service, and training material can be seen on the SHOT website (SHOT a, 2020).

The requirement to improve training and knowledge of the existing staff is also recognised as a requirement by the National Transfusion Laboratory Managers (NTLM) team and the National Blood Transfusion Committee (NBTC) (Bolton-Maggs et al., 2019). The deficiency

in training within transfusion has also been highlighted as an issue at a national level by the Chief Scientific Officer (CSO) and the Transfusion 2024 strategy (Allard et al, 2021). The CSO and Transfusion 2024 team have recognised there is a knowledge gap and have described actions that need to be implemented to resolve some of the issues with training seen in transfusion (NBTC & NHSBT, 2020). This report was the first nationally recognised report with support from all organisations involved in transfusion and is aimed at improving transfusion services nationally by targeting four key areas within the transfusion pathway. These are Patient Blood Management (PBM), transfusion laboratory safety, information technology and recommendations for further research and development (R&D) (Roberts, 2021). Within these key themes, there is a list of recommendations and actions to achieve these which are summarised in table two below (NBTC & NHSBT, 2020; Allard et al, 2021). The report has taken recommendations from the UKTLC findings and provided the evidence in a published document which is being used to drive change within transfusion (Allard et al., 2021). The transfusion workforce had been trying to implement the UKTLC requirements from Chaffe et al., (2014) but had been unsuccessful due to no national support from organisations such as Health Education England (HEE) meaning hospital management had not taken on board most of the recommendations (Bolton-Maggs et al., 2019). Transfusion 2024 tackled this and ensured support and money from HEE to ensure trusts are required to act and implement the recommendations to improve the transfusion service within England (Allard et al., 2021).

The strategy aligns with the UKTLC requirements for adequate training of BMS staff with minimum expected qualifications for bandings (Chaffe et al., 2014) and this is addressing both higher education and workplace training (Allard et al., 2021). Transfusion 2024 came about after the design of the project. So, the project was not aligned to the strategy however some of

the outputs and findings from the project are being used by the NHSBT chief scientific officer to inform some of the strategy (Personal Communication, 2023).

Table 2 -Transfusion 2024 Summary of recommendations (NBTC and NHSBT, 2020; Allard et al., 2021):

Patient Blood Management	Self-assessment of transfusion practice for hospitals to allow for bench marking
	Provision of resource to support clinical transfusion practice to include a national competency framework for transfusion practitioners.
	The inclusion of transfusion in national patient quality and safety initiatives
Laboratory Safety:	The review and strengthening of scientific training available nationally.
	Ensuring there is adequate staff and mix of staff within transfusion laboratories as described in the UK TLC standards (Bolton-Maggs et al., 2019)
	Initiating an integrated transfusion service.
	Creation of regional transfusion networks in alignment with national pathology networks.
	Continuation of work with integrating compliance with both the UK accreditation service and MHRA in order to reduce the compliance burden.
	Continue to encourage adverse event reporting to an independent body (SHOT).
Information Technology:	Creation of a blueprint for laboratory information system suppliers to improve the safety and allow for bi-directional communication between NHSBT and the hospitals.
	Electronic blood tracking from donor to patient available at all hospital Trusts.
Research and Development:	Encourage the use of data driven transfusion practice.
	Continuation of component development aligned to the patient needs.
	Increase phenotyping performed on both patients and blood donors.
	Continuation of transfusion research and seeking funding.

1.5 Evaluation of external reporting for service evaluation, e.g., SHOT and SABRE, to determine a topic of focus for the e-learning package:

A review of the SHOT data for the period of 2013-2016 was performed when deciding on a focus topic. A review of international haemovigilance data would have been preferential but this was not possible as this data is not publicly available (Politis et al., 2016). Figure five summarises data from the SHOT report for 2016 and figure six is the cumulative data from 1996 to 2016. As part of this project there was a focus on the near miss, acute transfusion reaction and incorrect blood component transfused data as this datum will encompass the ABO errors, which are included in figure five and six.

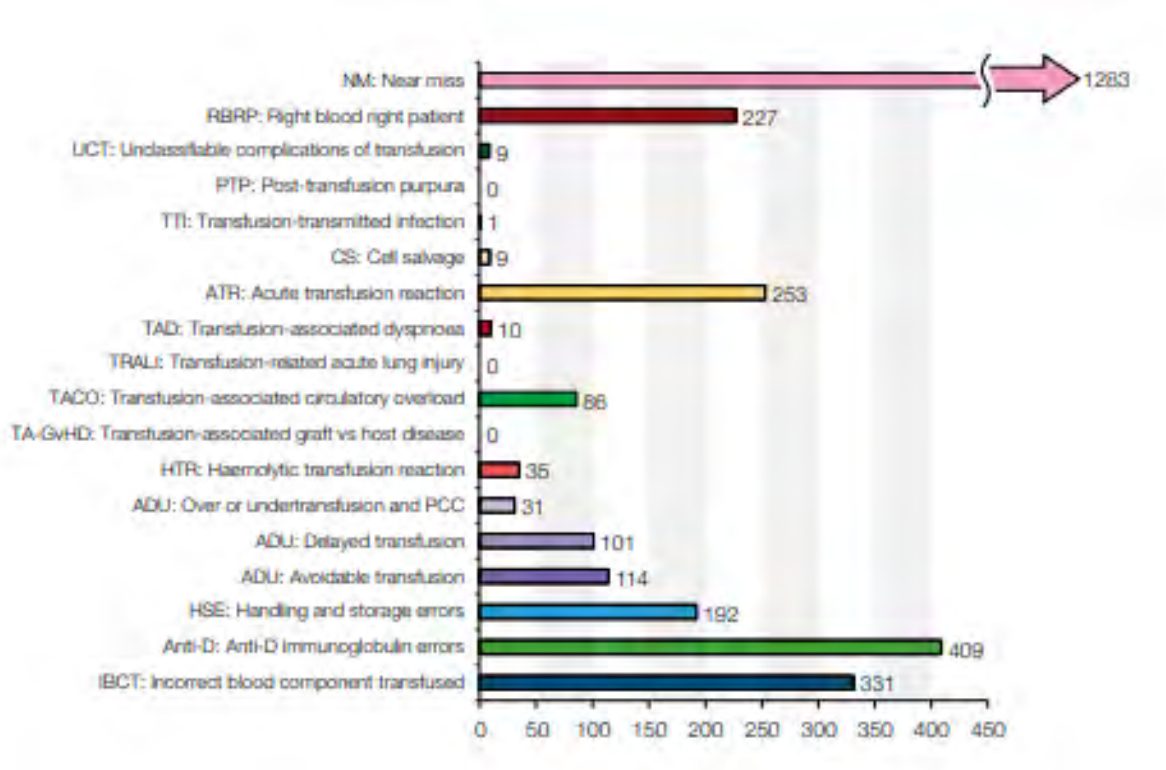


Figure 5 2016 data for the total number of errors, near misses and transfusion reactions reported to SHOT in the defined SHOT categories (Bolton-Maggs et al., 2017:13).

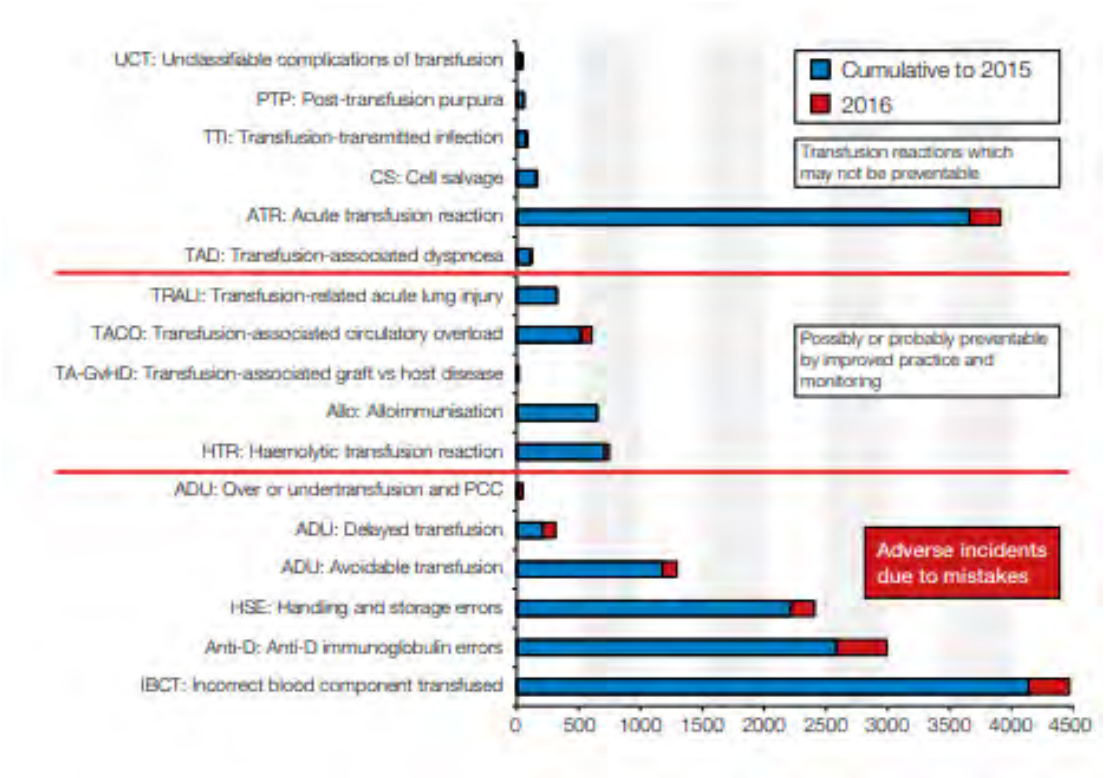


Figure 6 Cumulative data for the number of errors, near misses and transfusion reactions reported to SHOT within the defined SHOT categories 1996 -2016 (Bolton-Maggs et al., 2017:13).

As can be seen in figure five, the highest number of reports received in 2016 was for near-miss events, which are not further subcategorized in this section. Near miss events provide an opportunity to learn and are often discussed within the SHOT report's chapters and supplementary material. For example, the number of ABO-incompatible transfusions near misses reported in 2016 (n=264) is nearly 100-fold more than actual ABO-incompatible transfusions (n=3) (Bolton-Maggs et al., 2017:16). This provides evidence of underlying issues which current systems in the transfusion laboratories detect before they cause any harm to the patient. These systems include rules within IT to ensure incompatible blood cannot be released, bedside checks to confirm the correct blood group is given and electronic blood tracking

systems which aim to improve blood transfusion safety for patients (Rothschild et al, 2007). However, technology alone is not sufficient to ensure patient safety (Neville, 2008). A review in Portugal showed that 2.2% of the errors reported were down to ABO incompatibility which highlights this in not a UK problem but a wider issue (Escoval, 2014). This was supported by an article by Politis et al., which showed there were 511 ABO incompatible transfusions internationally between 2006-2012 (2016).

The second-highest reporting category was Anti-D errors in 2016 (n=409) to SHOT which was a combination of clinical and laboratory errors. A high percentage of the reports were due to storage and handling errors and late administration/omission of anti-D immunoglobulin (Bolton-Maggs et al., 2017:124). As there is already an e-learning package targeting anti-D immunoglobulin administration, and this is currently in review, this was not chosen for this project (E-learning for health, 2020; E-learning for health, 2023).

The next highest reporting category in 2016, which has been persistently high in other years, is incorrect blood component transfused (n=331) (Bolton-Maggs et al., 2017:60). This category includes specific requirements not met, incorrect blood component, e.g., giving plasma instead of platelets, and ABO-incompatible transfusions. The risks of each of these subcategories were assessed by reviewing the risk of mortality and morbidity to a patient. Patients receiving an ABO-incompatible transfusion was the highest-scoring in clinical significance to the patient as an ABO-incompatible transfusion has the greatest risk of causing major morbidity or mortality (Narayan et al., 2019:20).

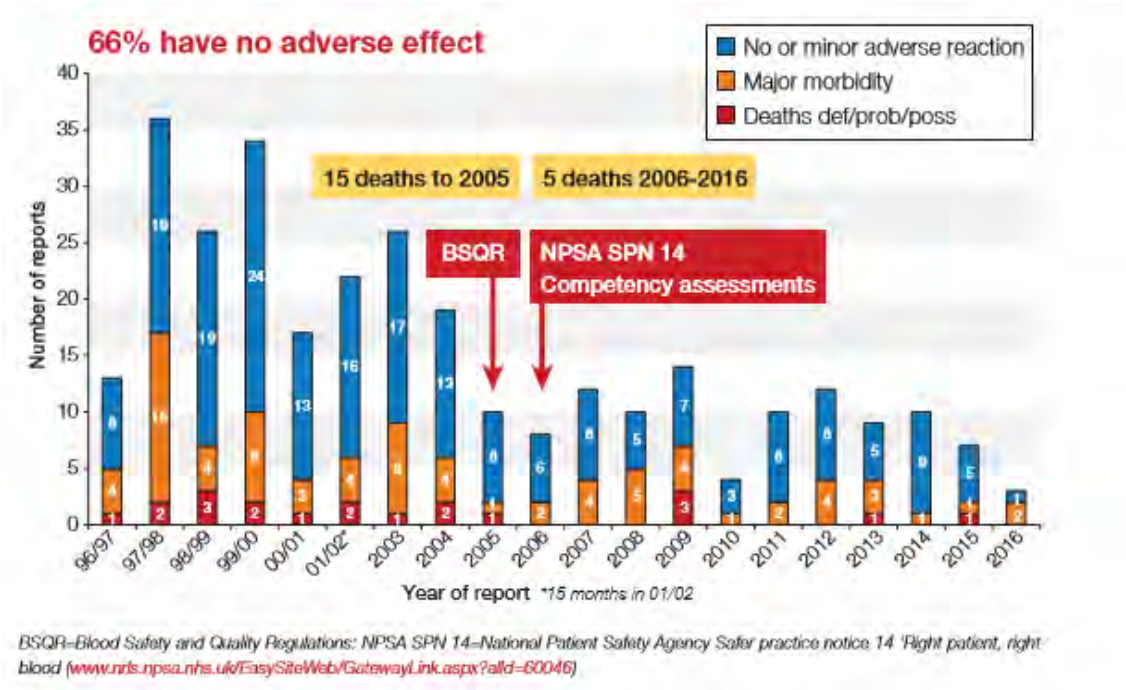


Figure 7 Outcomes of ABO incompatible transfusions 1996 – 2016 (Bolton-Maggs et al., 2017:16)

Figure seven indicates the mortality and morbidity associated with a patient receiving an ABO-incompatible transfusion taken from the SHOT reports (Bolton-Maggs et al., 2017:16). It has demonstrated a reduction in deaths and significant morbidity since SHOT began reporting in 1996. However, it highlights that whilst there has been a reduction in the reported events, there is still an issue with patients receiving ABO-incompatible transfusion. In the years 2013-2016, the data used to influence the project; there were two deaths and seven major morbidities reported in patients (Bolton-Maggs et al., 2017:16). Whilst the total number of ABO-incompatible transfusion reports remain in single figures each year, there is an increasing number of near-miss events related to ABO-incompatible transfusion reported to SHOT. Whilst these errors do not result in harm as the standard procedures (including laboratory information systems, staff training and electronic blood tracking) within the laboratory usually detect them, they have the potential to cause patient impact.

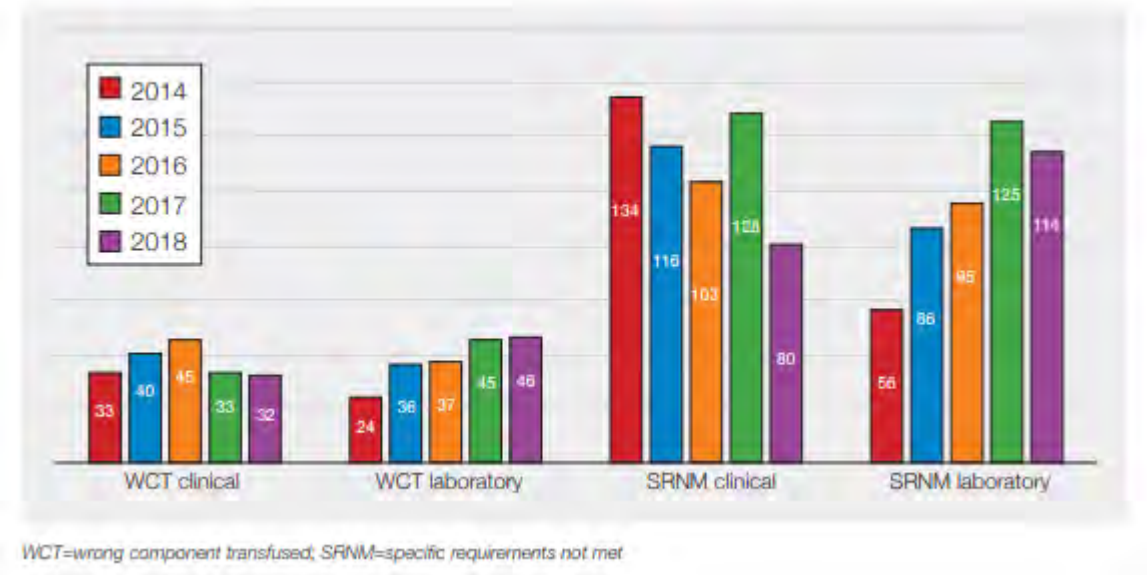


Figure 8 Wrong component transfused (WCT) figures and specific requirements not met for clinical and laboratory (Narayan et al., 2019:49)

Historically ABO-incompatible transfusions used to be associated with errors derived from the clinical area where there were lapses with the bedside check. This can be seen in figure eight, which demonstrates wrong component transfused and includes ABO-incompatible transfusions (Bolton-Maggs et al., 2019:49). However, the number of these errors associated with the laboratory has increased and now exceeds the clinical errors. In 2019 there were six ABO incompatible events four were associated with red cells and two with plasma; 3/6 of the ABO-incompatible events were ascribed to laboratory errors in selecting the wrong component (one red cells and two plasma cases) (Narayan et al., 2020:60). This includes all blood products in various settings such as routine transfusions and fast-paced scenarios such as major haemorrhage (Narayan et al., 2019). These data do not include when the laboratories issue a component that is not compatible with an antibody a patient has or does not meet the patient's specific requirements. Upon further investigation, by reading the SHOT reports particularly focusing on incorrect component transfused and the laboratory error chapters, it could be

ascertained these errors were often due to a combination. The causes included reduction in staff numbers as well as training issues which include knowledge of the staff both newly qualified and existing (Narayan et al., 2020:67). This is also highlighted in article by Bolton-Maggs et al. (2019).

There is a recurring challenge with certain aspects of ABO testing and issuing of blood products which includes post stem cell transplant patients whose blood grouping and product support can be challenging to manage and changing groups (Narayan et al., 2020:67). There are multiple reasons this is challenging: patients not having appropriate flags on the laboratory computer systems allowing the issue of incompatible blood, the conversion of blood groups being difficult to interpret, and laboratory computer systems that allow for incorrect blood groups to be selected. There is also an issue with the use of plasma products deemed universal (Narayan et al., 2020:60). Most years, there are case examples where BMS staff have incorrectly selected group O plasma products, assuming these are universal as would be the case for red cells. The computer system should detect these errors; however, this is not always the case due to the complicated coding required (Narayan et al., 2020:60). Therefore, there was a focus in both the beginner and the intermediate packages on dealing with ABO mismatches during stem cell transplant and universal blood groups for all products to include red cells and plasma.

1.6 Current Education Options in Transfusion within the UK:

Transfusion is usually taught with haematology both at the medical level and the scientific level meaning the subject matter is not always taught by a subject matter expert as it is often a haematology specialist teaching the transfusion content (Panzer et al., 2013). This has been highlighted as a deficiency in training and there is currently no solution found, which may reflect why the BMS staff's knowledge is reduced (Bolton-Maggs et al, 2019; Allard et al, 2021).

The STP and the PTP qualification routes both require the students to undergo training in both disciplines and no specialist training route available in transfusion. A PTP curriculum was designed with transfusion and transplantation (instead of the whole of life sciences) being the sole focus; however, it has not been used currently (NSHCS e, 2021). The STP requires students to undergo three out of the five modules in haematology, with only two being covered in transfusion. A curriculum review is currently being performed, aiming to address concerns over an STP in transfusion by having a shared first year and more separation from haematology in the second and third years (NSHCS f, 2021).

The HSST is available in transfusion alone (NSHCS HWWG, 2020; British Society for Haematology, 2020), and was approved in 2015 (NSHCS d, 2020); however, currently BMS staff are required to undergo equivalence as a CS to embark on the training or complete CS training before commencing the HSST. This has resulted in a barrier in achieving large numbers of trainees as there are very few CS within transfusion. However, there is a change

in the entrance requirement for the HSST commencing in 2021 and suitably qualified BMS will be eligible to apply for the HSST training (IBMS c, 2021).

Transfusion education is currently delivered in many formats across England and the rest of the United Kingdom (UK), leading to variation in the level and subjects covered (Allard et al, 2021). There are courses run by higher education institutes such as universities to PTP and STP level which use didactic lectures (NSHCS h, 2021; IBMS a, 2021; University West of England, 2021), courses run by professional bodies such as the BBTS to increase specialist knowledge level which use collaborative learning (BBTS, 2018). SpRs in haematology are currently offered courses run by NHSBT before their RCPath exams to supplement training they received at medical school whilst receiving education from other sources too such as study days (Duguid and Copplestone, 2008; FRCPath b, 2021). There are also courses for scientific colleagues using didactic lectures and practical assessments, but these are optional and not compulsory (NHSBT, 2021; Allard et al., 2021). Examples of these qualifications available in England can be seen in table three below with the target audience.

Table 3: Transfusion qualifications currently available in the England

Course	Level	Target Audience
Practitioner Training Programme (NSHCS h, 2021)	Undergraduate degree leading to BSc in Biomedical Science Blood Science – Not transfusion specific - provided by multiple higher educational institutes	Students aiming to become BMS
BSc Biomedical Science (IBMS a, 2021)	Undergraduate leading to BSc in Biomedical Science- Not transfusion specific - provided by multiple higher educational institutes	Students aiming to become BMS
Scientist Training Programme (NSHCS b, 2021)	Post graduate MSc in Clinical Science – Not transfusion specific includes >60% haematology provided by MAHSE	Students aiming to become CS
MSc Biomedical Science (University of Westminster, 2021)	MSc in defined subject usually haematology with transfusion included	Post graduate students wanting to advance their knowledge or BMS looking to become a Specialist BMS
MSc Applied Transfusion and Transplantation (University West of England, 2021)	MSc in Transfusion – 100% transfusion related - provided by the University West of England	Students wishing to gain a masters qualification in transfusion. Commencing in 2021.
Higher Specialist Training Programme (NSHCS d, 2021)	Post graduate DClinSci and fellowship exams to the Royal College of Pathologists (RCPath) – transfusion related with leadership and management section - provided by MAHSE	CS wanting to become CCS.
FRCPath in Transfusion (FRCPath c, 2021)	Fellowship exams – 100% transfusion - provided by the RCPath	CS
FRCPath in Haematology and Transfusion (FRCPath a, 2021)	Fellowship exams – predominantly haematology with a section of transfusion - provided by the RCPath	CS
FRCPath in Haematology (FRCPath c, 2021)	Fellowship exams – predominantly haematology with a section of transfusion -provided by the RCPath	Haematology SpRs

1.6.2 Accessibility to Education and Training in the UK and Internationally:

Table 4: Educational transfusion courses available and professional qualifications available in the England.

Course	**Level**	**Target Audience and Costs**
IBMS Fellowship exam in Transfusion Science (IBMS b, 2021)	Fellowship exam for the IBMS – purely transfusion both hospital and reference	Specialist BMS looking to become an Advanced Specialist BMS – available at a cost of £375 per trainee
Specialist portfolio in Haematology and Transfusion (IBMS b, 2021)	IBMS Specialist portfolio – combination of haematology and transfusion	BMS looking to become a Specialist BMS – available at a cost of £133 per trainee
BBTS exam (BBTS, 2018)	Level seven credits in transfusion	BMS looking to become a Specialist BMS – available at a cost of £891 per trainee
Courses Run by NHSBT e.g., Practical introduction to Transfusion Science (PITS), Specialist Transfusion Science course (NHSBT, 2021; Allard et al, 2021)	Various levels beginners through to advanced	Various levels of scientists – 200 places funded by HEE – additional places available at £120 per day per trainee Medical Courses are funded by the Deaneries
Learn Blood Transfusion (E-Learning for Health, 2020)	Basic Knowledge	Clinical areas for basic clinical transfusion and scientific staff – Free to access for all staff both clinical and laboratory

These courses all have varying entry requirements and varying costs associated with them as can be seen in table four; therefore, trainees in hospitals with small training budgets may not have access to some of these courses leading to inequalities in educational opportunities (Bark et al., 2016; Bolton-Maggs et al, 2019).

NHSBT courses are currently available for scientists to develop transfusion-specific knowledge and an opportunity to practice laboratory techniques. These courses are available at various levels designed to complement the workforce (NHSBT, 2021; Allard et al, 2021). These courses are available to all BMS staff; however, they come at a high cost to the hospital financially, costing about £120 a day excluding travel costs and loss of a member of staff from the laboratory for a week. Health Education England (HEE) has recognised the benefit of these courses and funds 200 places for scientific staff working within England each year (Allard et al., 2021; Rounding and Evans, 2021). These courses provide both an opportunity to be taught transfusion theory whilst applying this in practical experiences in the training laboratory, requiring follow up training locally to consolidate the learning. The courses are taught with a combination of trainers alongside specialists working in the reference laboratories.

In the current climate, where staffing resources are limited within the NHS and there is an ever-expanding workload, releasing staff to attend external courses is not always possible. Therefore, training and education of this nature is sacrificed for less appropriate local training/education to maintain compliance with ISO15189 standard to maintain UKAS accreditation (Williams et al., 2019). It is not always comprehensive as this often involves training to a procedure with no background theory or understanding of the process. The training usually occurs in a busy working laboratory on real patient samples providing no option for less experience members of laboratory staff to make mistakes in a safe training environment (Bolton-Maggs et al., 2019). This loss of valuable knowledge due to retirement with existing staff results in the newer generation of scientists not receiving sufficient training. Resulting in an environment when poor knowledge is passed from BMS to BMS. This has led to a workforce that is less knowledgeable in transfusion theory than previous generations (Pearse and Scott, 2023).

A review of the literature also highlighted other transfusion educational tools available outside of England which may be relevant to BMS and CS staff in the UK. These tools are summarised in the table five below. This is not an exhaustive list but demonstrates there is development in electronic educational tools within the workforce. There are also organisations such as Biomedical Excellence for Safer Transfusion (BEST) who are working to ensure there is best practice within transfusion internationally and they collate studies to allow practitioners to look at best practice (BEST Collaborative, 2020).

Table 5: Educational transfusion courses available internationally:

Course	Level	Target Audience
European Blood Alliance Lean Modules (European Blood Alliance a, 2023)	Awareness of lean within blood transfusion. Provided as a free to access for any member of the EBA.	All scientific staff working within blood transfusion
EBA Master Class (European Blood Alliance b, 2023)	Multiple master classes which include presentations and videos of variation of topics related to blood transfusion	All scientific staff working within blood transfusion.
ISBT e-learning modules introduction to antigen-antibody reactions (ISBT, 2023)	Introduction to antigen-antibody reactions.	All scientific staff working within blood transfusion.
Intraoperative Cell Salvage Education Workbook (UKCSAG, 2023)	Background information for operatives involved in the cell salvage process.	Any member of staff involved in cell salvage
Blood Safe E-learning multiple courses Australian Red Cross (Australian Red Cross, 2023)	Various courses aimed at introduction of key areas of transfusion. These are based on Australian guidelines.	All scientific staff working within blood transfusion and clinical staff involved in the transfusion process.
E-learning in transfusion medicine – New York Blood centre (Wasiluk et al, 2022)	Introduction to blood groups, transfusion reactions and basics of patient blood management.	Not specified
Patient blood manager – German PBM network (Wasiluk et al, 2022)	Comprehensive online module in patient blood management.	Not specified

1.7 The UK Perspective Academic Training

There was no literature to suggest a current standardised way of training our scientists both at undergraduate and postgraduate level in transfusion science and this is explored more further on when discussing degree courses. MSC has started to address the issue academically (Panagiotou, 2011) by using MAHSE for postgraduate qualifications (The University of Manchester, 2023; The Biomedical Scientist, 2018) and using the AHCS to assess undergraduate courses to ensure they meet the requirements from the IBMS (Pitt and Cunningham, 2011) and HCPC; however, the content of the courses is still variable.

Figure nine demonstrates the course design for the PTP in blood science which includes transfusion. Through-out the three-year degree course; there are only 80 credits available for specialist modules (see Figure 9): genetics, immunology, haematology and transfusion and biochemistry (NSHCS c, 2021) compared to the traditional Biomedical Science degree offered at the University of Portsmouth, which includes over 120 specialist credits (Portsmouth University, 2021). Both degrees are IBMS accredited, but the content is varied and, therefore, results in BMS students who have varying levels of knowledge. The courses are designed to give the students the underpinning knowledge and basic laboratory skills (e.g., pipetting and weighing out reagents) required to enter the biomedical workforce where training to perform the job occurs (The Biomedical Scientist, 2018).

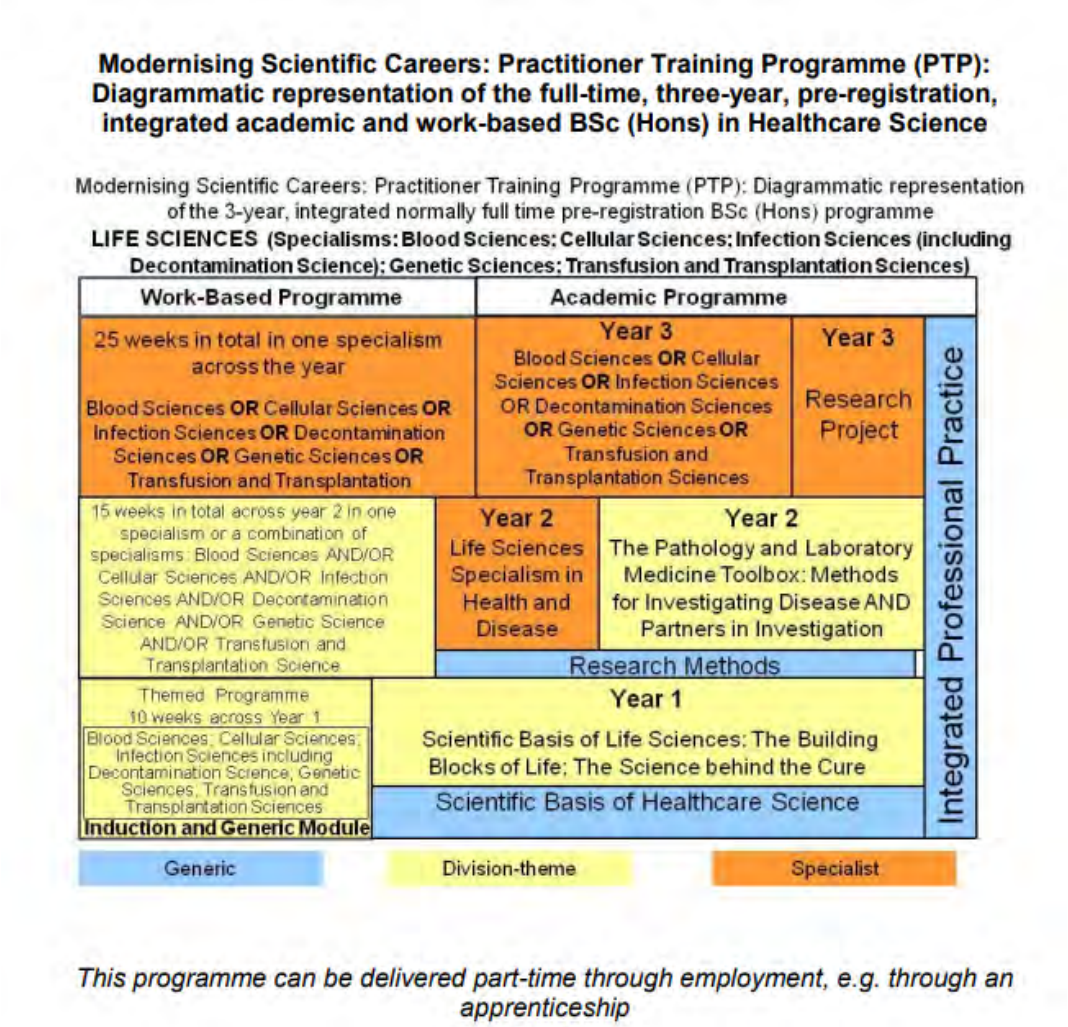


Figure 9 Three-year PTP course design (NSHCS h, 2021).

MSC also has attempted to standardise these trainees' placements by the addition of work placed assessments described in the PTP portfolio (NSHCS e, 2020). The placement providers are subjected to accreditation with the NSHCS to ensure they can support students and provide adequate training opportunities. Due to the large volume of work expected of these students in the PTP student with the completion of the IBMS portfolio, the PTP portfolio, and the academic component all within three years, students are often achieving lower degree classifications and there has been a decline in numbers of students enrolled on these courses (The Biomedical Scientist, 2018).

Workplaces are often resorting to taking on BMS students with degrees already or during their degree from universities who are IBMS accredited and supporting them with a year placement either during or after their studies (The Biomedical Scientist, 2018). This has resulted in a variation of the training being received within the workforce (Pearse and Scott, 2023). This may impact the quality of the graduate students as if they are developing academic knowledge at university that is not applied appropriately in the working environment, this may not be retained. Therefore, a combination of the academic course development alongside the NSHCS portfolio needs to be undertaken to ensure sufficient time and training are provided to our Healthcare Scientists (Bolton-Maggs et al, 2019).

1.7.2 The UK Perspective Professional Training

The literature search provided little evidence of transfusion education platforms/packages in the UK currently available, although there were many references for a requirement for additional educational resources (Allard et al., 2021). The methodology for the review can be seen in section 4.2.3 which outlines the search methodology. This was not unexpected as the previous SHOT director Paula Bolton-Maggs and Cohen (2013) described how, since the implementation of SHOT in 1996, there have been changes in practice. There have been recommendations in all of the SHOT reports to educate the scientific and medical workforce as it has been recognised reduction in knowledge has resulted in numerous errors. When reviewing the SABRE data 206/1178 errors reported are from the laboratory and attributed to inadequate or ineffective training (Narayan et al., 2019:19,193). The UKTLC has also recommended a requirement for additional training to be delivered to the scientific workforce; however, there has been little success to date (Bolton-Maggs et al., 2019).

Current training programs available for BMS staff often rely on staff release for several days from the laboratory. However, there is a recognition that there is not always the capacity to release staff from the clinical environment (Bolton-Maggs et al., 2019) and that adaptive ways of educating the workforce using e-learning may need to be used to reduce the total time spent away from the laboratory (George et al., 2014). Further research into how to educate transfusion scientists could look at a blended learning approach utilising RTC education days and this work is being undertaken as part of Transfusion 2024 (Allard et al., 2021). There are some examples of e-learning which has been developed in the UK, as described below.

In 2016, BBTS commenced their new specialist qualification, which was interactive and allowed learning to be recorded via forums and tutorials delivered online using an LMS (BBTS, 2023). This was different from the previous qualification, a self-directed learning programme; requiring the learner to read a textbook and complete a workbook of cases before completing an exam within the year (Qureshi, 2015). There was no requirement for the student to complete the workbook; therefore, there was no evidence of applied knowledge through-out the course. The changes in the way this learning was delivered have allowed for a better programme enhancing higher scientific knowledge in transfusion (BBTS, 2018) whilst allowing the scientists to apply the knowledge in a virtual environment. Participation on the online platform was compulsory as part of the qualification and reassured transfusion laboratory managers that there is active learning modelling PBL used by medical students (Zubala et al., 2019) with case studies.

BBTS has also increased the qualifications available with the introduction of a clinical transfusion package aimed at professionals working as Transfusion Practitioners (TP) to provide them with the knowledge they require to complete their roles (BBTS, 2020). The TP role is an evolving role (Miller et al., 2015) which, up until 2017, had a qualification available at Swansea University (Moss, 2018). The lack of formal training resulted in localised training, resulting in variation both in the knowledge and practice of TPs across England due to their varied backgrounds (Dhesi et al., 2020).

These courses offered by BBTS are designed for postgraduates specialising in transfusion. They can be used as an alternative to other specialist qualifications offered by the IBMS, such as the IBMS Specialist Portfolio (IBMS e, 2021) and to meet the UKTLC requirements for specialist transfusion knowledge (Bolton-Maggs et al, 2019; Chaffe et al., 2014). The courses

are available to all scientist to apply for however come at a cost of £891 per student (BBTS, 2018); they are delivered entirely remotely, reducing any additional costs such as travel and accommodation. As has been acknowledged in the UKTLC surveys laboratories do not have large training budgets so are often not able to fund courses like this (Bark et al, 2016; Bolton-Maggs et al, 2019).

1.7.3 Issues Identified with UK Training:

The UKTLC has highlighted that 30-40% of all reported errors are caused by transfusion laboratory staff (Chaffe et al., 2009). This is further supported by the recent SHOT report, which predicts up to 23.4% of all reported errors arose from the laboratory (Narayan et al., 2020:104). Whilst there is an acknowledgement that not all errors arise from insufficient training/education and that there are other causes such as distraction, insufficient staff and equipment malfunctions. The report produced by the UKTLC in 2009 provided recommendations for training and minimum staffing levels aiming to reduce errors by 50% by 2012 (Chaffe et al., 2009). It was hoped that with the introduction of internal and external training and education opportunities along with standard laboratory practice such as participating in external and internal quality control such as NEQAS there would be an improvement in practice which would reduce errors (Milkins, 2007). Whilst some of these recommendations were met, unfortunately, the required standard for training and minimum staffing was not achieved. Although the report provided recommendations from a collaborative body to include an improvement in the scientists working within transfusion training and education, there was no support from higher authoritative bodies such as DoH or HEE to implement these actions therefore, no funding was made available (Bolton-Maggs et al., 2019; Chaffe et al., 2014). The issue with training transfusion staff was further highlighted by the World Health Organisation (WHO) global database, which indicated that 72% of countries could not meet their identified training needs in 1999 (Damarihouri, 2009), suggesting the picture present in the UK is replicated in other countries.

A subsequent UKTLC survey was sent to all transfusion laboratories in 2017 which had a response rate of 245/302 transfusion laboratories. The results demonstrated that the previous

findings had not been addressed and highlighted an issue with knowledge and education for transfusion within the current and future workforce. In 2017 this was more pronounced, due to the reduction in the number of senior scientists leaving the service, and not being replaced with equivalent staff members in terms of experience and knowledge of transfusion (Bolton-Maggs et al., 2019). Other findings were highlighted in the report, and these can be seen in figure 10 (Bolton-Maggs et al., 2019).

Figure 10 Overview of the UKTLC survey and the inter-relationships contributing to the increasing risk of errors (Bolton-Maggs et al., 2019) (reproduced from the original article):

The 2017 UKTLC report stated there needed to be further work with the professional bodies such as IBMS and BBTS alongside HEE to improve training nationally, hopefully resulting in a standardised approach with funding available to ensure these recommendations are achieved before the next UKTLC survey (Bolton-Maggs et al., 2019). The report has contributed to the development of Transfusion 2024; a five-year strategy to address the issues within transfusion. This was a collaborative piece of work with the professional bodies and the chief scientific officer as well as representatives from the workforce. It was published in November 2020, so no output has been achieved yet, but the report addresses the critical issues around transfusion education (Allard et al, 2021). At the time of this project being developed Transfusion 2024 was not underway; however, since completion of the project Transfusion 2024 has been initiated. The strategy is still underway, however learning from this project and some of the content are now being included in the education aspect of the strategy. This project would align to the laboratory safety arm of the strategy which looks to ensure the UKTLC standards are being addressed and met within transfusion laboratories (Allard et al, 2021) with this project focussing on education of scientific staff ensuring appropriate knowledge (Chaffe et al., 2009).

One of the fundamental issues highlighted in the UKTLC findings is that there is a requirement for national training programmes for transfusion however currently there is no defined organisation or collective with a single responsibility (Bolton-Maggs et al., 2019; NHSBT & NBTC, 2020). This results in local initiatives occurring which demonstrate good practice such as Oxford however are not always replicated in other hospitals (Goodnough and Murphy, 2016); However, this is not being replicated within other hospitals due to a lack of funding or resource, as can be seen by the UKTLC reports (Bolton-Maggs et al., 2019). An example of exemplary training can be seen at Oxford, where the team have introduced an electronic system for blood product requesting alongside the other technologies, they also use such as the vein-

to-vein blood tracking (Davies et al., 2006) allowing for the review of appropriate transfusion requests by the PBM team. Where these requests are deemed inappropriate additional training and feedback is given to the requester to prevent inappropriate transfusions. This was targeted at junior doctors initially and saw an improvement in the use of blood within the clinical areas and is a development which would benefit other hospitals in reducing blood usage as well and improving patient care (Staples et al., 2020). It has proven that technological advances within transfusion can improve clinical practice and should be considered (Butler et al., 2015) and is recommended in the SHOT reports (Narayan et al., 2021:30). Whilst this is not an e-learning tool it demonstrates how technology can be used to train and educate the workforce within transfusion and improve practice which is a metric which will be reviewed as part of this project.

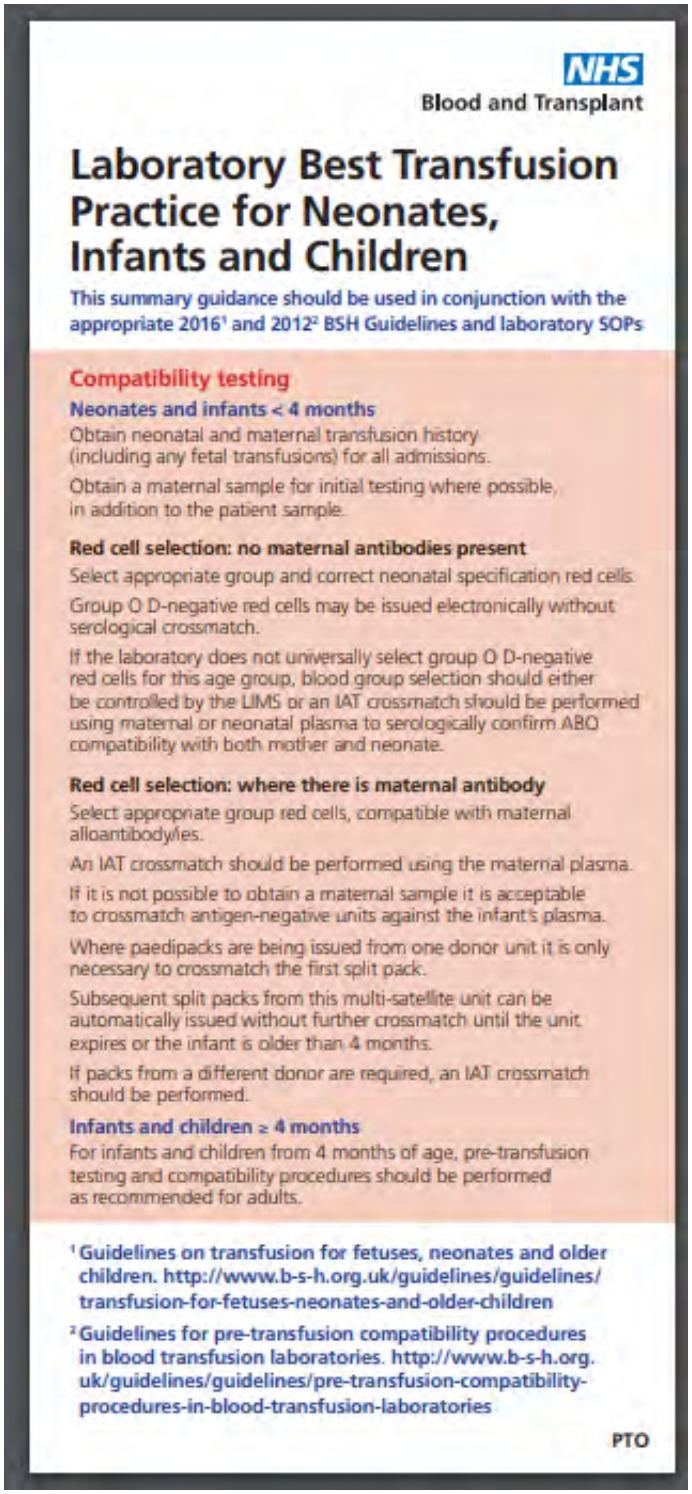
The disparity in the scientists' education and training increases some of the health inequalities seen within the NHS (Al-Riyami et al. a, 2022). This was addressed in a study published by Graham et al. (2016) which highlighted the requirement for a single group required to drive training and education to be successful and standardised. This paper suggested this should be the Hospital Transfusion Committee (HTC) responsibility, although this would not address the UK's problem nationally, as HTCs are localised in individual hospitals (Yorkshire and the Humber RTC, 2020). Other solutions would need to be established to address the national issue, such as considering using the RTCs to drive the education and feed into the NBTC. There is already a committee within the NBTC that is responsible for training and is working to find solutions to the issues highlighted in the UKTLC report in 2017 (Bolton-Maggs et al., 2019; NBTC Education Working group, 2022).

A study published by Garrioch et al. (2004) in a hospital in Scotland recognised a deficiency in transfusion knowledge in the clinical areas, which resulted in the varied practice of blood usage in patients. They introduced a local educational package to improve practice within their hospital. Firstly, they audited the current state in the hospital and re-audited it after introducing the e-learning package. They saw a reduction in blood usage, which was their outcome measure. They chose to use a combination of face-to-face teaching and follow-up discussion with the clinicians, often described as blended learning. They also investigated alternatives to face-to-face teaching, recognising this is not always possible as they wanted to maintain the same level of personalisation. They achieved this by using video clips delivered using distance learning, allowing a personal approach without face-to-face teaching. The use of video and patient stories been described by Petersen et al. as essential to ensure engagement with distance learning for adults (2008). This was further supported by a review of learning theory by Wang and discussed how personalisation could result in more efficient learning (2012).

The use of distance learning methods such as video would need to be considered in the context of this project. It is not possible to provide face-to-face training nationally for all transfusion scientists to access due to insufficient staff numbers (Bolton-Maggs et al., 2019), which is the current state; therefore, a video could provide a practical alternative. This would still allow for personalisation and ensure the connection between the teacher and the student encouraging engagement using multiple cognitive levels (Petersen, 2008; Bernard et al., 2000). Therefore, there must be personalisation allowing the learners to connect with the lecturer and the material; This should lead to a lower rate of drop out from the student whilst also improving the learning quality. Bernard et al. also described other characteristics required for adult learners to undergo effective learning (2000). It included learning relevant to their job,

providing a practical experience that assists their day-to-day work whilst also allowing them to apply the knowledge to their job (Melis and Monthienvichienchar, 2004).

Garrioch et al. (2004) used another method pocket-sized aide-memoire around transfusion subjects which had been identified as having reduced level of knowledge so all medical staff could carry them. This method was also used in England by the PBM team producing evidence-based bookmarks and an example of these bookmarks can be seen in figure 11. These bookmarks available for paediatric/neonatal and adult transfusions thresholds are used by clinicians involved in the transfusion pathway to guide their decision making for transfusion (NHSBT PBM, 2014). The introduction of bookmarks in the UK has shown some success, but there has been little follow-up of face-to-face training. There is still data from the SHOT reports and the National Comparative Audits (NCA) on blood usage and appropriate transfusions that suggest these are given inappropriately (NHSBT, 2019). However, there have been improvements noted within some clinical areas (Karafin and Bryant, 2014). This, therefore, indicates that if there is sufficient training provided to increase knowledge, it would, in turn, prevent some of these inappropriate transfusions from occurring, suggesting new methods of teaching need to be implemented.



NHS
Blood and Transplant

Laboratory Best Transfusion Practice for Neonates, Infants and Children

This summary guidance should be used in conjunction with the appropriate 2016[1] and 2012[2] BSH Guidelines and laboratory SOPs

Compatibility testing

Neonates and infants < 4 months

Obtain neonatal and maternal transfusion history (including any fetal transfusions) for all admissions.

Obtain a maternal sample for initial testing where possible, in addition to the patient sample.

Red cell selection: no maternal antibodies present

Select appropriate group and correct neonatal specification red cells.

Group O D-negative red cells may be issued electronically without serological crossmatch.

If the laboratory does not universally select group O D-negative red cells for this age group, blood group selection should either be controlled by the LIMS or an IAT crossmatch should be performed using maternal or neonatal plasma to serologically confirm ABO compatibility with both mother and neonate.

Red cell selection: where there is maternal antibody

Select appropriate group red cells, compatible with maternal alloantibodyies.

An IAT crossmatch should be performed using the maternal plasma.

If it is not possible to obtain a maternal sample it is acceptable to crossmatch antigen-negative units against the infant's plasma.

Where paedipacks are being issued from one donor unit it is only necessary to crossmatch the first split pack.

Subsequent split packs from this multi-satellite unit can be automatically issued without further crossmatch until the unit expires or the infant is older than 4 months.

If packs from a different donor are required, an IAT crossmatch should be performed.

Infants and children ≥ 4 months

For infants and children from 4 months of age, pre-transfusion testing and compatibility procedures should be performed as recommended for adults.

[1] Guidelines on transfusion for fetuses, neonates and older children. http://www.b-s-h.org.uk/guidelines/guidelines/transfusion-for-fetuses-neonates-and-older-children

[2] Guidelines for pre-transfusion compatibility procedures in blood transfusion laboratories. http://www.b-s-h.org.uk/guidelines/guidelines/pre-transfusion-compatibility-procedures-in-blood-transfusion-laboratories

PTO

Figure 11 Example of bookmark produced by PBM team at NHSBT for Transfusion Indications for Neonates and Children. A similar bookmark was also created for Adult Transfusions (NHSBT PBM, 2021).

Trusts have used aide-memoires in clinical areas for other areas of transfusion where errors are frequent, such as lanyards with checklists for MH and the Transfusion Associated Circulatory Overload (TACO) checklist, which SHOT has developed. Figure 12 shows the TACO checklist, which was recommended due to increased number of TACO reports (Narayan et al., 2019:141). The use of learning aids ensures that any previous learning's critical points are bought to the front of the professional's mind; these can be simple reminding the user of the guidelines seen in the PBM bookmarks or the use of a checklist such as the bedside checklist (Department of Health, 2017). The aide-memoires can be used to ensure a standard process has been followed and results in improving outcomes where there is a requirement to follow a standard process (Din et al., 2001). Checklists have been used successfully in many industries including aviation to ensure there is compliance with a standard operating procedure (Degani and Wiener, 1993) and, when used appropriately in medicine, can ensure there is improved patient safety which has been seen within transfusion (Tseng et al., 2016). One of the most successful examples of a checklist which has been implemented in medicine is the World Health Organisation surgical checklist, Haynes et al. (2009) describes how this has reduced the mortality and post-operative complications in a multi-hospital study highlighting that a well-designed checklist can have a positive impact.

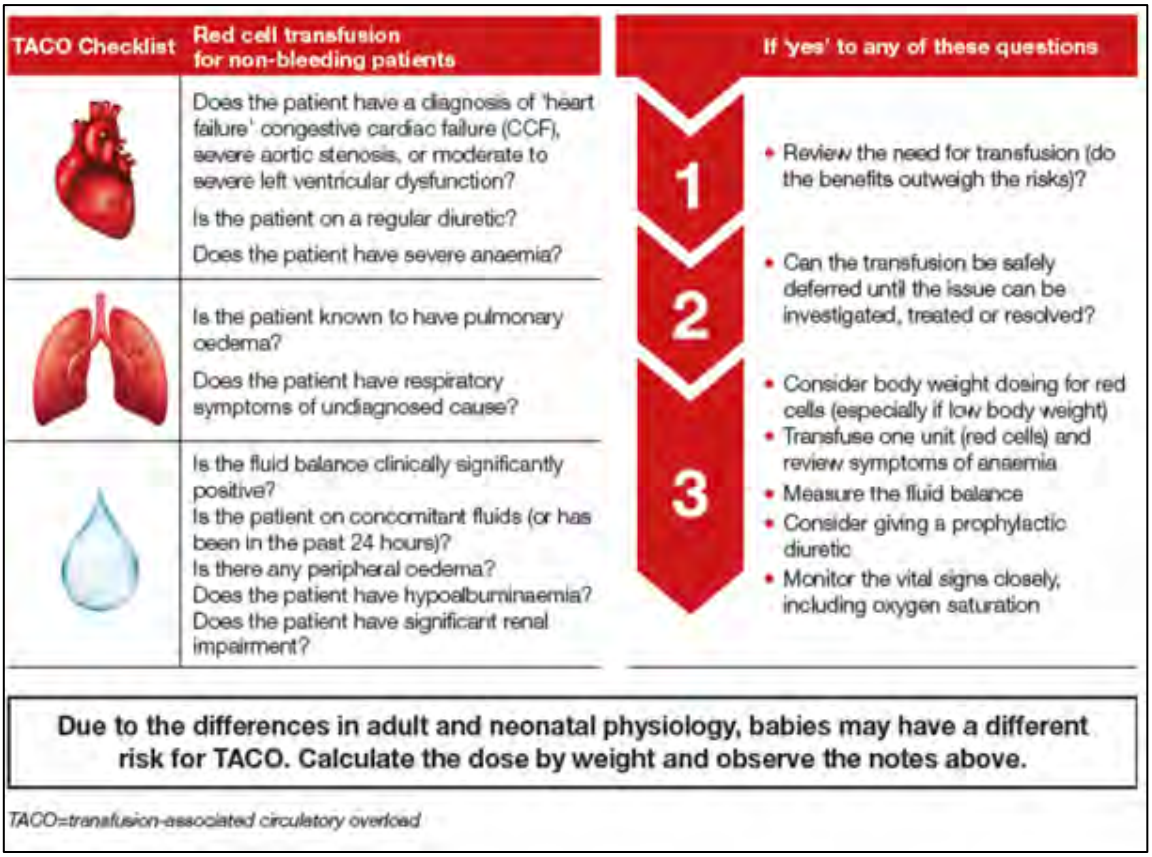


Figure 12 An example of TACO checklist from the 2018 SHOT report which should be used by hospitals to prevent TACO occurring in their patients. (Narayan et al., 2019:141)

SHOT has developed some further training resource, including SHOT webinars, or SHOT Casts which are virtual sessions delivered to healthcare professionals with an opportunity to ask a panel of experts after the session (Narayan et al., 2020; SHOT c, 2020), which includes topics such as appropriate transfusion. These sessions were started in 2020 due to the COVID-19 pandemic, where it was not possible to deliver the usual face-to-face teaching and allowed more individuals to attend compared to a single day conference.

1.8 The Australian Perspective:

The health system in Australia is managed in an equivalent way to the UK with health boards monitoring and funding hospital activity with overarching responsibility with the department of health (Ham and Timmins, 2015). As this is a similar set up to the UK there is a risk that the transfusion services could find themselves in a comparable situation to England where laboratories are understaffed with inadequately trained BMS staff (Bolton-Maggs et al., 2019). To avoid a scenario where training impacts service provision and increases errors there has been an investment in training the staff and Gallagher-Swann et al. (2011) described how the Australians are tackling education within transfusion and have devolved this responsibility onto the HTC. This initially used face–to–face teaching, which was further developed into E-Learning packages covered by Blood Safe (Wood et al., 2015). This has been demonstrated as a highly effective teaching method in blood transfusion in Australia (Gallagher-Swann et al., 2011; Ifediora, 2019). The clinical areas traditionally have little contact time for education and due to geographical distances, it can be challenging to arrange face-to-face training (Salter et al., 2014) which is comparable to the UK. It is, therefore, essential any learning which is provided is productive and effective as clinical staff have traditionally had the most errors reported associated with knowledge gaps (Wasiluk et al., 2022). The most recent report from the serious transfusion incident reporting group has highlighted there are reports being produced by laboratory errors and that transfusion education may help to improve these (Victoria Health, 2021).

E-Learning has not always been available in Australia; the HTC gained approval for a study, including funding. The success led to the project's continuation of transfusion education for Australia, resulting in increased patient safety and ensuring that safe practice was maintained

(Gallagher-Swann et al., 2011). These e-learning packages are also available for other countries to use but are based on Australian guidelines (Bloodsafe, 2020). The study was entirely driven by the HTC, with an additional staff member recruited with specialist knowledge. They were introduced into the team to promote education within the clinical workforce. Although this demonstrates success within transfusion education, it is not always viable to increase staffing levels, particularly where funding for staff resource is required.

Gallagher-Swann et al. (2011) described their successes by using real-life patient cases to capture the audience, improve engagement with the learning and ensure that learning could be applied to clinical practice, and this has reflected in other papers around education (Cook et al., 2008, Petersen, 2008). It was interesting to see how they had decided to use an e-learning package to support and supplement face-to-face training using a blended learning approach shown to improve learning outcomes (Mccutcheon et al., 2018; Vallée et al., 2020). The Australians reflected upon a UK study of haematology trainees where it was reported that there was a low uptake in e-learning (Hill et al., 2008) and therefore utilised personified blended learning to improve outcomes. It could be speculated that the low uptake of e-learning in Hills's study may be due to the IT infrastructure in the NHS and finding allocated time for training, which is not always given due to staff shortages (Bolton-Maggs et al., 2019) In comparison, there was a protected time in the Australian study for the materials to be completed ensuring better compliance and, therefore, a better outcome (Gallagher-Swann et al., 2011).

Gallagher-Swann et al. (2011) also highlighted that Australia had an increase in senior scientific staff commencing e-learning packages in transfusion compared to other staff groups,

indicating that e-learning may be a viable option for a scientific-based platform. This was of particular interest to this project, as this would be targeted at the scientific workforce.

The Australians have used e-learning in other areas of healthcare and demonstrated success there too. Bond et al. (2017) have developed an e-learning package to educate clinicians and allied health professions about the use and dose of vancomycin for patients. This trial looked at the improvement in knowledge of this specific antibiotic's use and was chosen due to an increase in the number of errors reported. The result established both an improvement in the knowledge and reduction in the error rate (Bond et al., 2017). Designing a transfusion study where an e-learning solution was implemented in an area where an increasing number of errors reported would hope to achieve the same outcome.

1.9 The US Perspective

The US are in a similar position to the UK as there is no national training strategy currently implemented; however, they acknowledge a requirement for an education strategy within transfusion. An article by Goodnough and Murphy describes how the training for transfusions fellows is usually a 12-month programme and physicians studying haematology may do a short rotation; however, this is centre dependant. There is no national curriculum unlike in the UK and there will be variation on training which will be centre dependant; however just like the UK there is a final examination (2016). The transfusion service is split into regions in the US with multiple blood providers (Blood Centres of America, 2021; American Red Cross, 2020), and there is no national service available like in England providing structures such as NBTC, RTCs and HTCs. Therefore, any training provided may be fractionated, making it harder to achieve standardisation (Panzer et al., 2013).

The USA reports from the Food and Drug Administration (FDA) (Koh and Alcantara, 2009) which can be found online highlighting deaths associated with transfusion and demonstrates the most common cause of death associated with transfusion was TACO (n=14) and there were 4 deaths associated with ABO incompatible transfusions in 2019 (Food and Drug Administration, 2019:4) and reviewing the data from 2012 – 2019 it can be seen that each year there is at least one fatality from ABO incompatible transfusion (Food and Drug Administration, 2019:5). The report only focuses on fatalities and does not provide all the near misses and other errors as seen the UK SHOT reports (Food and Drug Administration, 2020). Therefore, it is not possible to draw comparisons across the two countries as there is not a complete data set. There is also information available on the centres for disease control and prevention which describes the types of reactions and collates date from healthcare institutions,

but the data is not available for review by the public (Centers for Disease Control and Prevention, 2023).

There are examples of addressing the training issues identified and Annsburg et al. (2012) described how the National Heart, Lung and Blood Institute in 1983 attempted to submit a national curriculum in undergraduate medical training to ensure a baseline level of knowledge of all medical students for transfusion. This has so far been unsuccessful but has raised awareness of transfusion at a clinical level (Al-Riyami et al, 2021). There has been a similar drive in the UK to improve foundation doctors training in transfusion before commencing clinical roles. A move to an e-learning module was undertaken before local trust induction to improve awareness of transfusion (Graham et al., 2016). This resulted in an improvement of knowledge seen by the use of formative assessments and upon reflection junior doctors felt their knowledge in transfusion was far greater than previous years trainees and had more confidence with prescribing transfusion (Graham et al., 2016).

Annsburg et al. (2012) described how they improved transfusion safety in a study at their hospital. A survey of the clinicians established the current state of knowledge, and an improved training programme was given to ensure the appropriate use of blood products for their patients. Their survey results suggested that clinicians felt a minimum of five hours of training was required for this to be effective. The training was delivered using a combination of educational tools, which were non-digital and demonstrated improved blood usage. This was also echoed by Liumbruno and Rafanelli (2012), who acknowledged the need for various teaching methods to raise transfusion awareness in the clinical areas.

The survey results by Mitchell et al. (1989) described how 90% of the USA's clinicians (75 questionnaires sent out to five midwestern universities and 12 blood banks within Iowa) felt they required additional transfusion training. Of those, 40% highlighted concern about the lack of knowledge and the use of blood components. Although this survey was submitted in 1989, there has been a decrease in the training level reported in transfusion (Annsburg et al., 2012). The survey ascertained nine deficiencies in knowledge which can be seen in table six below in which medical staff felt they required additional support; this included ABO within sections six, seven and eight, which is an area that is of particular interest in this project. A more recent survey has been performed by Halford et al., which has also demonstrated 80% of 183 hospitals felt additional training in transfusion medicine was required and this would improve patient safety (2021). This demonstrates that since 1989 there has been no improvement in transfusion education in the US and there is work to be done to address the knowledge deficits. This could be addressed by using the exam designed by Haspel et al. and designing a curriculum around the knowledge gaps (2014).

Table 6 The nine main deficiencies highlighted in the survey from Mitchell et al. (1989).

1	The selection and use of blood and its products
2	Further knowledge required for both Immunological and Non-immunological transfusion reactions
3	There was a particular interest in transfusion associated graft versus host (TaGVHD) and haemolytic disease of the fetus and Newborn (HDFN
4	Interpretation of Coagulation results and supporting patients with coagulation disorders with blood products
5	Apheresis and its uses in the clinical conditions
6	Blood banking and the techniques used
7	Transfusion practice both in the blood banks as well as in the clinical areas
8	Administration and storage of blood and its products
9	How blood is procured and processed

1.10 The Spain and Italy's perspective:

A review of some European countries has been included which include Italy (Scalzo et al, 2009) and Spain (WHO, 2023) as they have healthcare systems which are publicly funded and therefore more comparable to the UK health service (Chang et al., 2011). Other European countries have established health systems however these are privately funded and therefore are not included in this section as they are not comparable to the UK health system.

An article published by Liumbruno and Rafanelli (2012) described how the HTC are responsible for transfusion training in Italy's hospitals. They discussed how this might be problematic in large hospitals due to the size of the small HTC team; however, it works well in smaller hospitals. The authors acknowledged whilst this system worked in Italy it may not be able to be replicated elsewhere as the HTC system in Italy was vastly different to the voluntary system in the UK (NHS Executive, 1998). The HTC in Italy has a defined infrastructure, and there is a collaboration between the hospitals and the blood service (Liumbruno and Rafanelli, 2012). This is not always the case in the UK where the blood service feeds into the HTC although this is not always defined and there are reports of varying practice across England therefore making the HTC responsible for education within England a unviable option (NHS Executive, 1998).

It is described that in Italy, the HTC had responsibility for transfusion appropriateness in patients and sharing good practice and guidelines which is comparable to the PBM team and TPs based in the UK (Miller et al., 2015). It has been acknowledged in a review by Maniatis and Muller, that across Europe there is still a way to go in evidenced based transfusion (2004)

and that practice of transfusion is clinician dependant (2004). The review described how transfusion is not included in undergraduate curriculum of 5/15 countries included in the survey demonstrating the variety of knowledge which has an impact on the practice of these clinicians. There are measures in place in these countries to try to improve transfusion practice such as the introduction of guidelines and specialist nurses in transfusion however the author suggested there were still improvements to be made (Maniatis and Muller, 2004).

Molina-Arrebola et al. (2020) describe how in Spain the HTC in a hospital in southern Spain moved face-to-face training to online transfusion training. They used satisfaction and knowledge transfer after one year as a marker of success. They managed to get 556/680 students to partake in their study of a period of three years. They noted a knowledge improvement mean of 19% and good satisfaction across all staff who completed the training. They also noted as part of their study that 90% of participants felt they were able to apply the knowledge gained from this training to their workplace. This example of online training can be used to inform this intervention as the outcome measures are similar to this project.

Another initiative in Spain they have been looking at to improve knowledge is a national quality incidence framework. This would aid benchmarking and allow for shared learning to occur from incidents with the aim of improving the processes (Romon and Lozano, 2017). Whilst this is not an educational intervention the output will allow for interventions and may result in national resources which can be used to train healthcare professionals.

1.11 Learning Theory:

Before commencing the development of any learning tools, it is essential to consider how learners learn utilising theory and styles to ensure any material produced meets the requirements of the users. There are several learning styles considered as part of this project and these are described further.

Passive learning can be described as didactic lectures such as those used to teach groups of student's theory in a university setting. This is the direct transfer of knowledge from teacher to student and should be used alongside other learning methods to ensure the knowledge is retained. Passive learning can play a role in educating healthcare professionals; however, it is widely acknowledged that exposure to a real-life scenario, either patient case or simulation, allows for the learning to be solidified (O'Regan et al., 2016) through active learning.

Participatory / Collaborative learning occurs when large groups of students can discuss a case or a learning concept and engage with one another, passing on learning from each other (Haidet et al., 2004). This is often used in medicine in examples of Problem-Based Learning (PBL) as an effective way to teach once the basic concepts have been taught and can be adapted to all forms of healthcare education. Haidet et al. (2004) showed no significant difference with medical students between a session delivered using a didactic lecture and that with a collaborative approach.

Transformational learning uses people's natural ability to apply learning and make meaning from the learning. This was first described by Mezirow, where a student needs to understand

the learning and reflect on the learning going through a phased process (Hoskins, 2013). Hoskins describes 10 phases in the transformative learning process which include: A dilemma, e.g. a concept, examining the dilemma, critically assessing, processing, and recognising any issues and transforming personal feelings, exploring new roles etc., planning of action, gaining the knowledge and skills required to fulfil the plan of action, building confidence in the new skills required and finally putting the new learning into practice based on the new perception of the student (2013). Transformation learning works best when using all aspects of the learning cycle to allow for complete learning (Baumgartner, 2001). An example of the learning cycle that has been adapted following the Kolb's learning cycle (Stice, 1987) approach can be seen below.

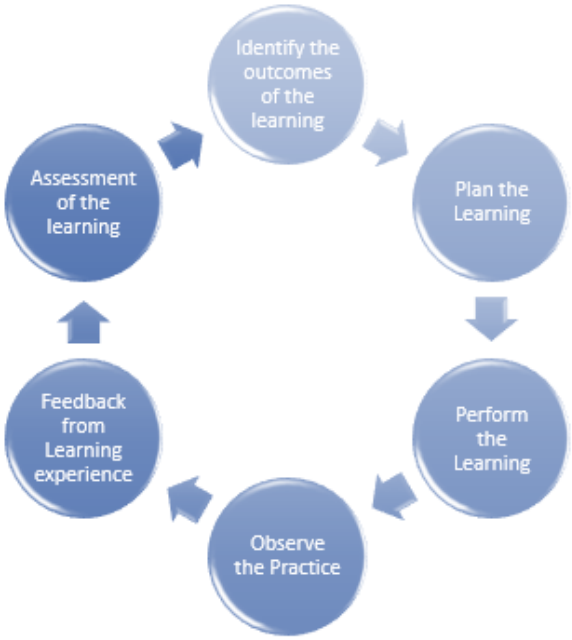


Figure 13 Adapted Kolb cyle which could be used for medical training within a clinical scenario (Stice, 1987).

Mastery Learning is setting a standard in which a student must achieve to progress with additional learning, which is quite commonly seen in e-learning (Kulik et al., 1990). This learning style provides the student with content, and they are assessed using a formative assessment at the end of the section and are required to achieve a defined pass mark before continuing with the learning (Grant and Spencer, 2003). Mastery learning has shown to improve the skills seen in healthcare workers in a review by Cook et al. (2013) and is often used in e-learning material for medical professionals (E-learning for Health, 2020). The use of the assessment at the end of the module also acts as a measure of engagement, ensuring users have completed the material and have demonstrated an understanding.

As this learning will be directed at adults with prior education in the subject matter, it is essential to consider andragogy which focuses on how to teach adults with prior knowledge. Forest et al. (2006) describes how there are four assumptions made with adult learners. These include the requirement for self-directed learning from adults, using the learners' previous experience, which is essential when developing additional educational material, the adult desire to want to learn, which is a requirement for their registration and finally discusses the performance related to learning. These four concepts will be used when developing any material for the scientific workforce.

From reviewing the literature, the methodology will be discussed in further detail in the methods chapter, but this included using multiple search platforms including Google Scholar®, it is evident that students learn in multiple ways, and therefore, there is not a single ‘size to fit’ all students. Therefore, when embarking on a learning project, it is essential to review the target audience and apply multiple learning methods to improve engagement with all students.

1.12 Methods of Delivering Learning:

Education provided by NHSBT, and other higher education institutions has been traditionally delivered in a face-to-face manner using didactic lectures restricting access to courses by laboratories with limited staff numbers (Bolton-Maggs et al., 2019). However, increasing the capacity by e-learning or other distance learning mechanisms enables a larger target audience to participate whilst gaining the knowledge historically that was provided on a face-to-face course (Sherry, 1995; Pearse and Scott, 2023). The COVID-19 pandemic has required higher education institutes to alter how they deliver teaching for healthcare courses and has been noted that there has been an increase in the number of institutes using e-learning to allow the student to continue with vital studies (Radha et al., 2020; Pearse and Scott, 2023). Universities are using a combination of asynchronous (pre-recorded material) and synchronous (live delivery using remote platforms) learning (Darras et al., 2020; Chatziralli et al., 2020). While moving from face-to-face courses to online courses has achieved the continuation of training through the COVID-19 pandemic, it can come at a cost to the student feeling they have lost some academic time. Therefore, the course's development needs to prevent this from occurring in a non-COVID era. This could be achieved by combining face-to-face learning and distance learning, referred to as blended learning (Hasan and Bao, 2020; Rowe et al., 2012; Garrison and Kanuka, 2004).

An example of blended learning used in transfusion is the STP masters in haematology and transfusion run via Manchester Metropolitan University (The University of Manchester, 2023). Students attend for a short amount of face-to-face teaching at the University and then return to their workplaces to practice the knowledge gained from the academic qualification and continue this learning with e-learning material and assessments (NSHCS b, 2021).

A change in the delivery of learning is required to enable more students to access the available courses (Rambiritch et al, 2021; Al-Riyami et al a, 2022). The move to an increase of asynchronous learning allows students to control their learning, which may be better suited to individuals working in the NHS (Darras et al., 2020).

The University of Manchester has used asynchronous learning to develop five haematology modules. These modules were used as part of the final assessment for the students and were found to enhance learning and allowed for the application of the knowledge gained in lectures (Keown and Chaudhry, 2011). The use of pre-recorded material allowed for more students to partake in learning and, if used alongside face-to-face learning or remote synchronous learning, can positively impact the students' learning experience (Bashir et al., 2021). This may also help to improve standardisation due to allowing access to subject matter experts (Allard et al, 2021).

1.13 Differences Between learning types:

Before considering difference in learning styles a definition of training and education should be discussed. These two terms are often used interchangeably however have different meanings. Education is described as the knowledge and understanding behind a concept such as immunohaematology for transfusion students and will allow the student to make evidenced based decisions and provide them with the foundations to continue with practical training in the discipline (Flausino et al., 2015). The aim of the knowledge-based education would be to prevent knowledge-based errors which can occur in a busy working environment (Flausino et al., 2015; Bolton-Maggs et al, 2019). Whereas training is gaining the experience practically in the workplace in transfusion this would be in the laboratory (Flausino et al., 2015). Training provides the student with the practical skills to perform the job and ensure errors do not occur to insufficient training to standard operating procedures (Narayan et al., 2021:23, 137). Training and competency are both required as part of ISO15189 standards which laboratories in the UK should have accreditation with (Williams et al., 2019). Both training and education are required to reduce errors and neither in isolation will resolve the issues seen within transfusion and therefore any intervention either educational or training would need supplementing with the other to address some of the deficits seen in transfusion laboratories currently (Bolton-Maggs et al., 2019; Narayan et al., 2021:137).

Learning can be achieved in many ways which include the use of face-to-face teaching or distance learning utilising 'electronic learning.' Face to face teaching has been used successfully for years within the school and university environment; however, since COVID-19 there has been an increase in online learning (Al-Riyami et al b, 2022). Online learning or

electronic learning can include lectures delivered in a synchronous or asynchronous manner, online packages and virtual learning activities (Kala et al., 2010). More often now institutions are using a more hybrid approach which uses both e-learning and traditional face-to-face teaching often referred to as blended learning (Garrison and Kanuka, 2004) which is reported to improve results seen in other studies (Morton et al., 2016; Garrison and Kanuka, 2004). This allows the learning to be supported by the Learning Management System (LMS) content which allows a hybrid of traditional teaching methods alongside technology to enhance the learning experience (Pishva et al., 2010; Bashir et al., 2021). The other advantage of using a blended approach is that all students can start the material simultaneously, which allows for conversations to occur on a forum allowing further development opportunities and increases the grade seen for students embarking on courses of this nature (Sahni, 2019). The use of blended learning also allows students to interact with one another, which is hard to achieve, using only an online package (Garrison and Kanuka, 2004).

The use of e-learning can allow not only for interactivity using various media e.g., videos, chat forums, interactive quizzes etc. (Rambiritch et al., 2021; Huang, 2005) but also the flexibility for the student to determine the learning content (Anaraki et al, 2004; Kala et al., 2010). This is essential when considering additional learning, e.g., training in the workplace, as the learners' needs and styles will all be different (O'Donnell et al., 2015; Mayer, 2019; Beer et al., 2010), and the baseline knowledge will vary from user to user. Learners' needs may include appropriate equipment to complete the learning or a sufficient internet connection to allow the package to work as intended (Shahzad et al., 2020; Schulz et al., 2013). The use of blended learning allows them to tailor the course to their individual needs, which could not be achieved in a traditional classroom setting and has shown to enhance outcomes (Li et al., 2021; Lane and Harris, 2015). Making this form of teaching dynamic (Zhou et al., 2008) and ensures a

better performance from the student compared to traditional teaching methods alone (Pishva et al., 2010). A study by Issa et al. (2011) of medical students looked at differences in knowledge between traditional teaching methods compared to those using multimedia methods. Students improved their knowledge in both arms; however, the retention of knowledge was more significant in the multimedia arm, demonstrating the importance of considering media use in any developed learning.

It is also important to consider engagement. There is a requirement for students to take ownership of their learning (Kim et al, 2019; Sahni, 2019). There can often be a reduction in engagement with the system if the packages are too long and it is not possible to look for visual clues of engagement when using e-learning (Tanner, 2013). Therefore, when designing e-learning, this needs to be considered (Rogers, 2008). Some tools can be used to improve online learning engagement, such as having interactive material, considering gamification, ensuring the length is not too long and a variety of delivery methods (Wood et al., 2015; Childs et al., 2005). Stuart and Rutherford (1978) showed when looking at medical students, the maximum concentration peak was reached within 10-15 minutes into an hour lecture; therefore, the assumption would be this would apply to e-learning.

A study by Lee et al. (2019) established in their study six factors that can improve engagement in e-learning systems. These factors include collaboration with peer' personal motivation, seen in further education settings. The ability to be able to solve problems such as the use of PBL. Being able to interact with the course instructor, which could be achieved by using online forums or email communication. Having peer support could also be achieved in the same way as instructor interaction. The final area for improved engagement was to be able to self-manage

the learning. These critical areas of engagement could also be addressed by using a blended approach where students partake both in face-to-face learning and e-learning, which has been recognised to improve outcomes and reduce the attrition rate (Dantas and Kemm, 2008).

The use of e-learning also allows for asynchronous learning or point of need learning, which means that not all learners have to participate at once (Lee at al., 2019). This allows adaptability for the student to pick up learning as they have time (Anarki, 2004) which is critical in the current climate where the NHS is highly under-resourced (Bolton-Maggs et al., 2019); therefore, learning and development are sometimes sacrificed due to the time constraints it poses (Bark et al, 2016). The student's ability to determine their learning is essential when used as a training tool to provide additional learning to ensure engagement with the system (Blaschke, 2012).

When utilised, E-learning can allow the learner to participate in activities such as PBL, which is often used in medical training to develop the critical skills of the trainee doctors and move away from didactic teaching (Tsai and Chiang, 2013; Hung and Tsai, 2020). The use of interactive exercises allows the student to develop knowledge and apply it in a clinical scenario improving the learner's experience (Anaraki, 2004). Interactive cases can be based on real-life patient scenarios, which appeals to the emotional learner improving their engagement with the e-learning (O'Regan, 2003). However, all these positives do rely on the learner interacting with the LMS, which is not always the case, for the learning to be successful (Kinash et al., 2012; Anaraki, 2004). The interaction in the LMS can be enhanced by ensuring the system is user friendly and intuitive (Veluvali and Surisetti, 2022) and reduce the attrition rate (Rogers, 2008). This allows the student or learner to interact with the system to allow for maximum

learning (Subramanian et al., 2014; Itmazi and Megias, 2005); therefore, it is essential to consider the LMS when developing a new platform.

It is important to see what tools are available on the LMS to analyse engagement and motivate students to engage with the system (Wang, 2017). Higher educational institutes are using free tools available to determine student engagement and allow them to see their progress (Scater a, 2014; Scater b, 2014). Attrition data can provide information regarding the success of the product. If the learning package has resulted in good engagement, there will be a reduction in the number of students failing to complete the package. In contrast, the opposite may be said of a package that does not result in good engagement. It is documented that attrition rates can be 10-20% higher for e-learning than traditional teaching methods (Kola and Landis, 2004). It is thought the attrition rate can be addressed, and the problem may not be down to the content of the learning but the user's ability to interact with online systems (Martinez, 2003). There are many other causes of reduction in engagement which are not impacted by the course content which include access to appropriate equipment, time constraints, other work commitments. These are harder to address when developing learning material (Sambrook, 2003). Therefore, this project's focus will determine the engagement with the learning and improve this for future projects.

1.14 E-learning Platforms:

1.14.1 Current E-Learning Platforms Available:

The content for any e-learning package could be developed on a programme such as Articulate Storyline 3®, allowing the author to put the material in a storyboard. Use of programmes such as Articulate Storyline 3®, allows for the use of tools ensuring the package is interactive by the use of hotspots, quizzes and different forms of media to ensure full engagement of the user (Slade et al., 2014).

E-learning packages require a platform to host all the information required as part of the package, and this is sometimes referred to as an LMS or a Learning Content Management System (LCMS) (Saeed, 2013). LMS's roughly all provide the same service, although each platform has different capabilities with services and functionality that they can provide the developer and learner.

LMS's such as MOODLE® and Blackboard® have many of the same essential functions: discussion forums, quizzes, course construction wizard, and the ability to contain lots of different file types (Subramanian et al., 2014; Bremer and Bryant, 2005). These functions would be essential when delivering a e-learning package.

The two most used platforms MOODLE® and Blackboard®, both provide mobile options that allow the site to be accessed from any mobile device upon download of a host App. The mobile

sites provide all the content in one area; however, the Blackboard® mobile site does not allow for saving pop-ups and requires the user to log back into the system if they want to re-access this information (Kinash et al., 2012). This has been extensively studied within the university setting, where students often accessed the content for their course on mobile phones or tablets although it is acknowledged these devices may not provide an optimum learning experience (Almaiah et al., 2020). It has been noted that there is enhanced participation in the course if they can access this from a mobile device (Itmazi and Megias, 2005). However, there were no studies to replicate this in the health sector, although this could potentially be extrapolated. Other advantages of using an LMS include only developing once as this is not device-specific and can be used on static machines and mobile devices.

The NHS has a digital learning platform, E-Learning for Health, which is a repository for e-learning packages and would be ideal in the long term for any education resources created for transfusion to be available (E-Learning for Health, 2020). Since the creation of this project there have been multiple uploads of transfusion packages available to healthcare professionals (Health Education England a, 2023). The increase in e-learning can be attributed in part to Health Education England increase in funding available for development of packages within the NHS (Health Education England b, 2023).

1.14.2 Platforms Using App Technology:

Another technology available in electronic learning is apps where the developer can decide to use a phone or tablet App, which can be downloaded onto a device upon development, providing both a knowledge resource and the ability to interact with the user (Franko and Tirrell, 2012). The use of Apps has been widely adopted but requires the user to have a personal device which they are happy to download the content on (Shankar and Yadalla, 2012). It may also require the App to be developed on multiple platforms to ensure that it is suitable for all mobile devices; If individual development is required, this would have to be on two of the leading platforms: Android® and IOS®, which would have a cost implication (Gavali et al., 2017) with a higher cost in App development over e-learning packages, which local IT can often develop (Emizentech, 2021).

There are, however, advantages to using App-based technology, such as the software being able to be accessed anywhere without worrying about connectivity (Criollo-C et al., 2021). This can increase users' frequency of access as they can complete sections whilst commuting to work and improve engagement (Pechenkina et al., 2017). It does, however, make managing the App more complicated as the content is not kept up to date on the App if an update is not performed and there is a risk of providing incorrect information to the student (Yang et al., 2020). This is particularly important when considering using this in a medical background where the practice should always be based on the most up-to-date evidence (Sackett et al., 1996) and requires management (Jacob et al., 2023).

Apps often have a lengthy change process involved if amendments are required and require users to update the App for these to take effect (Existek, 2019). This is a risk when considering laboratory-based practice, where changes occur with guidelines or new advances in the subject field (Meetoo et al., 2018). Whereas the use of a learning platform also allows for localised content management (Bremer and Bryant, 2005), it can allow content on the e-learning package hosted on the LMS to either be updated or removed should this be required due to a change in the guidelines for example.

1.15 Use of E-learning in the Healthcare Setting

The use of distance learning has been widely published, and Cavanaugh described the successes with positive results seen with e-learning using interactive methods compared to traditional teaching methods such as classroom teaching (1999). This success, echoed by Williams (2006) and Ricciardi and De Paolis. (2014), demonstrated a slight increase in allied health professionals' success. They studied distance learning, such as e-learning, compared to traditional teaching methods, indicating there are successes to be had within the healthcare sector.

Williams broke this down further in her study, looking at working professionals who have a better outcome when participating in distance learning when compared to traditional classroom teaching (2006), which is the main method used by the NHS (Surr and Gates, 2017).

Toy describes how various platforms, including e-learning, have been used to develop knowledge in transfusion (1996). Although this article is old, the content concurs with other reports describing traditional teaching methods such as face-to-face and at conferences are successful; however, not always practical (Bolton-Maggs et al., 2019). The author also describes the use of algorithms to aid decision making (Toy, 1996); this could be utilised in some transfusion practices such as ABO blood grouping. The use of tables and decision tools has been adopted in the BSH (British Society for Haematology) guidelines, such as the Pre-Transfusion Compatibility Guideline (Milkins et al., 2012), allowing scientists to follow simple algorithms to reduce errors. This could easily be translated into e-learning or online problem-based learning to allow students to apply knowledge and gain practical experience in a non-clinical setting.

Bernard et al. discusses how learners develop their abilities to learn as the demographic of the learners change (2000). Although this was describing distance learning in the university setting, it described the changing demographic of learners resulting in different learning methods. This is applicable in the healthcare setting as the age range is wide in the scientific workforce in pathology; see figure 14 (NHS employers, 2017). They described some of the limitations of distance learning, including high drop-out rates and low quality of learning and skills learnt. Bernard et al. then discussed how to overcome some of these barriers, and one mechanism they used was personification, where they used case studies to engage the learner and ensure adequate learning (2000). They described how interactive computer-based technologies using forums, for example, can improve learning, which is one of the projects that aim to create an interactive platform to educate and allow the application of the knowledge (Cakir, 2013). This is described as constructive learning through collaboration which consolidates previous learning experiences whilst encouraging active dialogue to develop further knowledge (Notari, 2006; Laal and Ghodsi, 2012), allowing for classroom-style learning but at a distance. There are issues with collaborative learning that require the educator to assess the learner's requirements. This could be challenging to achieve with distance learning; however, there may be an opportunity to develop a preliminary case study that assesses the learner's needs as part of a baseline assessment. The case study results would then direct the learner to the most appropriate level of training.

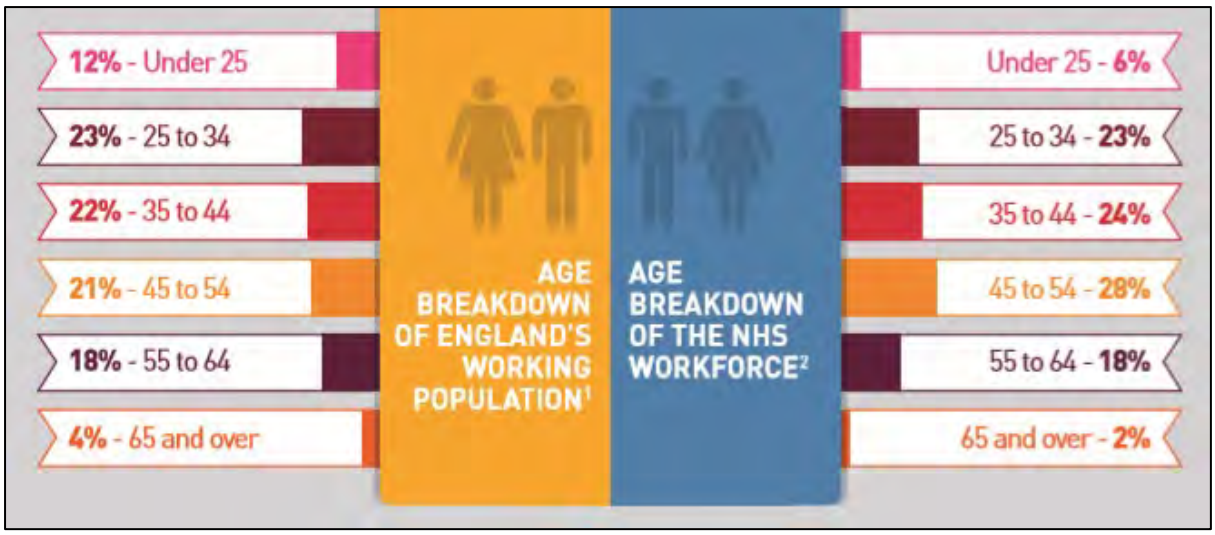


Figure 14 NHS age demographic (NHS Employers, 2021)

Moule et al. (2010) describe how e-learning was used with student nurses with varying success. This was not due to the content of the package but due to engagement with the system. This has been highlighted by other authors (Williams, 2006, Ricciardi; Di Paolis, 2014); therefore, it would require addressing in this project to ensure it fulfilled the student's requirements.

1.16 The use of Gamification in Healthcare

Sherry (1995) describes how interactivity is critical in the engagement and success of learning. This is a crucial concept for the provision of this service for it to be successful. The Landsteiner game (Nobel Prize, 2017) allows users to test the blood sample to allocate the appropriate blood group and then provide blood products to the patient. This game led to this concept being developed in this project to provide interaction and an opportunity to compete and gain credit for completion.

The use of gamification has been successful in other healthcare areas and allows interaction and entertainment whilst also providing a learning opportunity (Nah et al., 2014). The use of games where knowledge can be applied can result in retained information (Blakely et al., 2009) while ensuring better engagement with the system (Ricciardi and De Paolis, 2014). This project could utilise both e-learning with gamification like the BTLP TACT® system. It would be hoped the engagement from the game as described in the literature would inspire the user to continue with the programme to gain further rewards ensuring further learning. Although this concept may not appeal to all generations of scientists, this should capture a high proportion, as scientists tend to be quite competitive (Fang and Casadevall, 2015). There are other areas of medicine currently using gamification to improve knowledge and application (Abdulmajed et al., 2015), and these successes would suggest this would work in transfusion.

1.17 The Current State of Online Transfusion Education Worldwide:

1.17.1 Online Learning Available within Transfusion:

Online education has been a rapidly evolving field over the last 12 months (January 2020 to December 2020) because of the COVID-19 pandemic resulting in a cessation of face-to-face learning (Hasan and Bao, 2020; Al-Riyami et al. b, 2022; Pearse and Scott, 2023). There has been a move from higher education institutes and organisations such as NHSBT delivering courses using pre-recorded material (asynchronous learning) and live sessions (synchronous learning) using online platforms such as Zoom® (Teräs et al., 2020; Radha et al., 2020; Pearse and Scott, 2023). Use of online learning has been used in many contexts for years; however, it is less common in the healthcare workforce. An article by Al-Riyami et al. looked at e-learning and education internationally within transfusion and this highlighted since this project was commenced due to COVID-19 there has been an increase in the number of e-learning packages available with some of these being relevant for a wider audience than currently used for (a, 2022).

There are reports of medical schools both recently and also historically adapting teaching methods due to reduced classroom time and implementing online PBL exercises that allow students to continue to study in a safe environment (Ahmed et al., 2020; Williams, 2006). Reports from universities show the students have received this well, and they felt there were efficiencies when it came to student time (Khalil et al., 2020) such as the convenience of learning (Radha et al., 2020; Regmi and Jones, 2020). Other studies have also supported this, also looking at online learning's impact during the COVID-19 pandemic (De Michele et al.,

2020; Bashir et al., 2021). Whilst there is evidence to suggest online lectures have been well received, there is a common theme such as the students access to appropriate technology and the ability to have group discussions which were limited to when having lectures on Zoom® (De Michele et al., 2020; Li et al., 2021). Universities have been investing in online learning during this pandemic, and there may be a shift to a more blended approach in the future where students have both face-to-face lectures and digital learning (Wang, 2017; Bashir et al., 2021).

The use of e-learning in transfusion is not currently widely used which was evident when reviewing the literature, the only examples found nationally available are described in more detail below (Al-Riyami et al. a, 2022). This has provided evidence to suggest this can be adopted as an alternative for delivery of courses and considered for future national learning projects. It can be acknowledged there may be local solutions which unless published the author is not aware of therefore this may not represent the entire e-learning adoption within transfusion (Al-Riyami et al. a, 2022).

Many NHS Trusts use the Good Manufacturing Practice (GMP) and Anti-D training packages developed by the Scottish Blood Service and NHSBT in the UK to ensure compliance with this training (E-learning for Health, 2020). This package is free to access and has improved training delivery, allowing standardisation and transferability of this training to other hospital trusts for staff. The Scottish blood service acknowledged that the anti-D package has not been reviewed for a while and was heavily focused on the clinical teams. The package is currently in review to update all the information in the product and ensure relevant information for both clinical and laboratory staff (E-learning for Health, 2020). Since completion of this project the anti-D

module has been updated and there is the addition of more e-learning courses available (NHS England, 2023).

Utilising these techniques to have national training programmes within transfusion would improve staff access and for transferability of skills to another trust this is desired as there are local and national inconsistencies with the BMS training (Allard et al, 2021) and may alleviate some of the issues seen in the hemovigilance reports.

Current transfusion training is often available as face-to-face; however, the idea of providing knowledge-based training could be supported by practical application in the laboratory using Internal Proficiency Exercises (IPEx) (NHSBT c, 2023) or UK NEQAS's BTLP TACT® (NEQAS, 2021). This would provide an excellent compromise in training the current workforce providing both knowledge and skills required of a BMS. BTLP TACT® allows BMS staff to gain competency in transfusion scenarios in a computer-simulated laboratory. Staff are required to follow the process of a sample through the laboratory and give results. These results are then scored against the model answers and attributed to an individual learner's record. There is oversight from the TLM who can see staff performance and allow for intervention where there is evidence of concerning practice. The BTLP TACT® system is available through UK NEQAS as part of a subscription service for laboratories to purchase for each staff member (NEQAS, 2021). A hospital in the Southwest used BTLP TACT® as part of their competency assessment for existing staff within transfusion. They report an improvement in their competency and an improvement in staff knowledge of antibody identification (Personal Communication, 2020). The laboratory staff have not published the

data however they have noticed a local improvement, and this was discussed between the author and the transfusion laboratory manager.

1.17.2 Apps Available in Transfusion in 2017:

IOS® and Android® app search functions were searched to provide evidence of available apps. Search terms which included transfusion, transfusion science and transfusion medicine were searched. The date of 2017 was used in this search as this was when the product for this project was created. Since 2017 there is an acknowledgement there has been an increase in the number of Apps available; however, there is still potential for lack of standardisation.

Apps are often used to provide easy access to information and provide learning opportunities as they are downloadable onto a device that makes them accessible and often do not require the internet; therefore, they can be used anywhere (Ming et al., 2020).

One available App is from the Australian blood service. They have developed a transfusion game, which allows the user to predict the blood groups but provides no knowledge (Blood Safe Learning, 2017). This is similar to Landsteiner's game available on the internet that, although 'fun' provides no learning around the theory but is an excellent opportunity to apply the knowledge gained elsewhere (Nobel Prize, 2017). These Apps are an excellent example of how gamification can enhance learning (Ricciardi and De Paolis, 2014).

Another App provided by Ortho Diagnostics®, which provides an antibody index (Medical News, 2012), but no knowledge, however, would be a useful tool for scientists working in transfusion who require additional information about a blood group.

The PBM team has also developed an App (NBTC Blood Components App) that provides practical transfusion advice directed by the National Institute for Health and Care Excellence (NICE) and BSH guidelines (Booth et al., 2021). This was the first national App within England for transfusion and has been successful within the clinical teams. The App provides transfusion triggers that the BMS staff can use to empower them to challenge unreasonable requests.

The PBM team have more recently invested in modern technologies to increase awareness and improve access to knowledge and resources required to influence decision involved in the transfusion pathway by creating an App Blood Assist (NHE, 2015). The App provides the NBTC indication codes for transfusion and thresholds based on best practice to improve the clinical outcomes. The App is new, so the impact is still to be assessed, but users' feedback has suggested that this resource is invaluable and will improve transfusion safety (Marshall and Davidson, 2020).

A recent release of an App by SHOT allows instant access to reports and other learning resources produced by them. The App will provide an invaluable resource to both clinical and laboratory staff and allow easy access to learning material, hopefully improving the knowledge (Narayan et al., 2020).

1.18 Summary of the Introduction:

As can be seen, there is a potential crisis in the transfusion workforce where staff are being trained to varying degrees which may be contributing to an increase in errors being reported nationally alongside other contributing factors such as a staff shortage (Bolton-Maggs et al., 2019; Narayan et al.,2021:137). This has attracted support from organisations such as the UKTLC to attempt to resolve the issues seen within transfusion laboratories across the country (Allard et al., 2021). It is recognised there is a requirement for additional learning for the scientific workforce which is accessible to all (Bolton-Maggs et al., 2019). The requirement for the learning to be in a virtual environment is essential as there is not sufficient staff to cover absences from the laboratory and distance learning can reduce the amount of time staff are absent from the laboratory (Bolton-Maggs et al., 2019; Flausino et al., 2015).

The utilisation of e-learning has been adapted in many areas of healthcare and could be adapted for transfusion (E-learning for Health, 2020; Al-Riyami et al. a, 2022). There have been attempts at improving learning occurring, such as the Italian system looking at utilising the HTC to the Americans who looked at addressing the undergraduate training of medical students. There are examples of successes that could be used to inform this project (Liumbruno and Rafanelli, 2012; Annsburg et al., 2012).

Overall, the literature worldwide has highlighted some key points to consider when developing distance learning in the healthcare setting. The articles which have been reviewed have discussed how to ensure the learner's best engagement, and it needs to be user-friendly and use personal cases to ensure engagement (Williams, 2006; Cavanaugh, 1999). It suggests the use

of gamification or a place where knowledge can be applied leads to better outcomes (Hung and Tsai, 2020). Finally, it shows how a single approach is not practical in learning and how different staff cohorts require different approaches (O'Donnell et al., 2015) and therefore, a blended learning approach may be best (Garrison and Kanuka, 2004). There are some examples of excellent work being carried out by other countries, but it has highlighted room for further development for distance learning within transfusion.

2 Project Aim:

The project aimed to design an educational package that could either be downloaded as an App for smartphones as well as / or being able to run on the internet in real-time using an LMS platform to enable scientists to improve both their knowledge and confidence in a single topic of transfusion science.

2.1 Objectives to Achieve Project Aim:

- Selection of a single topic to create the content for the educational package.
- Educational package aimed at various levels of staff to include newly qualified and specialist BMS staff (bands four -seven).
- Knowledge assessment which could be used for Continuing Professional Development (CPD) or competency assessment of staff.
- Interactive methods of teaching e.g., gamification to be adopted through the educational package to reduce the attrition rate amongst users and allow application of knowledge to improve knowledge retention.

The e-learning package would be the first of its design in the UK incorporating both learning material and interactive exercises allowing for application of knowledge on the chosen topic ABO blood grouping using UK guidelines. This would utilise all the best practice available and use well-known methods, which include real patient cases enabling better, more efficient learning. The use of e-learning and lessons learnt from other training packages reviewed as

part of the literature review will be used to develop an e-learning package that is fit for the current NHS workforce's purpose.

3 Research Questions:

The research questions which are to be answered by this project include:

1. What areas of knowledge are weaknesses in the current pathology workforce within transfusion which may result in errors occurring due to lack of knowledge (Covered in the introduction)?

2. How can theoretical transfusion knowledge be made interactive using distance learning methods yet still be based on accepted best practice?

3. Can distance learning improve both a student's actual and perceived levels of knowledge and is this retained after a three-month period?

4 Methods:

The project was split into three sections which included:

- A service evaluation of the current training platforms/courses provided by NHSBT and the user requirements for future training programmes by e-learning/distance learning including stakeholder engagement.

- The design, procurement, and creation of an e-learning/distance learning package, including the developed product trial within hospital transfusion laboratories.

- An evaluation of the learning from the developed product and its impact on practice for the individual staff.

Each section is described below with finite details about the methodology and how the data was gathered. The methodology will also include a rough timeline of events seen in table 7 in the form of a Gantt chart that allowed for planning the project and providing time points to ensure deadlines were adhered to.

Table 7 The timeline of events was as follows in the form of a Gantt Chart:

	Week																																					
Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Service evaluation survey sent to users																																				
Service evaluation results interpretation alongside national error rate																																				
User specification created for e-learning project																																				
Story board creation for e-learning project																																				
Development of e-learning project																																				
Consenting potential candidates																																				
Sending out pre-knowledge checks to candidates																																				
Candidates to complete project																																				
Candidates to complete post knowledge check																																				
Follow up knowledge check to be sent																																				
Thank you, letter sent																																				

4.1 Service Evaluation:

This section is broken down into two subsections which were:

- A stakeholder engagement sent out to the service users in the Southwest region.

- An extensive review of the national reporting errors to both SHOT and SABRE to ascertain the areas of concern within transfusion focussing on areas where additional training to supplement the prior learning from both University and the Hospital Laboratory may provide a benefit.

4.1.2 Stakeholder engagement of Southwest Service Users:

The initial part of the project was designing a method to evaluate the current training service provided by the NHSBT training department, focusing on training Healthcare Scientists. Service users were asked to assess via a survey how useful they felt the content in these courses was and if they met their needs as an employer with additional questions around how they felt about the accessibility of the courses. There were several key focus points in the design, including the level of training, quantity, frequency, and method of delivery which were of particular interest for this project. Questions were directed to inform the training level required, including for which staffing group this would be used. There were also questions around the training duration; for example, would the user prefer a modular approach or a whole week. There was a focus on the mechanism of training if the users would prefer a blended approach or pure e-learning, for example. The final area of interest was the topics in which the LMs felt

their staff required training, which would inform which subject to focus on as part of this project.

Ideally, all service users would have been approached to ensure a complete view of the transfusion workforce (Groves, 2006); however, this was logistically challenging, and this is acknowledged as a pit fall in this project as it has introduced as service user bias (Artino et al., 2014). There was a focus on the Southwest service user feedback for this project which is served by the Filton blood centre based in Bristol. The Southwest region was selected as the author was based in Bristol; therefore, able to attend regional meetings to gain interest in the project. The Southwest region can be seen in figure 15. Another advantage of selecting the Southwest users was that many Transfusion Laboratory Managers (TLMs) in the Southwest are actively involved in the National Transfusion Laboratory Managers (NTLMs) group, supporting the development of transfusion education methods. Therefore, they are more likely to want to be involved in an educational intervention. There were multiple biases introduced by only using the Southwest area which include: personal bias, most of the laboratory managers collaborate closely with the author in their professional role and met the author at the RTC which may make the user more inclined to respond. This could not be addressed without expanding the survey outside of England as the author works nationally (Williams, 2016). Unfortunately, time did not permit the author to take the survey outside of England and therefore this must be acknowledged when interpreting the data. The second bias was the geography of the service users who were approached. The discussion describes how this may have affected the results obtained as the region has a stable workforce and most students will attend one higher education institute. This could have been corrected in extending the survey to a second area in England however this was not explored during this project due to availability of the author. There was however a review of existing national data such as the UKTLC

surveys (Bolton-Maggs et al., 2019) and the results compared with the survey results. The results from this section will therefore be interpreted with caution and discussed further in the discussion.

Figure 15 A map showing the hospitals in the Southwest Region covered by Filton (Bing Search, 2020)

The survey was designed with simple questions which were short and simple to increase the comprehension of the respondent (Scott et al., 2020) and ensure maximum response within the user group. The responses selected for the survey avoided using terms which may have been open to interpretation such as frequently or sometimes to ensure consistency between responses (Scott et al., 2020).

To enable data interpretation the questions used had a defined answer, with most requiring a simple yes or no response which in a review by Callegaro et al. has shown to increase the response by utilising a forced choice option (2015) although there were some multiple-choice responses. At all points of the survey there was an opportunity to provided comment as this

can provide useful data; although this can be challenging to interpret (Scott et al., 2020). The questions used as part of the survey can be seen in appendix 2.

The survey was created on an online platform called Bristol Online Surveys (BOS) as NHSBT had a subscription to this service, which allowed for all the functions to be used. The electronic survey version was preferential; however, from experience with engaging with service users, some prefer to complete surveys on paper and therefore, this survey was also made available in a paper format upon request (Beebe et al., 2007). Surveys completed on paper by LMs were entered onto BOS and checked twice to prevent transcription errors, this ensured all the data was collected on a single platform to aid in the extraction of the data.

Another aim of the survey was to collect information around laboratories interested in participating in a trial of any products designed. This was included to allow for full staff evaluation of the product and ensure it is fit for the laboratory's requirements.

LMs in the Southwest region were given twenty-eight days to complete the survey and provide feedback. There were two reminder emails sent out as late submission was not accepted for data gathering; however, comments that were received late were considered in the project's development. Twenty-eight days were selected to increase the number of responses gathered; this allowed staff to be on leave during the October half-term holiday and still have sufficient time to complete the survey. The survey was launched at the Southwest Regional Transfusion Committee (RTC) in October 2017, which allowed for discussions on the topic. A presentation was given to provide a background to the project, as shown in appendix 1.

The results were extracted from BOS after the 28 days and were used in conjunction with the SHOT data to determine the topic area for the project and how to deliver the package. Data were extracted from BOS into a PDF to allow for the analysis. The data were analysed by looking at the total responses, and the response rate for each answer. For example, the question around the level of training required the two answers with the highest score was selected to be included for the package development. The highest scoring along with the data from the external organisations such as the UKTLC results and SHOT reports influenced the projects direction and topic.

4.2 Development of the E-learning Module:

4.2.1 Review of Haemovigilance Reports:

The results from evaluating the SHOT reports were performed in two ways. Initially, a review of all the reports within each reporting category was performed; this is then broken into avoidable errors, e.g., human error or not avoidable errors which is already categorised by SHOT each year, e.g., unexpected, for example, patient reaction to a transfusion. The focus was then on the deemed avoidable errors, which are also subclassified by SHOT (Bolton-Maggs et al., 2017:13). These errors were reviewed by the author and assessed for the error location, either in the clinical environment or the laboratory. This was important as the e-learning package was aimed at laboratory scientists. Based on the review the areas which had the most errors were then looked at in terms of clinical significance and the area which score the highest in total number of errors and near misses as well as the biggest clinical impact was selected. It should be noted if any errors were deemed as 'never events' (NHS Improvements, 2018) then these were given a higher score.

The service evaluation's final stage was to look at the SHOT reports over the three years 2013 - 2016 and look for common themes within the reported errors. These years were selected as there have been changes to training with MSC in the BMS and CS workforce, which would reflect this period. This required evaluating the published reports and reviewing the errors that have occurred, considering where there was a potential for additional training to reduce the likelihood of this error occurring in the future. This required looking at both the total number of errors published and reading the additional information given for individual cases to

establish if there was a root cause that attributed to training. These errors were then risk assessed; this was based on the potential impact on patients and the profession's reputation if these were to occur again. The area with the highest risk associated with it, which would benefit from further additional training, was selected for this project this is further discussed in the results section.

The 2016 breakdown of the SABRE report, which looks at laboratory-based errors as well as reactions reported was interrogated. The report is formatted in an identical way to the SHOT report and breaks down the individual reporting categories, which allow for comparison of the data sets with SHOT. Since 2012 the SABRE report is contained in the SHOT report therefore all errors could be reviewed through the single SHOT report for each year and the data evaluated to determine the sources of errors and potential for improvement from the laboratory. Although this project was completed in 2020, the design of the e-learning package occurred in 2017. Therefore, data after this point was not considered as it was not available at the design time. Data from the SHOT and SABRE reports after 2016 will be discussed in the discussion to highlight the requirement for educational developments further.

4.2.2 Design of the E-learning Package:

There was funding for two e-learning packages to be developed £10,000 in total; therefore, it was designed into two levels beginner and intermediate. The requirement for both levels has been recorded in the literature for both newly qualified and existing BMS staff (Bolton-Maggs et al., 2019). A URS (User Requirement Specification) was designed, as shown in appendix 3. The package designer was then evaluated against the core content and graded with meets requirements or not, the core points are included below, and the full URS can be seen in appendix 3.

When determining on the methods to be used for learning the author took into consideration the literature reviewed on learning preferences to ensure learners' needs were met. This followed a constructive alignment approach to learning (Biggs and Tang, 2007:52) using structured learning outcomes at the start of a section of the e-learning package (Wang et al., 2013) and this was assessed at the end with a short formative assessment (Biggs and Tang, 2007). Constructive alignment has been shown to be beneficial in workplace learning (Walsh, 2007) and is used in other e-learning packages available for students (Ali, 2018). The use of quizzes and interactivity, for example, were included to ensure there was the capacity for active learning and engagement in the package which had been demonstrated as a success in other studies (Hoskins, 2013). The package was created using an ADDIE method (Analysis, Design, Development, Implementation and Evaluation) (Nazarova et al., 2020). The author was responsible for four out of the five aspects (Analysis, Design, Implementation and Evaluation) and required the package designer to do the development of the e-learning package.

Essential requirements for the package are summarised below with justification for their inclusion in the project and were used to create the full URS.

- Video was used to enable a personified approach and allowed users to visualise aspects of the laboratory in ‘real life’. This included the use of videos to visualise laboratory techniques which aided understanding of the theory behind the techniques.

- Games and gamification were used to enable users to apply knowledge, whilst be able to practice their interpretation of blood transfusion results within a simulation environment. There was also the use of interactivity in the package to ensure that there is engagement from the students which was achieved both using the game and other interactive tool such as exercises throughout the package.

- Managerial overview of the student which allowed for the managers to review progress and aid students where any additional help required was highlighted as part of the training. It also allowed for the author and student to review their progress with the package which was used as a marker of engagement for this project. For this to be achieved there was a requirement for individual logins to ensure students only completed their training.

- Section breakdown which allowed for students to complete small sections to ensure their attention span was maintained throughout the package. This also allowed for the package to be completed within natural pauses within the working day to improve engagement with the package.

- Quizzes to be included at the end of sections which were used as a marker of engagement in the package. The quizzes also formed part of a formative assessment which allows both the student and manager to determine if they have achieved an understanding of the content of the package.

- Discussion forum which enabled collaborative learning amongst the students and allowed users to share knowledge.

- Content available without internet connection which allowed students to complete the package whilst commuting or when there was available time which may increase the use of the product. This also increased the number of devices which would have been available to be used to complete the project.

4.2.3 Review of Existing E-learning Packages:

The literature review performed provided information on training methods and successes in e-learning by other research groups. These methods were then evaluated for successes within trials and the feasibility of utilising these methods for this project. The results for this can be seen in the literature review section. The package designer dictated the final software development package as this was the package they were trained to use.

The methodology of the literature review of existing e-learning packages involved searching PubMed® and was supported by supplemented searches on Google Scholar®.

The search terms included: ‘e-learning methods’ or ‘platforms’ within ‘transfusion’, or ‘transfusion science’, ‘transfusion education programmes’, ‘transfusion education’, ‘e-learning in transfusion’, ‘distance learning in transfusion’. Further searches were also performed on other e-learning examples within other areas of healthcare science and medicine and included within the literature review section if they provided relevant information for this thesis. There was no restriction on the date of publication and all countries were included in the search. Studies were excluded if there was no relevance to transfusion or transferable learning which could be applied to transfusion education. Other literature was sought from Google® searches which provided some of the examples of e-learning packages available currently.

The inclusion criteria for articles included e-learning packages which were directly relatable to transfusion or where there was an element of transfusion education associated with distance learning packages. Articles which just referred to face-to-face learning for transfusion were excluded as these were not relevant for this project. Articles which refer to other healthcare

science e-learning or distance learning interventions which had applicable learning for this project were included in the literature review as these may provide insight into lessons learnt in these studies which may impact on this project.

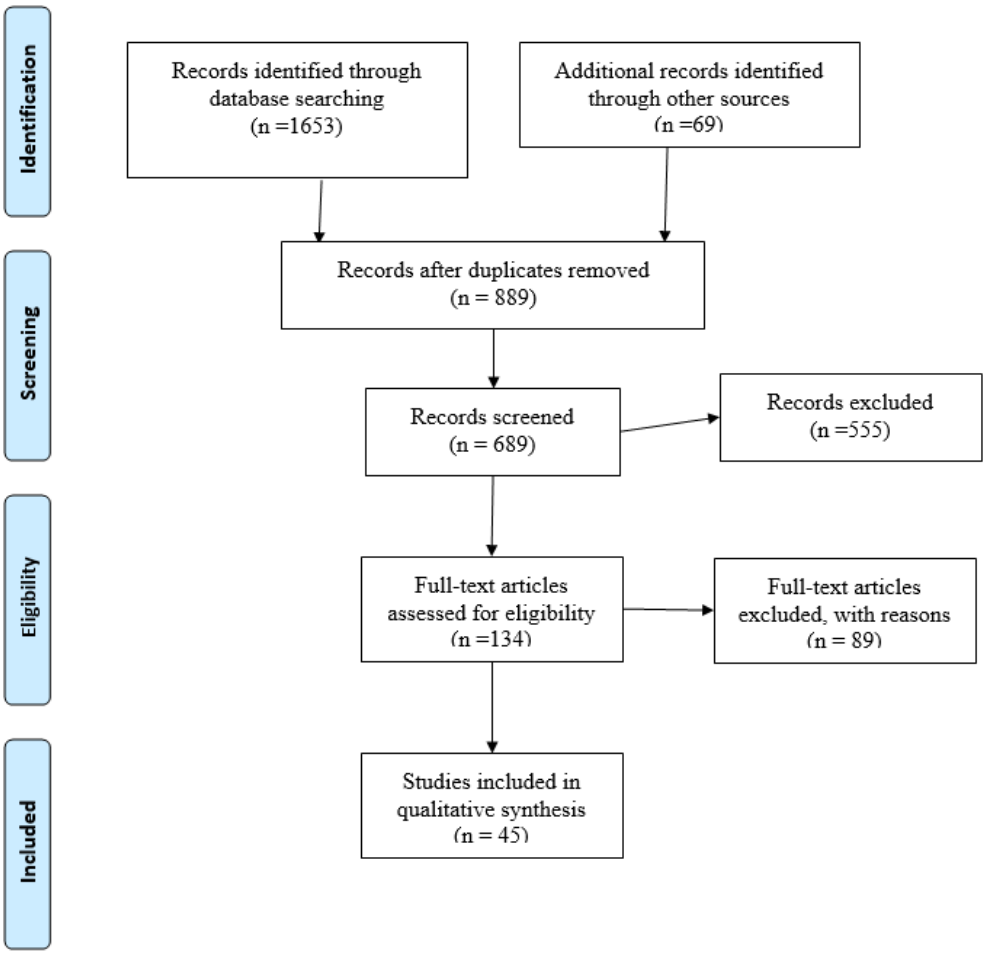


Figure 16: PRISMA-P diagram of literature search for e-learning in transfusion (Page et al., 2021).

4.2.4 Content of E-learning Development:

A storyboard was created by the author in PowerPoint®, which provided the content for the two e-learning packages – i.e., back to basics and developing the knowledge. Images or direction of the desired image were included in the storyboard and any graphics that required the package designer's development. Where a requirement for a video was highlighted, an example and a description were included see appendix 17. The package designer created the content in the form of a video as part of the development of the e-learning package.

There were also directions where interaction for the learner was required, such as the use of hotspots (additional information available on the click of the mouse) or video clips to demonstrate a technique that may be used to investigate patient samples. Other tools used to create interactive exercises within the e-learning package sections included extended matching questions requiring the user to input the correct responses which was included to ensure engagement with the package.

There was also the addition of questions included in the sections' core content, which required user input and, once complete, gave further information (Ross et al., 2018). These tools were used throughout both packages and were integrated, so every other slide was interactive. It was decided not to have interaction on every slide as this would have resulted in the user feeling less connected with the material but needed to occur often enough to ensure full engagement. The author determined the level of interaction from their knowledge of other e-learning packages and how they had best interacted with them. This was also supported by the literature reviewed in other studies by Thorpe and Godwin (2006).

The Storyboard was broken into individual sections from the main topic. This project's focus was ABO serology and grouping, with the justification for this being explained in the results section. The individual sections within the modules for both levels can be seen in table eight. The content was derived from sources including Learoyd et al.'s, introduction to blood transfusion science book (2009:30-52) and Quinley's principles and practice of immunohematology (1998:16,67-72 89-105, 111-114). Whilst the sources used for the content are old the theory around ABO grouping has not changed and therefore these were suitable sources. The learning outcomes were then taken from existing NHSBT courses practical introduction to transfusion science and specialist transfusion science practice (NHSBT a, 2023; NHSBT b, 2023). The learning outcomes from the existing courses were used as they provided a framework which has been accepted by HEE to provide courses for scientific staff within the NHS.

Each section was designed to only last a brief period approximately half an hour (Stuart and Rutherford, 1978). These short sessions also allow for learning to occur within natural breaks in the working day. The responses directed the length of time these sections will take to the survey and personal experience working in a transfusion laboratory.

The storyboard was then transposed to Articulate Storyline 3® by the project designer to develop the e-learning package. The storyboard was a working document and was adapted continuously throughout the project by both the author and the project designer. For example, if the author had intended a function to be performed using a tool that was not available on the software, this was reviewed, and amendments were made to ensure the package remained interactive. The storyboards for both levels (beginner and intermediate) are included in

appendices 4 and 5, these are attached as PDF documents which can be reviewed by clicking the link.

The development of interactive methods was then expanded to include the development of a game. This used the concept of gamification to support the learner to apply the knowledge they had gained throughout the e-learning package to ensure retention. The game was the processing of a sample in a patient scenario. The user was required to test the sample, interpret the results, and provide appropriate blood cover for the patient. This game was created within Articulate Storyline 3® and had some limitations discussed further in the results and discussion section.

The final component of the package development was the knowledge quizzes at the end of each section, a formative assessment. These were not used to measure knowledge achievement in this project but were used as a marker of engagement in the system. The user survey highlighted the requirement for a knowledge assessment for the final e-learning product; therefore, this was built into the system as part of this project and provided the function of determining the system's interaction. A bank of knowledge questions was created for each of the sections within the module. These questions included multiple-choice, extended matching, and free text of specific blood groups, for example. Questions that required a long free text answer were not used as the coding on the system to mark these can be difficult. This could result in incorrectly marked answers if the exact words in the model answer are not used in the student's response. Questions were then allocated to the appropriate training package, either basic or intermediate, and then attached to the sub-section the question was assessing. Questions were set up by the package designer to be randomly generated upon completion of the section. Each section had at least ten questions in the bank to ensure the same questions

were not used if the student attempted the quiz on a second occasion. Students were given five questions at the end of each section with one attempt at each question, and upon answering, they were given the correct answer and feedback. The quiz questions can be found in appendix 6.

Table 8 – List of sections within each module for ABO at each level with a summary of the content:

Sub sections covered within the module
ABO Antigens – Structure and function of the carbohydrate, causes of loss or gain
ABO Antibodies – Basic immunology, Structure and function of antibody, reactivity, causes of loss or gain
ABO Inheritance – Family trees, genetics, genetic variants e.g., Bombay Phenotype
ABO Testing – Methods used, advantages and disadvantages, genetic testing
ABO in Patients - Causes of unusual results, discrepancies, management of patients including post allogeneic haemopoietic stem cell transplant
D Typing in Patients – Methods used, management of patients
ABO and D Typing in Blood Donors – Methods used, management of donors, requirements for grouping
Interactive Case Study - Case studies allowing the user to apply all knowledge from all the previous sections.

Project update meetings were arranged at regular intervals usually every two weeks during the initial design phase and monthly once the project was created. The package designer and author discussed the package and review sections on the Articulate Storyline 3® online review platform. These meetings were conducted using Skype® to allow for a screen sharing capacity. Individual sections could be discussed with the author as the package designer was not based in England. This allowed the author to input the formatting of the e-learning package and ensure the package's interactivity and learning outcomes were achieved as described in the

URS. The regular review meetings also ensured that the package designer completed any technical corrections as transfusion was not their specialist area. For months, the production was kept under constant review and adaptations made after each consultation. Once the final package was completed, this was then reviewed one last time. This followed a simple plan, do, check and act cycle within the review step and was performed multiple times until the final e-learning package was ready for use by the students.

4.2.5 Recruitment and Selection of Users for the E-learning Trial:

The e-learning trial users were selected via all trainees already enrolled on courses run by the Training Department at NHSBT in the six months from January 2018 to June 2018. The two courses selected to enrol students were the Practical Introduction to Transfusion Science course aimed at junior BMS staff, e.g., band four to five and the Specialist Transfusion Science Practice course, aimed at specialist BMS staff, e.g., band six to seven (NHSBT, 2020). These two courses directly correlated to the two levels designed in the e-learning project, which were basic and intermediate. All students on both courses underwent the same additional learning and were given precisely the same lectures over a one-week period which would prevent any participant having a knowledge advantage. The two courses also ensured that scientists from bands four to seven were invited on to the project which ensured that scientific staff working within pathology were invited to partake in the trial. The participants were invited through NHSBT as there were contact details and knowledge of their bandings and were all based in the UK which was the guidelines the package was based on. International participation was not undertaken for this trial. Firstly, this occurred during the COVID-19 pandemic and additional workload on scientists was not deemed appropriate. Secondly the package was based on UK guidelines. Whilst these may not differ in every country a review and amendments to the package may have been required to make it appropriate and this fell outside of the remit of this project.

Ethics approval was sought from the Research and Development (R&D) office at NHSBT before commencing student contact. Completing the R&D ethics tools demonstrated no requirement for ethical approval for the project; however, it was essential to gain consent from all participants. R&D approval, including the ethical requirement, can be seen in appendix 16.

Permission was sought from the students to have their emails addresses given to the author to allow discussion with the prospect of participating in an e-learning trial. Once students had given consent to be contacted, 50 students were invited to take part in the project to allow for students to not complete the project and still have adequate numbers of participants. The number of students who were invited was not limited to 50; however, this was the number who expressed interest by agreeing to further information from the author and attrition data can be seen in the results section. The author then approached the students by email, asking for interest in participating in an education trial associated with a professional doctorate. It is acknowledged that all participants dealt directly with the author for this project which may have introduced personal bias into the project. The bias was limited where possible as all communication was made by email and the students never met with the author. Whilst this did not completely eliminate the bias it aimed to reduce the personal bias. All students were sent the same emails when the author was trying to engage the participants with the aim to reduce personal bias. The author also created a schedule for communication with participants ensuring all students received communication at the same time points with the same content (table 7). It should be acknowledged that if a student emailed the author, they responded to the individual which may have increased the student's motivation for completing the project.

Once the student responded, this information was collated onto a spreadsheet. A supporting participant information sheet and consent form were sent to the individual to complete and return to the author. An example of this can be seen in appendix 7 and 8.

A consent form was required from each student due to participation in the project where identifiable information being held on a database following general data protection regulation

requirements. The consent form included how the data would be used, stored and what data were required from them. If a consent form was received, they were enrolled in the project to access the e-learning package.

Consideration was made to students' selection bias, which again was an area that had not been considered before the literature review. As the participants were currently in training positions or undergoing additional specialist training, they are more likely to complete further training (Salgueira et al., 2012). This was overcome by recruiting scientists at all bands and not just trainees to overview how the project worked for the healthcare scientist workforce in transfusion. This was essential as this learning targets trainees and may be used as CPD for established scientists as required by the HCPC (Stevens, 2016).

Figure 17 below provides an overview of how the recruitment and project was undertaken within the NHS. This project was more of a feasibility study and further evaluation would be required and this could be expanded outside of England to determine the success of the project.

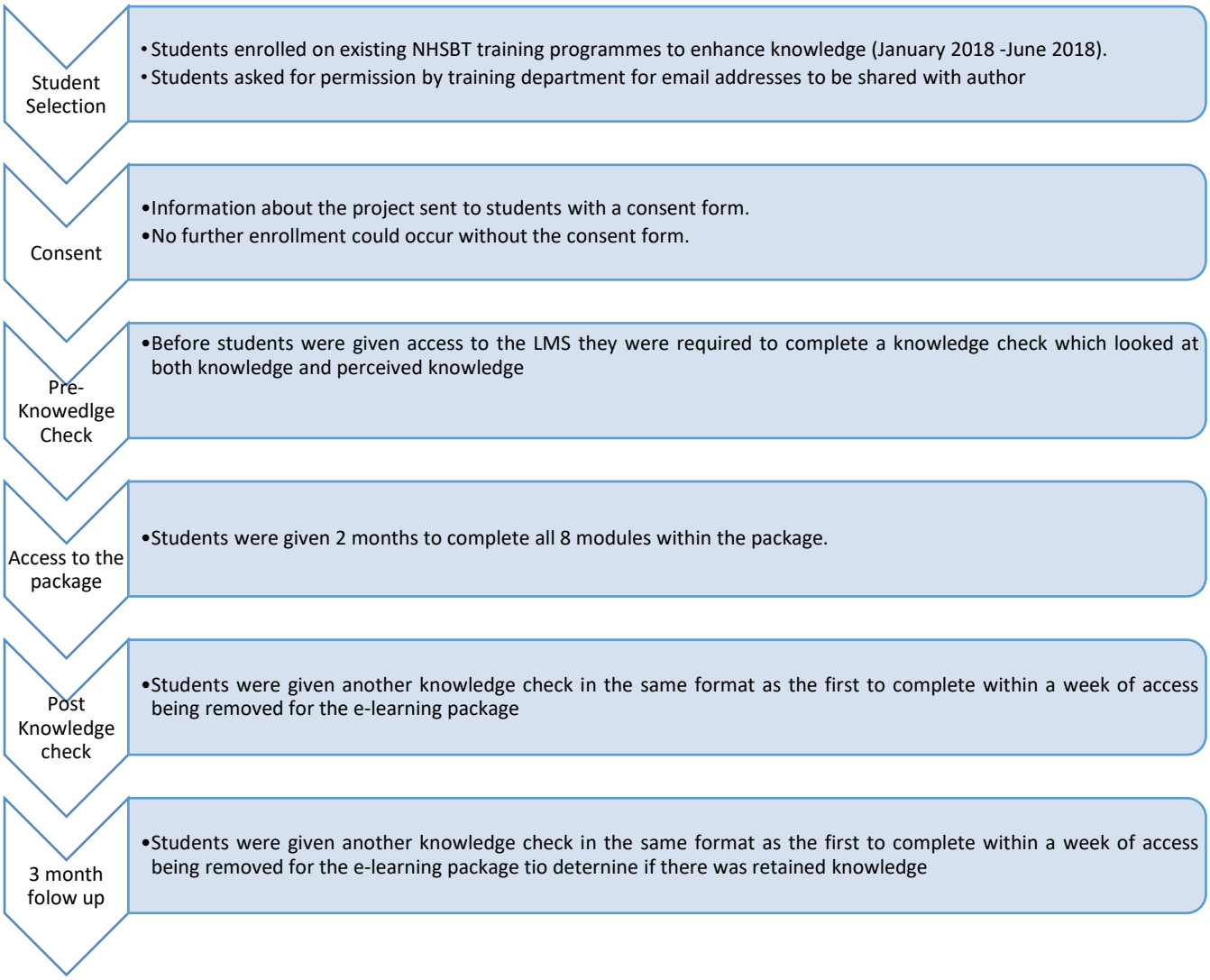


Figure 17: Overview of student recruitment and participation in e-learning trial.

4.2.6 Development of Knowledge Assessments:

Analysis of the e-learning package was performed using knowledge assessments required at three defined stages of the trial. This was based on the concept seen in other studies reviewed (Salter et al., 2014). These defined time points were: before the participant commenced the e-learning package designed to gather the baseline knowledge level, immediately after finishing the product to determine if there was any improvement in the learning directly after completing the programme, and then there was a follow up three months post completion of the programme to determine if the knowledge gained was retained and able to be applied to clinical practice which would be level three or four of the Kirkpatrick education models (Smidt et al., 2009; Salter et al., 2014).

Knowledge assessments were applied to both the basic and intermediate levels of training, and the questions were adjusted to the appropriate knowledge level. Knowledge was assessed using a range of question types based on knowledge gained from the package: complete the blank and open-ended questions which allowed the author to determine the application of knowledge (Kulasegaram and Rangachari, 2018). Both the questions and the model answers were reviewed by other Consultant Clinical Scientist Trainees who are familiar with teaching scientific staff within the two groups selected for this project and can be viewed in appendices 9-14. The questions in the knowledge assessments were changed for each assessment, although they followed a similar format. Questions were changed, so there was no potential for the student to memorise the answer and allowed for an accurate assessment of knowledge. The assessment was delivered in a paper format via email.

All responses to the knowledge assessments were marked by the author reducing the risk of variation in the assessment. The model answers provided a standardised mark scheme where students could achieve marks for each point within their answers. Each question had a total mark of one available. If a student gave an answer that the author felt answered the question, there was the potential for the student to obtain marks. Where students provided partial answers, these were graded appropriately and allocated a proportion of the available mark for that question. An example of the mark scheme can be seen below in figure 18 with the expected response in blue and the mark allocated in red and can be viewed in appendices 9-14.

2. Name the antigens of the ABO blood group system for each of the blood groups below.

A	A & H (0.25)
B	B & H (0.25)
AB	A, B & H (0.25)
O	H (0.25)

Figure 18 Example of the mark scheme used for knowledge assessments:

The author entered the final marks obtained in the assessment onto a spreadsheet to allow for data collection. The scores were all anonymised and used as part of the assessment of the project's success but were not the only measurable outcome.

Students were required to submit all three knowledge assessments to be included in the project's final data collection. However, because of COVID-19, fewer knowledge checks were returned from the participating students. This was discussed in the results and discussion sections.

4.3 Delivery and Analysis of the E-learning Package:

An overview of how the delivery of the trial occurred can be seen in figure 20.

A baseline knowledge assessment was sent to all students once the consent form was received to determine the current knowledge level. Students were all given access on the same day. The two-month period was the same for all participants, so there was occasionally a month between completing the baseline knowledge assessment and commencing the e-learning package. Emails were sent bi-weekly by the author to remind the students to access the package and to inform them of the remaining time left to participate.

At the end of the e-learning package, a post product summative assessment was sent to all students for completion within two weeks. This assessment was determining both the students perceived level of knowledge and also their demonstrated actual level of knowledge. Questions were selected, which required students to demonstrate the application of the knowledge they had gained from completing the e-learning package. These questions followed the same format as the baseline knowledge check, so they were comparable when interpreting the data obtained from them.

Students were contacted three months after completing the e-learning package with a final assessment that reviewed how the students felt they had retained and applied the knowledge and a summative assessment that looked at the retained knowledge and how the students applied this. Students were asked to complete this assessment within two weeks of the three months. This assessment followed the same format as both the previous assessments and the

questions were comparable to allow for data comparison. Due to the COVID-19 pandemic, the final assessment was adapted to include feedback on the e-learning package regarding the user experience and improvements in the subject content.

Upon completion of the final assessment, all students were sent a thank you letter. The letter was created to thank students for participating in the project. It could also be used as evidence for a portfolio, either training or specialist or as CPD required by the HCPC (HCPC, 2014). An example of the letter can be seen in appendix 5.

4.4 E-learning Package Evaluation and Success:

As learners who could be accessing these e-learning packages are potentially from diverse backgrounds and experience levels it was essential to assess their baseline knowledge in order to provide quantitative results, and determine their perceived knowledge level, which was qualitative. The knowledge assessments were assessed against the mark scheme and results recorded.

The qualitative results relied on participants declaring their feelings towards their perceived knowledge before commencing the package and their perceived improvement of knowledge or their knowledge application after participating in the trial in each of the modules within the e-learning package. Students determined how confident they felt in each module topic on a scale of 1-10 (Likert scale); one being not very confident and 10 being very confident. This approach has been used in other studies and therefore was adapted for this project (Bond et al., 2017). The perceived levels of knowledge could introduce a bias which is why both quantitative and qualitative methods were used to assess the project outcomes to provide an overall picture as students may grade themselves higher (Atir et al., 2015).

The final evaluation of the product design and its potential use within a transfusion laboratory was due to be performed face-to-face workshop to allow for feedback immediately; however, because of COVID-19, this was not possible. The reason behind using a face-to-face workshop was to ensure full engagement from all the participating students. As it was not possible to use face-to-face workshops, the developer considered using an online forum such as Microsoft Teams® to allow for the workshop. The move to a Microsoft Teams® session was not actioned as during this first peak of COVID-19, staff resources were stretched working in busy clinical

laboratories with a reduction of staff in the laboratories, resulting in a low participation rate. It should also be noted the author was working clinically during the pandemic and was unable to host a workshop at the time of completion and collecting data retrospectively was not possible as participants may have forgotten the study. An alternative approach was used, which involved additional questions on the final knowledge assessment, sent out to the users to their email addresses. Two questions were included on the final questionnaire, which asked how the students felt the package worked for BMS staff within a busy transfusion laboratory. The second question was around the software and the package itself. The questions were written based on a review of the literature on how to ask participants about feelings and attitudes to an intervention (Isaacs, 2014) and allowed the author to look at the student attitudes towards the learning (Mohajan, 2018). These questions were chosen to explore two areas which the author was interested in feedback and to ensure any future projects could be adjusted before use by NHSBT training to influence future e-learning projects. Data were entered into a comments table 24 in the results section, with a summary of themes seen in table 25 and provided feedback on the system's e-learning package.

Ascertaining the e-learning package's success also allowed the author to determine if the level of training was appropriate, and users were asked to comment on the level of the training. This was achieved both by how the users felt their knowledge had been improved and comments regarding the e-learning package. These results were captured both in the overall learning improvement figures as well as the comments.

Table 9 Location of appendices in thesis:

Tittle of page	Location in Thesis
4.5.1 Participant Information Sheet:	Appendix 7
4.5.2 Consent Form:	Appendix 8
4.5.3 Pre-Knowledge Baseline Assessment for the Basic Package with Model Answer:	Appendix 9
4.5.4 Post Package Knowledge Assessment for the Basics Package with Model Answer:	Appendix 10
4.5.5 3 Month Follow up Knowledge Assessment for the Basics with Model Answer:	Appendix 11
4.5.6 Pre-Knowledge Baseline Assessment for the Intermediate Package with Model Answer:	Appendix 12
4.5.7 Post Package Knowledge Assessment for the Intermediate Package with Model Answer:	Appendix 13
4.5.8 3 Month Follow up Knowledge Assessment for the Intermediate Package with Model Answer:	Appendix 14
4.5.9 Completion Thank you Letter to all Participants:	Appendix 15

4.6 Evaluation of Results:

Data collected from this project involved quantitative data, including the pre, post, and follow-up assessment scores for the individual students. The results were then tabulated, and the mean of the student's grades was reported in the results section. Knowledge improvement and perceived knowledge were measured on the Likert scale. Dependent samples T tests were performed to compare Likert scores before and after training. Assessed knowledge and perceived knowledge scores were correlated use the Spearman method.

Engagement with the system was also reviewed. Attrition data was available and has been included in the thesis (table 23). The data collected looked at each phase of the project e.g., consent forms sent, students embarking on the project and completion of all knowledge checks and collected total numbers of students at each point. Data from LMS was not obtained at the time of the trial and therefore was not available for review for the thesis as the LMS was no longer available within NSHBT.

The minimum data set required was 30 students distributed between the basic and intermediate packages to be able to gain results which may demonstrate statistical significance. This number was derived from a sample size calculation assuming that there was a confidence value of 95% of all students would improve both their perceived and actual knowledge with a margin of error of 8% (Kang, 2021). To achieve this figure 50 students were invited to take part in the trial which allowed for a significant attrition rate. The trial was undertaken during the COVID-19 pandemic which impacted staff availability for additional work. As an LMS was available and it was unknown if this would be available again the project was undertaken in February 2020.

There were 19 students who expressed an interest to complete the project, which whilst this did not meet the minimum data set allowed the project to be completed as a feasibility study. As this work was undertaken as part of a professional doctorate and there was a deadline for the completion of such work there was not the possibility to wait until after the COVID-19 pandemic to continue with the research. The author acknowledges that alternative approaches may have achieved a greater sample size such as the involvement of the international community.

5 Results:

There are three main sections within the results these include:

- Service evaluation which was conducted before commencing the practical aspect of the project.

- Product design which was the design of the e-learning package.

- Service user's evaluation of the project and the impact this has had on the learner's knowledge.

Each section will be analysed individually, and a summary will be provided at the end of the section. A final summary of all results will be available at the end of the chapter.

The results include a combination of results from surveys seen in a graphical format, quantitative data, which included results from knowledge assessments and the trainees' opinions.

5.1 Stakeholder engagement

This section reviews the results from the stakeholder engagement survey sent out to all LMs within the Southwest.

A questionnaire was sent to TLMs within the Southwest RTC to determine their evaluation of training within transfusion science. This was sent to nineteen TLMs, eight responded, which gave an overall response rate of 42%. The service evaluation question was not distributed to the other regions for reasons already discussed in the methods. Any data gathered via stakeholder engagement has been compared to national data found in the UKTLC reports or SHOT reports which can be seen in table 11.

Table 10 provides an overview of the hospitals who completed the engagement survey and shows the services they provide and the number of patients they have seen annually. All the hospitals had an onsite blood transfusion laboratory, and all have a service level agreement with NHSBT for referral for complex cases to RCI Filton. It should be noted one of the laboratories was a small private hospital. As the survey was looking at the BMS staff and their knowledge and training this did not impact the results provided from the user however would not have made them a viable option for trialling the product.

Table 10 Information of the hospitals surveyed as part of the service user engagement:

Hospital numbered to provide anonymity	**Number of patients seen 2022-2023 (NHS 75 Digital, 2023)**	**Services Available sourced from NHS Choices (2023)**
1	66935	A&E, Theatres, Obstetrics, Oncology and haematology
2	113115	A&E and major trauma centre, Theatres, Obstetrics, Neonatology, Oncology and haematology
3	172330	A&E, Theatres, Obstetrics, Oncology and haematology
4	172330	A&E and major trauma centre, Theatres, Obstetrics, Neonatology, Oncology and haematology
5	161585	A&E and major trauma centre, Theatres, Obstetrics, Oncology and haematology
6	46990	A&E, Theatres and Obstetrics
7	265	Elective Surgery – Private hospital
8	87530	A&E, Theatres, Obstetrics, Neonatology, Oncology and haematology

Table 11 User engagement results from the Southwest:

Question	Response	Supported by UKTLC data / SHOT Data
Do you feel that current level of transfusion education / knowledge of new and existing staff within your laboratory is adequate for service provision?	5/8 respondents felt the knowledge of staff was adequate. For note staffing within Southwest laboratories are very stable and may not be representative of the workforce in England.	UKTLC and SHOT data disagree with the finding from the Southwest and believe knowledge and education has been inadequate (Bolton-Maggs et al., 2019).
Do you feel you are able to support knowledge and training for staff within your laboratory	6/8 respondents felt they were able to support their staff with training within their laboratories.	The UKTLC report notes that laboratories report insufficient time to train BMS staff (Bolton-Maggs et al., 2019) and the SABRE data in the 2020 report shows 13% of errors reported were attributed to ineffective/lapses in training (Narayan et al., 2021:230).
Would your laboratory be able to send a member of staff on a weeklong course for face-to-face training at NHSBT to develop transfusion knowledge?	Two respondents said yes, one said no, and five respondents said maybe. However, this would depend on factors such as cost and staff shortages.	This result is supported by the UKTLC report, which states there is less funding and time allocated to development activities such as training courses for pathology staff (Bolton-Maggs et al., 2019).
Would you be able to support members of staff to undertake an e-learning package for transfusion education?	7/8 responded yes with one laboratory saying maybe as they felt face-to-face learning was more efficient than distance learning.	Transfusion 2024 has suggested a hybrid approach to training as face-to-face alone is not addressing the workforce problems (Allard et al., 2021).
How would you like a training package to be delivered?	5/8 respondents wanted face-to face training. 7/8 respondents wanted a pure e-learning approach. 5/8 respondents wanted a web-based platform for training. 1/8 respondents wanted an App training. 4/8 respondents wanted a website training platform. 1/8 respondents wanted a discussion forum for training staff.	Transfusion 2024 highlighted the requirement for adaptive teaching which would include the use of e-learning and face-to-face training (Allard et al., 2021).
How long would you like each section to take to complete with an educational package?	5/8 respondents wanted the package to take one hour.	The UKTLC report acknowledges release of staff as an issue within transfusion which requires overcoming before any intervention

<table>
<tr><td></td><td>3/8 respondents wanted the package to take two to four hours.
Two TLMS responded twice and gave additional answers of one day to several days to complete a learning package. The TLMs also commented on the format of the learning and the requirement of release of staff.</td><td>for training for training can be successful (Bolton-Maggs et al., 2019).</td></tr>
<tr><td>Would you as the transfusion manager require oversight of the progress of your staff?</td><td>7/8 of the TLMs required oversite of any package and progress. The Laboratory managers wanted to see evidence of learning which does not exist with the current training provided by NHSBT.</td><td>This finding aligns with existing platforms such as BTLP TACT® in which managers have oversite of their staff’s progress (NEQAS, 2021). The progress and evidence of completion of training could be used as evidence for UKAS to maintain ISO15189 accreditation (Williams et al., 2019). All data sharing would be subject to compliance with the data protection act 2018 (GOV UK, 2023). If this was not plausible alternatives such as certification may be suitable.</td></tr>
<tr><td>Would you be willing to pay for the service of an educational platform?</td><td>5/8 TLMS said they would be willing to pay for the service; however, acknowledged they were not in control of the budget.</td><td>The UKTLC reports discusses the funds available for CPD has seen a reduction for transfusion laboratory staff (2017).</td></tr>
<tr><td>What level of staff would you be interested in using this service for?</td><td><table><tr><td>Number of Laboratories out of 8</td><td>Band of staff</td></tr><tr><td>3</td><td>4</td></tr><tr><td>8</td><td>5</td></tr><tr><td>5</td><td>6</td></tr><tr><td>1</td><td>7</td></tr><tr><td colspan="2">One laboratory wanted to use the service for BMS staff from other disciplines.</td></tr></table></td><td>The UKTLC report has highlighted newly qualified BMS staff have insufficient knowledge in transfusion which would align to band 5 BMS staff (Bolton-Maggs et al., 2019).</td></tr>
<tr><td>Which levels of training would you be interested in?</td><td><table><tr><td>Number of Laboratories out of 8</td><td>Level of training</td></tr><tr><td>5</td><td>Beginner</td></tr><tr><td>7</td><td>Intermediate</td></tr><tr><td>1</td><td>Advanced</td></tr></table></td><td>The levels required by the TLMs is in keeping with the findings in the UKTLC report (Bolton-Maggs et al., 2019).</td></tr>
</table>

Would you be prepared to partake in a pilot once a platform has been developed?	8/8 respondents were happy to enrol in a pilot study and provided their contact details.	N/A

The final question asked of the Southwest users was which educational topic they wanted covered for the project. This data was gathered to inform this project but also to be used by the training department as part of an HEE funded project for e-learning within transfusion and results can be seen in figure 19.

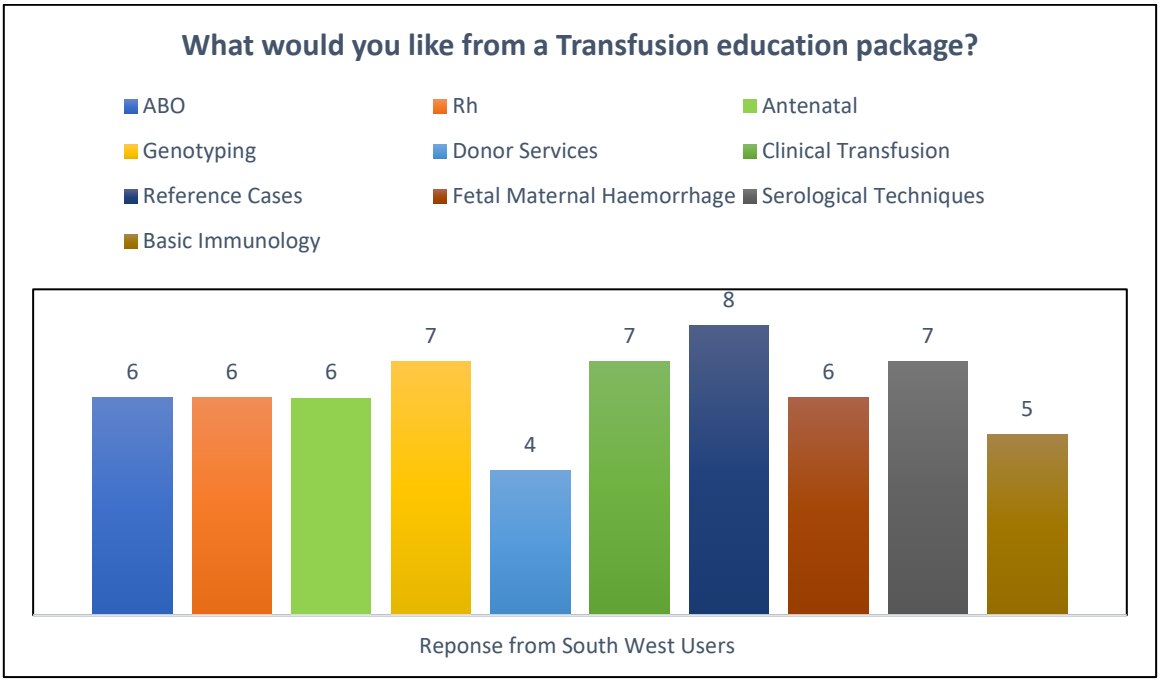


Figure 19 Response to user engagement survey for subject matter for the project:

This section's results demonstrated that Southwest users wanted most topics covered in any training material. There was a particular focus on activities conducted by RCI and other NHSBT departments as it was felt there was not the expertise within the hospital to provide

this training. This was discussed at length at the RTC day, where techniques and investigations performed by RCI are felt to add value to the BMS workforce. This list, alongside the hemovigilance review results, has led to the conclusion that ABO blood grouping to be the focus for this learning package. However, there is a requirement for other subject areas to be covered by NHSBT to ensure that sufficient training is available to all BMS staff. The question asked users to select all topics they wish to see additional training available for and did not rank the results as their highest priority.

5.2 Summary of the Hemovigilance data:

The SHOT report data was discussed in the introduction of this thesis and a focus of ABO blood grouping was decided upon for the e-learning package. Table 12 below summarises some of the key findings and justifies why the projects focus was ABO blood grouping. It also highlights were possible where the cause of the error was attributed to laboratory staff as this could be used as a marker of success in future studies with the e-learning package.

Table 12 Hemovigilance data used to support the development of an ABO grouping e-learning package:

Year	Reference	Error (%/n=)	Root Cause	Availability of current educational intervention	Impact of the training
2016	Bolton-Maggs et al., 2017:15, 69, 70	ABO incompatible transfusions n=6 3 red cell events 3 plasma events	The red cell units were due to clinical errors. Plasma all due to laboratory errors all due to component selection errors which include knowledge.	Covered in degrees and local training.	Not sufficient as each year there are errors reported within the SHOT reports.
2016	Bolton-Maggs et al., 2017:15, 17	ABO near misses n=264.	Multiple – clinical errors e.g., wrong blood in tube 249/264, human factors including knowledge lapses	Covered in degrees and local training.	Not sufficient as there are increases every year.
2016	Bolton-Maggs et al., 2017: 203	Stem cell transplant ABO errors n=6.	Three of these errors were attributed to lack of understanding in the laboratory.	None – creation of guidelines recommended to aid education (Staley et al., 2016).	Not sufficient as each year there are errors reported within the SHOT reports.
2016	Politis et al., 2016	ABO incompatible transfusions 2006-2012 internationally 511 cases 305/511 transfused with reaction and 205 without reaction.	Not broken down further in the article.	N/A	N/A

5.3 Service Evaluation Summary:

The user engagement survey was sent to each laboratory manager in the Southwest region and completed by them or another designated person e.g., training offer. The aim was to gain a holistic view of the whole laboratory through a single survey comparable to other transfusion surveys such as the UKTLC survey (Bolton-Maggs et al., 2019). The survey was researching the issues within the hospital transfusion laboratories and therefore the blood services were excluded from the data collection.

The results above highlighted between the UKTLC survey and the Southwest engagement data there is a requirement for further training in transfusion (Bolton-Maggs et al., 2019). This training can be provided by NHSBT and since the completion of the project there has been support at a national level for this (Allard et al., 2021).

There was a requirement from the users for this to be accessible using distance-learning as there are increasing pressures from trusts not to release staff from the laboratory for training as reported by the UKTLC survey (Bolton-Maggs et al., 2019). The results also demonstrated that TLMs do not want a complete e-learning solution to training. They still felt that a combination of face-to-face training with the support of e-learning would benefit both staff members and the department.

There was a particular interest in further training being made available in specialist reference service work with 8/8 selecting this option, e.g., the casework of Red Cell ImmunoHaematology (RCI). This topic's interest was due to the hospital having no practical experience in this area as RCI completes these cases. This topic will be included within this

project as there will be examples of further work performed on samples as part of an investigation within RCI for ABO blood grouping. This could also be included in future e-learning projects and will be discussed in the future work section of this thesis.

Dependent on this project's success, reference services may be a topic developed further by the training department to meet the needs of the service users. As there were limited responses, there was no real significant difference in the topics which the service users felt needed covering and would like all topics developing into further learning. This was not possible within the remit of this project but could be considered for future developments from the training department within NHSBT.

Overall, the results showed interest in a distance learning platform for training at a basic and intermediate level. The desire was not for a distance learning programme to remove the need for face-to-face training but to allow for a blended learning approach. There was a need identified by the LMs for all topics in transfusion to be provided; however, after interpreting the SHOT data that ABO blood grouping requires further education. Taking all of these results together, the topic chosen to develop an e-learning package was ABO blood grouping.

5.4 Results Product design:

5.4.1 Comparison of User Requirement Specification (URS) against the Articulate Storyline® software:

A user requirement specification (URS) was created for the project and sent to the package designer, who completed a brief appraisal of the work they were able to complete compared to the URS and the storyboard provided by the author. They were unable to complete some aspects as it was not within the design software's capabilities or their skills. The designer was able to complete the work at a competitive price as they were studying, and this was a small company they had set up. A complete appraisal of the URS can be seen in table 13 onwards which identifies if the package designer was able to meet the specification or not using the articulate software; further comments were made by the author regarding their final work and justification for the specification. The limitations were discussed, and compromises were made, which included creating the game aspect of the project as the author had envisaged. This was not possible within the development software, and therefore it was decided to use an interactive case study session with elements that required user input and should be enjoyable.

Table 13 URS results showing Operational functions such as browsers and computer requirements:

Specification	**Justification for inclusion**	**Criteria met or not – Additional comments from the author upon review of the package designer**.
Browser Compatibility The designer must ensure the package is functional on Internet Explorer 6® or higher, Safari 4® or higher, Firefox 3® or higher and Google Chrome®.	Not all NHS trusts are using up to date IT software so this needs to not be a limitation of any trial (Collier, 2017).	**Met** – The package was able to run on all mentioned internet browsers.
Operating Compatibility The designer must ensure the system is able to operate on Windows XP® or higher as well as Mac operating systems®		**Met** – The package can run on both Mac® and Windows operating systems including Windows XP®.
Screen Resolution The designer must ensure it is compatible with screen resolution	It is important when using multimedia, the resolution is considered to ensure	**Met** – This was possible and achieved.

1026 x 768 or above and with an internet connection of 4 Mb or above.	the quality and also that the bandwidth is sufficient to ensure the package runs smoothly (Horton and Horton, 2003:376-377).	

All three of the operational functions were able to be met by the package designer. The package would function on all computer systems identified by the author at the appropriate screen resolution.

Table 14 URS results showing functionality of the package the package designer was able to meet:

Specification	**Justification for inclusion**	**Criteria met or not – Additional comments from the author upon review of the package designer.**
Package design The designer must collaborate with the author to ensure the content is produced in the expected way.	This is to ensure that the package utilise the expertise of the package designer to ensure the development of a successful e-learning package. It was acknowledged in the literature that packages often fail due to inexperience of e-	**Partially met** - The product required editing post-handover to local IT at NHSBT as there were sections of the programme which were not compatible with the LMS, and the formatting required editing. This was due to the way the package had been developed within Articulate® and was due

	learning development (Childs et al., 2005).	to a lack of understanding by the package designer on how Articulate communicates with an LMS. The LMS did change during the project from Moodle® to LMSX®; however, this would not have changed how the product should have been designed.
Proof reading Content The designer must ensure that the package is appropriately proofread before sending to the author for assessment.	Mistakes in the final product may impact the engagement with the user and therefore is essential when designing a package (Anowor et al., 2012).	**Met** – This required a lot of feedback regarding typing mistakes where the package designer had not proof-read or understood the terminology which was to be expected as they have no specialised knowledge in transfusion.
Package Format The designer must ensure the format of the package is suitable for users and the format and fonts used are legible and easy to read.	The format needs to be suitable for a wide range of users to ensure appropriate engagement with the system (Lawn et al., 2017).	**Met** – An easy-to-read font was used, and appropriate colour schemes were used.
Printable Content It would be desirable if the user were able to print the content for	Students like to have the ability to print material to be able to refer to at a later date	**Met** – This was set up on the sections the author required. As specified, it

their learning at specific points in the package to allow for continuing learning.	(Cottrell and Donaldson, 2013).	was not possible to print all of the package.
Pausing of Module The product must allow for the user to be able stop the content halfway through a module and be able to pick up where the user left off at an alternative time.	This was essential as the students want control over their learning which ensures they engage with the system and makes learning more effective (DeRouin et al., 2004).	**Met** – Due to the design of the package this was possible. This information was held on the LMS under the username. Users were able to log off and return to the package and complete the package where they left off.

As shown in table 14, the package designer was able to meet most of the required functionalities that the author wanted (4/5); however, after developing the e-learning package, there were some issues with the package's functionality, which the package designer did not correct. The local IT department at NHSBT addressed these as the product had been developed in Articulate®. They had a license, so they could make corrections before the package was published on the LMS. The choice of the package designer is discussed in further detail in the discussion section.

Table 15 URS results for the defined learner pathway, assessment, and certification:

Specification	Justification for inclusion	Criteria met or not – Additional comments from the author upon review of the package designer.
Selection of Material The product must allow the user to be able to select sections of the module to complete without the need to skip material.	This was essential as the students want control over their learning which ensures they engage with the system and makes learning more effective (DeRouin et al., 2004).	**Partially Met** – Between the package and the LMS users can complete sections of the module and attempt other sections at a suitable time. This does require the user to skip material, but they are able to move in both directions in a module. The requirement to skip material was to allow users to define their own learning pathway to improve engagement.
Assessment The product should allow for quizzes or other examination methods to be utilised throughout the package with a variety of answer options to include matching questions to	This was essential for this project as it allowed the author to measure engagement but also demonstrated to the student, they had understood the learning and also informs the author the package has been understood in real	**Met** – Using a combination of in module assessment and a question section at the end of each module users are assessed throughout the package. The final assessment questions are scored, and the results are recorded on the LMS.

answers, multiple choice, short single word, or number answers as some of the examples.	time. This formed part of the formative assessment which is used in adult learning (Barbosa and Garcia, 2005).	This can be used for a measurement of achievement in practice.
Certification The product must have the capacity at the end of the module provided all content has been passed to have a certificate or recognition of the learning to allow this to be used for continuing professional development – this can be achieved by the LMS or by the package itself. If provided by the LMS this will be assessed in house.	This is essential as for all additional learning which can be used as CPD there needs to be a record of this and a certificate can be used for this (McKimm and Swanwick, 2010).	**Met** – the LMS used allow for the student to gain a certificate of completion. After the completion of each module a completion screen was shown which had the capacity to be printed if this was required by the user for evidence.

The results showed that it was possible to create assessment and certification of the e-learning material required by the TLMs. This also allows training to be used as part of CPD. Unfortunately, it was not possible to completely meet the selection of material criteria. The workaround was to provide a function for users to move between the slide in both directions. This requires the student to enter the material and move through the slides; however, it is

possible to complete the module without reading all the material if the user feels this is appropriate.

Table 16 URS results requirements for the content development and interactive tools required by the author:

Specification	Justification for inclusion	Criteria met or not – Additional comments from the author upon review of the package designer.
Storyboard The designer should ensure that their software is compatible with development of the content in the form of a story board created in Microsoft PowerPoint ® or Apple Keynote®.	The storyboard is created by the subject matter expert (author) and ensures the final product is suitable for effective learning (Salim, 2012).	**Met** – The storyboard was created in Apple Keynote® and converted to PowerPoint®. These slides were then used to create the content in Articulate Storyline 3®.
Hotspots The product must allow for the use of Hot spots or selecting information from a picture or diagram.	The use of interactivity in e-learning can improve the learners experience and help improve engagement in the system (Cottrell and Donaldson, 2013).	**Met** – throughout the package there are hot spots used on both text and also images. This was also used to create a glossary of terms.
Interactivity The product must allow for the use of tools to allow interactivity allowing the user to be able to define their own		**Partially met** - there is the capacity to skip sections and choose which module to commence. The package does not allow for users to bypass whole sections

learning pathway within the defined module.		without using the skip function.

The results show that the package developer could utilise the storyboard created in PowerPoint® to develop the content in Articulate Storyline 3®. This result should have allowed for a seamless transition of material from one platform to another. Hotspots and interactivity for users were also a requirement in the package to ensure user engagement, and the package developer could provide both of these in the final package.

Table 17 URS results looking at the use of videos within the e-learning package:

Specification	**Justification for inclusion**	**Criteria met or not – Additional comments from the author upon review of the package designer.**
Videography It would be desirable if the designer could aid in professional videoing facilities as well as audio recording were defined by the author.	The use of multimedia such as videography helps with the personification, emotional engagement and allowing students to feel connected with the educator (Issa et al., 2011). it was essential the	**Met** – The product designer was able to create several videos for the package.
Video Editing It is essential the designer can edit videos and graphics for the project as part of the product design.		**Met** – The product designer formatted videos to provide subtitles to them and also have background music.
Video playback		**Met** – The final product was able to have edited

The product must have the capacity to be able to run videos and allow for both sound and subtitles to be played whilst using this function. There should also be the capacity to re-run fast forward and rewind videos at the user's discretion.	videos could be stopped, rewound, and skipped to allow the students to have control over their learning which ensures they engage with the system and makes learning more effective (DeRouin et al., 2004).	videos on it which met all the criteria. The videos were edited on another platform to allow for the addition of the subtitles. The software used supported the capacity for videos to be paused and rewound etc.
Skipping Videos It should also be possible for the user to be able to skip a video and continue with the rest of the module.		**Met** – Articulate® allows for videos to be incorporated in a project but allows the user to skip them if they want.

The author wanted to utilise videos to allow students to observe practical techniques which may not be available within their laboratory. The package designer created the videos under the author's direction. The package designer was able to produce professional videos with subtitles to allow the student to understand what is being performed. The videos are not compulsory in the package and can be watched if the student wants. The student can also fast forward and reverse the videos if they want to allow the user to define how they use the tool within the e-learning package.

Table 18 URS results around the game development within the e-learning package:

Specification	Justification for inclusion	Criteria met or not – Additional comments from the author upon review of the package designer.
Gamification The product must have the capacity to allow for games and gamification to be part of the module within the e-learning package.	This was to allow the students to apply knowledge to real life cases which helps ensure knowledge application and retention (Rahm et al., 2021). Studies have shown that gamification can improve learning outcomes and engagement and was part of the novelty of the project (Blakely et al., 2009).	**Partially met** - The package has interactive sections however did not allow for the development of games. Articulate® did not support a game being inserted into the package. The developer also did not have the capability to create a game on an alternative software.
Game Development The designer must be able to support the development of games and interactivity in the package.		**Not met** - The package designer was not able to create a game as this was not his area of expertise. This was discussed prior to commencing the project and the decision to use an interactive case study was agreed.

The original intention for this project was to include a game to allow students to apply their knowledge in a simulation environment. It was the original design to create a simulation laboratory in which students would be able to test samples, interpret the investigations, and provide blood for the patients. Unfortunately, the Articulate® software and the package

designer were unable to produce this product. Therefore, a solution was found in which the package designer created an interactive case study that allowed the students to test the sample and interpret the results. The interactive case study was not seamless as it was produced on multiple slides and therefore appeared quite clunky when used by the students. Although this was not the game as it was envisaged, it allowed students to apply the knowledge they had learnt in the module.

Table 19 URS results design software and ability to alter the e-learning package:

Specification	Justification for inclusion	Criteria met or not – Additional comments from the author upon review of the package designer.
Flexibility for Package Alterations The designer must be able to develop the content into a training package which is user friendly and adaptable should there be any requirement for change.	Articulate storyline was used for the development of this package which is advantageous as this is one of the most common development packages and this was essential as it allows for developments to occur retrospectively, it also produces products which students are familiar with as other e-learning will have been developed using this	**Met** – As the package was produced in Articulate® it allows other users to adapt the package if there is a requirement to change any of the content.
Design Software The package should be developed on a platform which other designers have access to, should there be a need for amendments post the design phase.		**Met** – As the package was produced in Articulate® it allows other users to adapt the package if there is a requirement to change any of the content.

	software (Blagoev et al., 2021).	

The package was developed on software for which NHSBT had a license for which allowed local IT at NHSBT to make amendments to the package once it was handed over for upload to the LMS. Articulate® is also amenable to alterations or allowing a designer to take existing material and use it in another package which was an unexpected outcome.

Table 20 URS results deadline for the completion of the project and turnaround times for changes to be made:

Specification	**Criteria met or not – Additional comments from the author upon review of the package designer.**
Turnaround time for Changes The designer must ensure that all changes can be made within a one-week turnaround time to ensure there is no disruption to the service.	**Not Met** - There were significant delays in returning corrections this was partially due to the developer being in a different country and IT limitations within NHSBT. The author acknowledges international collaborations work well in other areas of development but for this project it was a limitation.
Completion of Project The designer must be able to complete the work before the 1st of March 2018, to allow a week of testing where any errors must be addressed within a	**Not Met** – The product was not completed until December 2019. There were multiple reasons including parental leave of the author, but the primary delay was due to the package designer. This date was set in order to achieve university deadlines however as this was not

working week for the product to go live to the customer.	achieved an extension was granted due to parental leave of the author.

This criterion of package development by 1st of March 2018 was not met as the product took over one year to develop, and the alterations were not completed within a week. Delays with the package designer resulted in the product not being available for the original student cohort requiring the author to find alternative students to complete the trial.

Table 21 URS results around IT support for the transfer of the e-learning package to the LMS:

Specification	**Justification for inclusion**	**Criteria met or not – Additional comments from the author upon review of the package designer.**
Compatibility with LMS The package must be compatible with MOODLE® or LMSX® as the host site but also other learning management systems (LMS) for future developments by the organisation.	The LMS played a vital role within the e-learning experience and as such there needs to be a smooth transition from the package which has been created in articulate to the LMS and ensure there is compatibility in	**Met** – This was compatible with both LMS Extra® as well as MOODLE® which allowed for easy upload onto the LMS. The project had not been developed into the single sections required for the final product so had to be adapted by local IT at NHSBT.

IT Support The designer must be able to provide appropriate IT support for the project to include the development of the package as well as post development during the implementation phase of the package to correct any identified issues with the product.	how these are arranged (Ueda and Nakamura, 2016). The LMS in this project was dictated however NHSBT use a different system routinely so the e-learning package needed to be suitable for other LMS's so that it could be used in the future (Aydin and Tirkes, 2010).	**Not Met** - The IT support was provided by locally. Local IT at NHSBT had to make multiple corrections to the product as there were glitches in the final product which prevented it operating as it was designed. Once the product was designed the project designer no longer provided any support for the package upload onto the LMS or amendments required.
Transfer to LMS The designer must be able to provide IT support of the transfer of the package onto the LMS. If this is not possible discussions with local IT at NHSBT to determine how to achieve this.		**Not Met** - The IT support was provided by local IT at NHSBT. This was agreed at the start of the project as local IT at NHSBT were the host of the LMS therefore, they were the only people able to upload projects to the system.

The package designer could not provide any IT support for the movement of the final e-learning package onto the LMS. He was also not aware of how the e-learning package would need to interact with an LMS, which resulted in the local IT department at NHSBT having to amend the final package to ensure the module's formatting was correct. As the package was hosted

on an existing LMS, there was no capacity to change the formatting. As the e-learning files are within control of NHSBT there is the capacity to make amendments when required and also allows for the files to be hosted on another LMS once this has been procured by the IT department within NHSBT.

Table 22 URS results for the development of an App:

Specification	Justification for inclusion	Criteria met or not – Additional comments from the author upon review of the package designer.
App Development It would be desirable if there was the capacity to develop the platform into an App which is downloadable on a defined platform such as IOS® or Android®. This could be achieved by the downloading of the LMS onto a device and the package being downloaded onto the device.	The project did not allow for the development of an app, so this was not explored further.	**Not met** – The product was designed in Articulate which was run on LMS Extra®. It is possible to run this on a mobile device but would require internet connection.

Results show the package designer could not create the content in the form of an App, which was agreed upon at the project's outset. The development of an App was a desirable specification, but it was apparent when the costs came in this was not achievable as part of this

project. It was discussed that the LMS was able to run on a mobile device, although this was reliant on internet connection but did provide the option for students to complete the training on the go if they desired.

5.4.2 Product Design Results:

Figure 20 below summarises the design steps involved in creating the e-learning package which followed an ADDIE methodology (Analysis, Design, Development, Implementation and Evaluation) (Nazarova et al., 2020). The analysis involved the formation of the learning outcomes, the design was the storyboard along with the directions required for the package, the development was the package designer creating the package on articulate, the implementation was the trial for this project and then the evaluation of the results in both actual and perceived knowledge improvement.

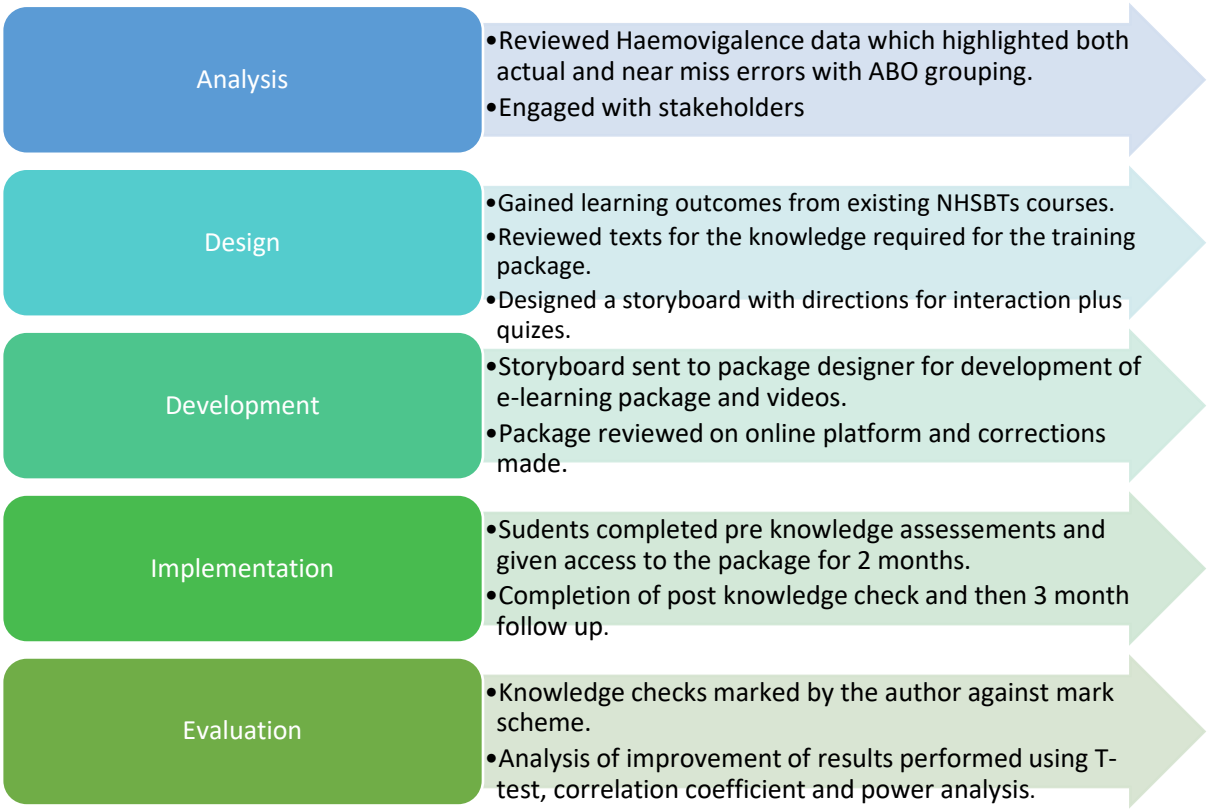


Figure 20 The development of the project and summary of results

The package was created from a storyboard designed in Microsoft PowerPoint® with explicit comments, handwritten on a hardcopy to indicate where interactivity was required. An example of this can be seen in figure 21 below. Handwritten notes were required as it was hard to have electronic notes, which allowed for the content designer's vision to be included in the storyboard.

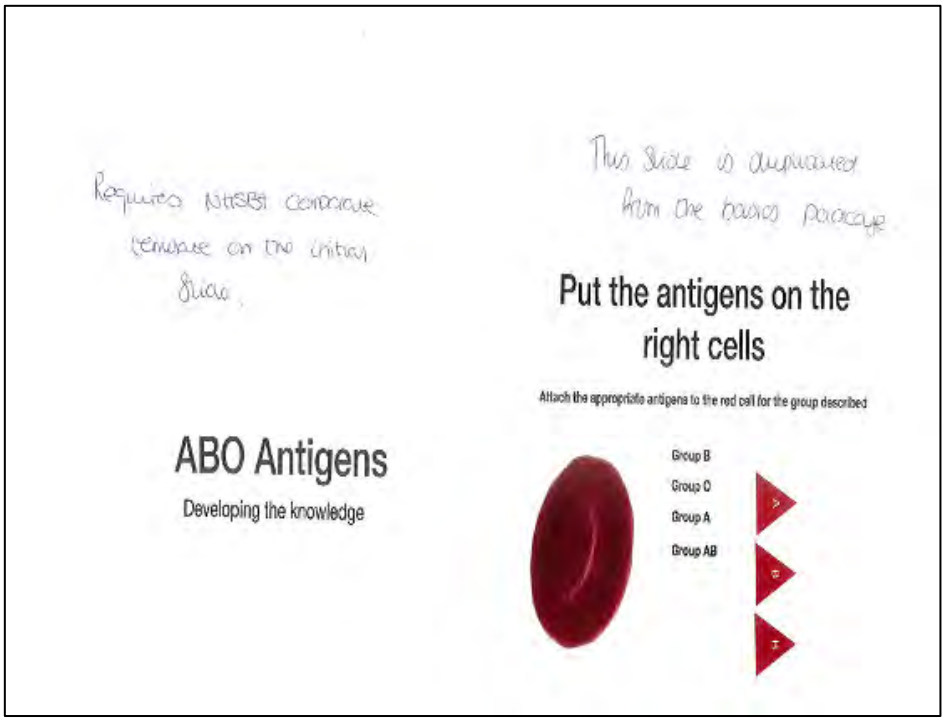


Figure 21 Example of the storyboard created:

There was a challenge encountered as the author did not know how Articulate Storyline 3® worked and therefore relied on the professional package designer to programme the software. This issue was also encountered the opposite way as the package designer had no transfusion knowledge, so he was reliant on the author to provide input here as the subject matter expert.

An additional challenge was encountered during the product design stage, as it became apparent the package designer was not familiar with the software they were using. So, when there were suggestions regarding the use of interactive tools, the package designer could not

implement them as they could not code the software. This required the author to investigate options available on Articulate Storyline 3® and provide instructions on how to achieve this to the project designer. This was not part of the URS and extended the development phase of the project significantly. It also potentially resulted in a project which was not coded correctly as the project designer was not familiar with the software.

The package was reviewed continuously by the project designer and the author by an online review platform, part of the Articulate Storyline 3® software. This was advantageous as it allowed for a two-way conversation on specific aspects of the package. This ensured that specific problems could be highlighted in the package's appropriate section, which reduced the risk of misinterpretation. This worked incredibly well, although comments were not viewable once they had been set to resolved; therefore, it was difficult to look back at the package and confirm issues had been resolved.

The final electronic Articulate Storyline 3® (SCORM file) e-learning package was handed over to the local IT department within NHSBT, who could upload this to the LMS. Once the package was on the LMS, it was possible to distribute the students' e-learning package. The storyboard for the project is included in appendix 4 and 5. The figures below show screen shots available from the package and demonstrate some of the essential criteria required by the author.

Figure 22 shows the front pack of the basics package which was designed by the package designer. This was the same design in the intermediate package. The page was designed to allow students to select the module they wanted to complete to allow them to have control over their learning.

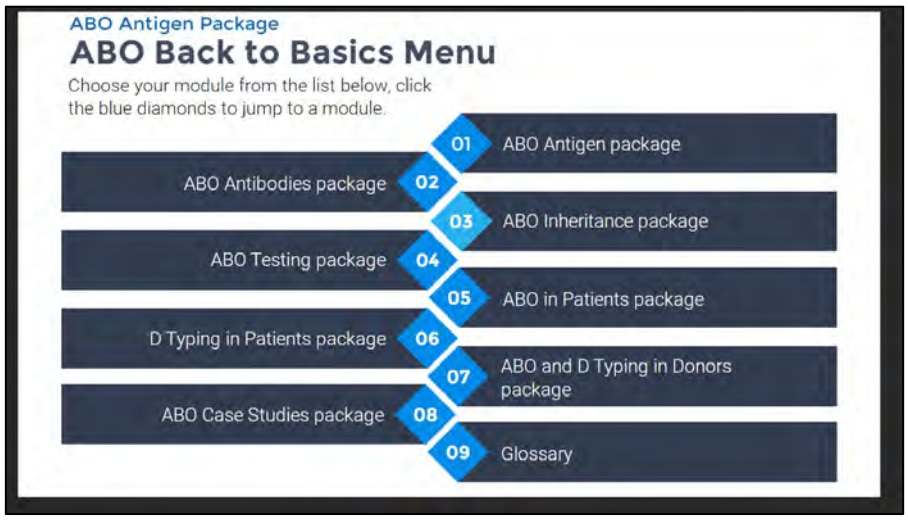


Figure 22 Front page of the basics e-learning package

Figure 23 demonstrates some of the interactive tools which were used throughout the package. The image on the left is the use of hotspots with images; the user selects an image, and this bring up some additional learning. The user can look through as many of the images as they want before moving onto the next slide in the package. Hotspots were used a lot throughout the package as it prevented having a lot of information in a single slide but allowed the user to select the information, they felt they needed. On the right hand of figure 23 is an example of some of the interactive exercises used in the package. The example here is asking users to select the correct antigens present on the blood cell for a given blood group. There were lots of interactive exercises available in both packages and directions for these can be seen in the story boards in appendices 4 and 5.

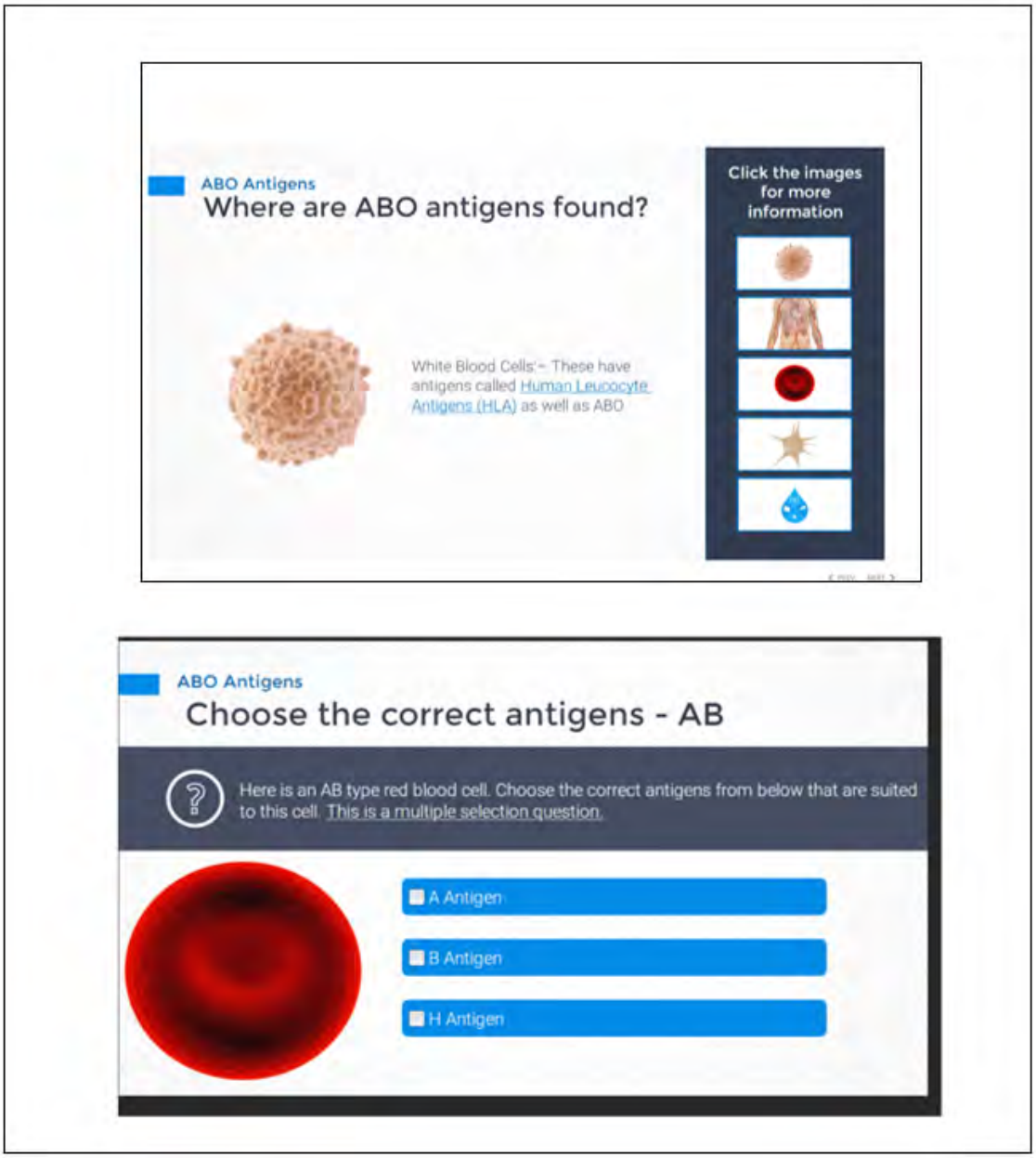


Figure 23 Examples of the interaction in the two e-learning packages.

Figure 24 gives a further example of an interactive exercise where the user needed to assign the correct genotype in the family tree. There were several exercises the user could complete to ensure that they had understood the principle, and these were available in both packages. The image on the right is an example of the end of module quiz. The user was given feedback at the end of the question to help them understand if they did not get the answer correct. The

quizzes were available at the end of each module and were taken from a large question bank created by the author.

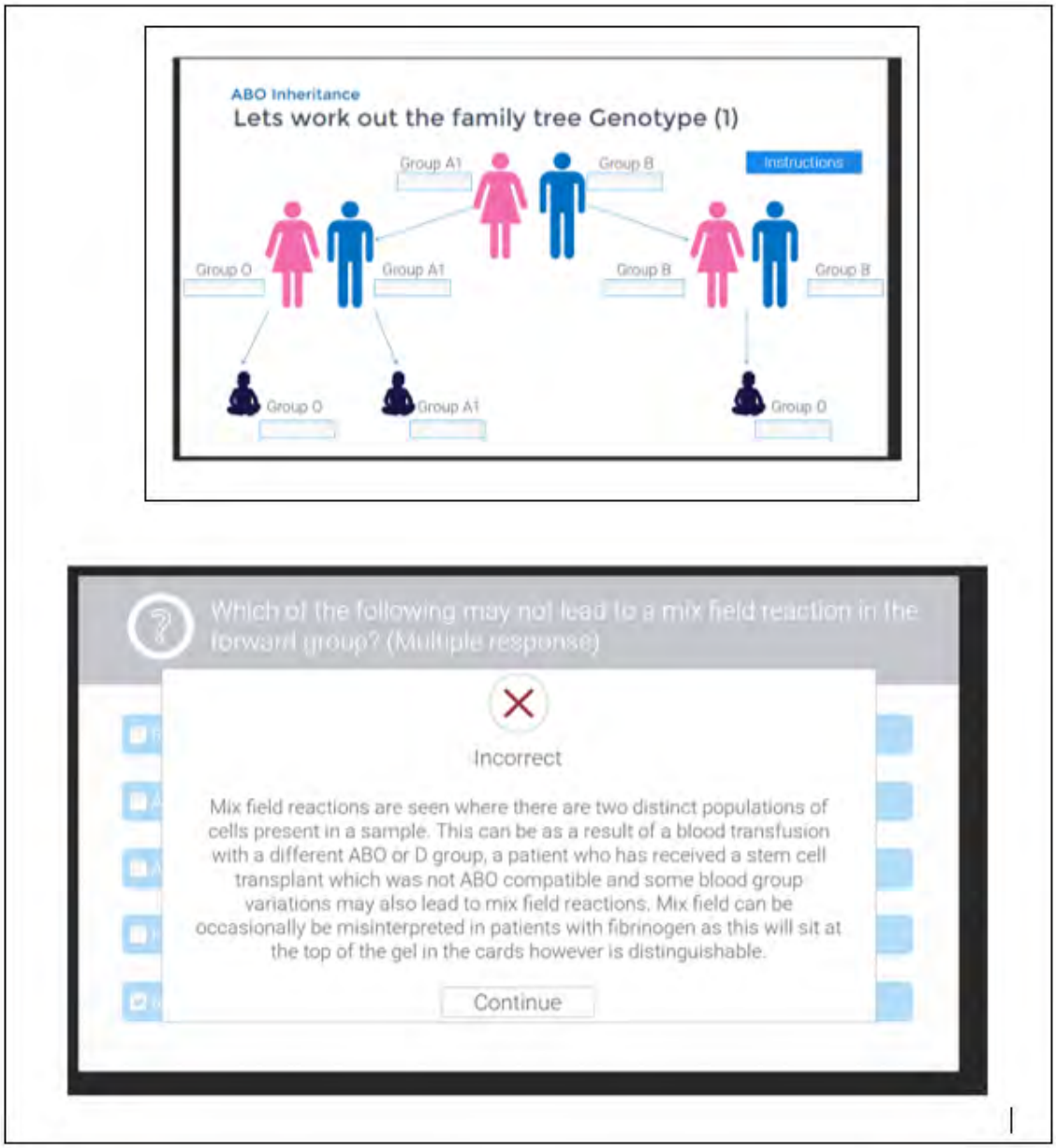


Figure 24 Example of interactive exercise and end of module quiz.

Figure 25 below shows an example of the videos available in both packages. The author created storyboards for three videos which looked at three techniques: ABO grouping by card, ABO grouping by tube and ABO grouping by tile. The first two were selected as they are the most common technologies used for grouping. The tile grouping whilst not routinely

performed in modern laboratories allows visualisation to the user as to how the reagents and patient sample interacts and therefore is used by the author when teaching blood grouping. These videos we created to a professional standard and included sub-titles and music in the background.

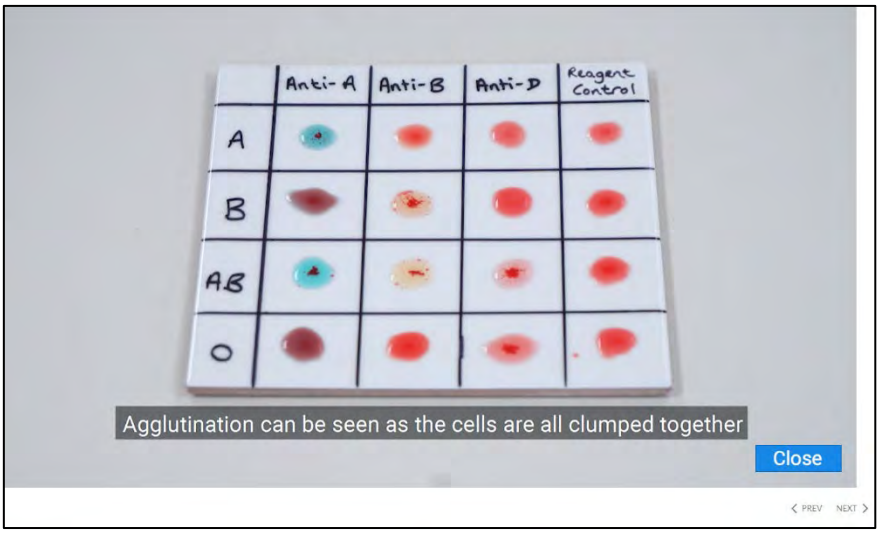


Figure 25 Example of the videos created for both e-learning packages

Figures 26 and 27 show how the interactive game was produced in the e-learning package. The game started with an introduction slide which guided the user on how to complete the interactive case study. The student was then taken through a patient case study and required to take a blood sample, separate the sample and then test the sample. They were then given case scenarios and asked to select the most appropriate blood/plasma product for the patient based on the results they had achieved. The game allowed the student to complete the whole transfusion pathway and allowed them to apply the knowledge they had gained from the previous seven modules. There were several case studies available for each package so students could choose to complete more than one if they felt they would benefit from this.

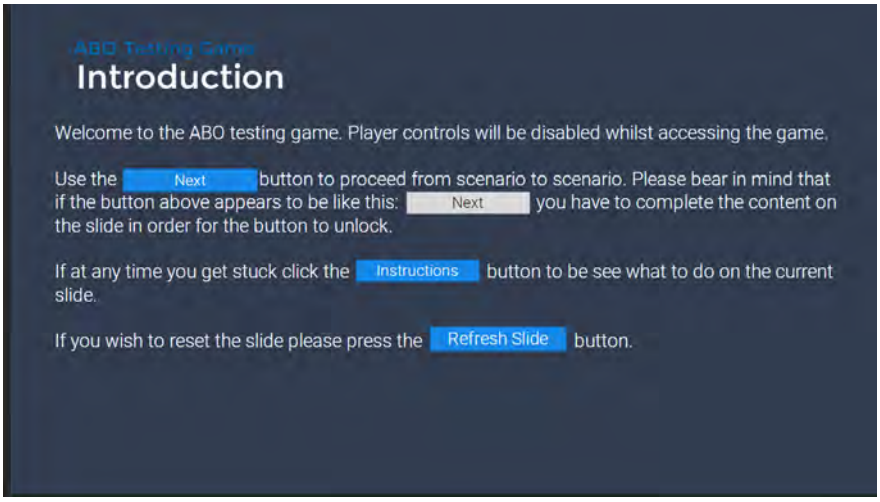


Figure 26 Introduction to the game in the e-learning packages

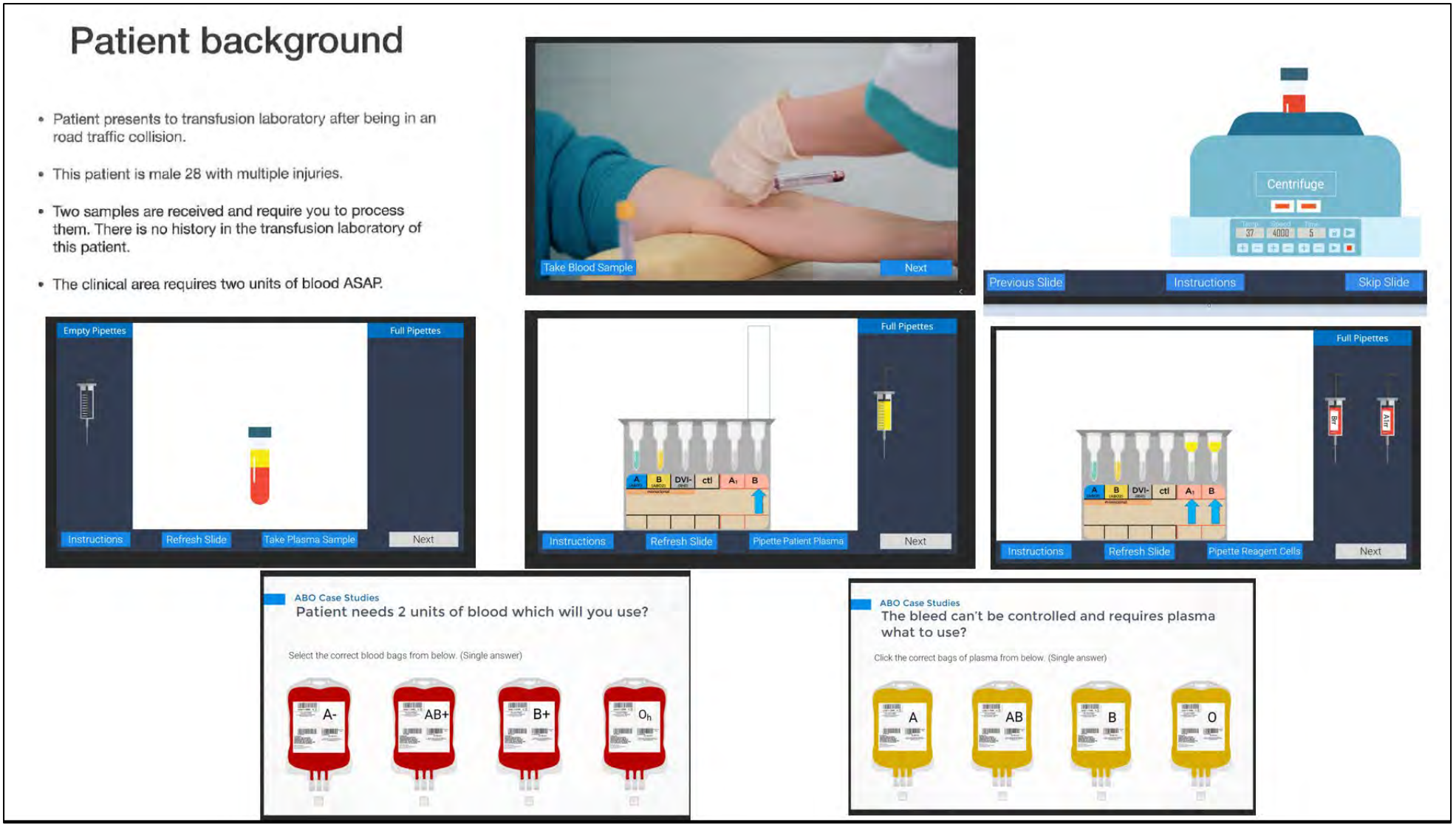


Figure 27 A selection of screen shots from the transfusion game available in the e-learning package.

During the development period, the LMS planned to be used was changed due to the contract ending with the existing LMS MOODLE®. The new LMS used was LMSX® which was a new platform to NHSBT, and because of this provided some technical difficulties when setting up the user experience. For example, the e-learning package had been built as a single product, and LMSX® did not support grading at each section with this design. So, it required the IT department to split the package into eight individual sections within the module. As a result, when the sections were set up in LMSX®, the grading was not correctly set up, meaning some of the sections showed the students to have failed a section despite passing the module. When the e-learning package was set up, each section had the end of the section assessment. This formative assessment was built into the package as required by the service users; however, the quizzes only functioned as a marker for engagement and completing a module for this project. The pass mark was set at 80% for these quizzes (Grant and Spencer, 2003), as is the standard practice with online learning, especially when using multiple-choice questions to ensure confidence in the results and reduce the risk of passing by guessing (Bramley, 2018). When the e-learning package is used as a training platform, this would need to be rectified. Managers would have oversight of this information to assess their staff members knowledge and competency. The introduction of a new LMS did not impact the user as this format was similar to all other LMS platforms already available on the market.

5.5 Results Product evaluation and success:

5.5.1 Knowledge Assessment results:

The e-learning package released to students was delayed until February 2020, which coincided with the COVID-19 pandemic. The pandemic had an impact on laboratory staff which meant fewer trainees signed up to complete the package than anticipated, and the target of 30 participants was not met despite engaging with 50 potential students. Table 23 below shows the attrition data for the project. The project was completed in April when the country had entered lock-down resulting in additional staffing pressures and re-deployment to other pathology areas. As a result of the national pandemic and its effects on the healthcare science workforce, the e-learning package results were sparing and missed for most of the participants. There was a lot of feedback from students they had insufficient time to complete the project due to the COVID-19 pandemic and the impact this had on their jobs. As has been discussed throughout thesis the project was distributed to NHS staff in England as it was based on UK guidelines.

Table 23 Attrition data for e-learning trial:

Timeline	Number of students
Discussion with students around project	50
Consent form and participant information sent out	31
Students enrolled onto e-learning package	19
Completed all required knowledge checks	8

The data on how the participants felt the e-learning had impacted their knowledge and changed their practice ensuring patient safety became the trial's focus rather than the knowledge assessment. This was in part due to the small number (N=8) of participants who completed all three knowledge assessments. The three-month post-e-learning completion data allowed the participants to demonstrate they had retained the knowledge and applied it to their clinical practice. Data were collected in June, still during the pandemic but with the NHS in the recovery phase. It was hoped that this should have allowed for more data to be collected; however, this was not the case. Only eight trainees responded to the final knowledge assessment and the evaluation of the product. All eight trainees agreed that the package improved their knowledge and was retained after three months and in some instances due to COVID-19 a longer delay.

When designing this project, perception of knowledge was decided to be the best marker, although the three knowledge assessments supported this. The knowledge assessments of the trainees were conducted at three intervals. The baseline assessment demonstrated that the student's knowledge before commencing any additional learning, which would be expected of a qualified BMS, was reasonable.

There was a post-e-learning knowledge check which had minimal uptake due to COVID-19. Despite only a small number of responses, there is still an indication that there was improved knowledge as there were concise answers. This was supported by the three-month post-learning follow up which demonstrated retained knowledge of the subject area. The overall marks for the pre, post and three-month follow up knowledge assessments are in table 24 below**,** with the range scores being provided.

Table 24 Results from the knowledge checks:

Timing of Knowledge Check	**Basics Score Range out of 10 (5 Participants)**	**Intermediate Score Range out of 10 (3 Participants)**
Pre-E-learning	4.5-8.25	6 (only one response with answers)
Post completion of E-learning	6	No Responses Received
Three Months post completion of e-Learning	6.75-8	7-7.5
Perceived knowledge Pre-Package	3-7	5-7
Perceived Knowledge Post package	6-10	6-9

Table 25 Statistical analysis of perceived and actual knowledge improvements

Test	**Actual Knowledge**	**Perceived Knowledge**
Point knowledge increase (Scale 1-10) and SD	1.3 SD 1.25	1.8 SD 1.2
Dependant Samples test	T=3.4 (p = 0.009)	T = 3.9 (p = 0.006)

The results in table 25 show there was an increase in the knowledge for both perceived and actual knowledge for both the two packages. There was also a dependent T test performed on the data which further supported the significant increase in the knowledge improvement for both perceived and actual knowledge.

A Spearman ranks correlation was performed which looked at the correlation between the actual knowledge against the perceived knowledge. The correlation coefficient was 0.7, though the sample size limits the interpretation of this finding. The scatter plot can be seen in figure 29. This only included data from six participants as there was an incomplete data set for two of the students.

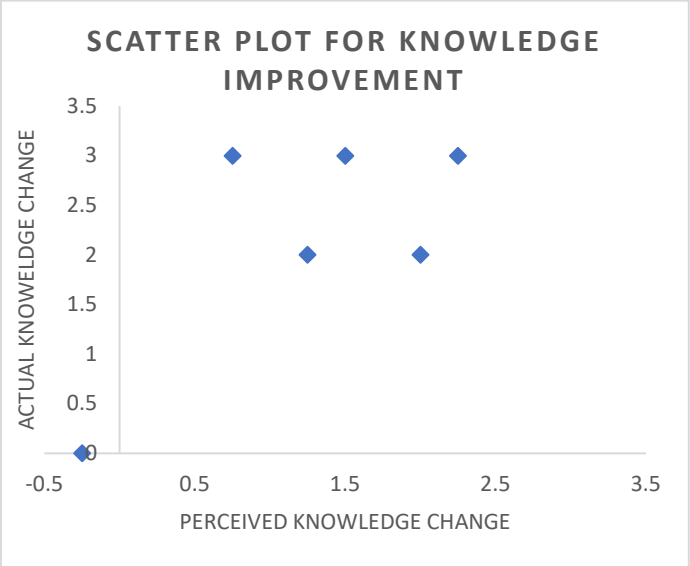


Figure 29 Scatter plot for knowledge improvement – students perceived knowledge against the actual knowledge change.

The effect size was estimated using a Hedge's G statistic for actual knowledge and was -1.19. For perceived knowledge Hedge's G was -0.19. Owing to low sample size and the need for

future replication studies a *post hoc* power calculation was performed. For the actual knowledge, a one tail calculation was performed as it was believed that an intervention could only increase knowledge. This produced an observed power of 0.65. Suggesting additional data would be required in a future study. The perceived knowledge also had a power calculation performed using a two-tail approach as an intervention may have improved or decreased a student's perceived knowledge. This produced an observed power of 0.82. Based on this an *A priori* analysis was performed to determine the required sample size in future studies with the required statistical power. For both knowledge and perceived knowledge to be tested with a β 0.8 there needs to be a minimum of 12 participants in the final analysis in future studies. Based on the observed attrition rate in the present study an estimate of 16-20 participants would be required. All calculations were performed on the G* Power software (Faul et al., 2023; Kang, 2021).

5.5.2 Results of Product Design and Application in the Workplace

Due to the COVID-19 pandemic there was an adjustment in the students' satisfaction measure with the e-learning project which went from a face-to-face workshop to additional questions on the final knowledge check. At the time of the review of the project which was at the peak of the pandemic it was felt unsuitable to perform the workshop remotely. This was due to both the author and students describing their workload as unmanageable at the time.

The students were positive about being able to apply knowledge included in the e-learning package as they felt this allowed them to practice what they had learned in a 'safe environment'. They felt the practical elements had been covered by the 'game' although they still felt strongly that the face-to-face learning offered by NHSBT currently was required to provide a blended learning approach.

Evaluation feedback was collated regarding the e-learning package and how effective this project was, both about the use of e-learning in practice and the ability to provide knowledge. These results can be seen in table 26**.** These comments will be used to develop the e-learning for future use as part of the training department commitment to provide more learning by e-learning in alignment with the rest of the NHS. Table 27 highlights the qualitative themes seen by the students who completed the package.

Table 26: Evaluation comments from the post knowledge assessment regarding the e-learning package.

I really enjoyed the package and as a trainee BMS, I found it a really useful resource. I liked the setup of the package and thought the subjects were divided up well. The package also included a variety of topics which was useful to broaden my knowledge. It was interactive which made it enjoyable to complete as you were not just reading and trying to take in lots of information. The interactive parts that showed the testing of samples gave a great insight into how different techniques are performed in the laboratory. Overall, the package did not take too long to complete. As the topics were divided up you could easily start a topic and come back to it another time. The only issue that I had with the package was that once I had completed some of the topics, the system did not seem to register that I had complete the topic, and I had no score. For some of these I had to repeat the topic to receive a score. Overall, the package is a really useful resource that explains the basics of blood grouping really well and would help anyone that would like to find out more about the work of NHSBT
Whilst I felt that the package was of a suitable length and structure, there were elements of the assessments that I did not feel were covered adequately (if at all) in the learning slides. Therefore, I do not feel that my understanding of these areas has been maintained as a result of the lack of explanation in the package, which I think will be evident from the post-knowledge checks.
As time has passed since the package, without consolidating the knowledge acquired I feel like I am less confident in the learning and would have benefitted from access to the package for a prolonged period of time. I also wonder if it would have been more beneficial for me to have completed each section independently rather than completing the package in its entirety in one sitting.
I liked that different sections of the ABO package were split in different parts which made it easy to absorb the knowledge. The online courses were very visual which made it interesting. Each section had enough content to learn from which made it easy to complete each section within a reasonable timeframe. The courses would not save properly on 'Train Easy' for the first time which could just be a technical problem.
The e-learning package was easy to follow however was too long at sometimes and require more attention.
Good length and good arrangement into sections. Found the lab explanations are a little basic, but not sure if that is just because I know how these works. It would be good to explain D-typing and molecular techniques. For someone working in a general lab it would be good to have more information.
I think I did not get the full benefit of the package as I rushed through it to complete it as I had university commitments. I would love the opportunity to do it again if possible now that my other commitments are finished. I can now focus on learning the theory behind my job. I really enjoyed how it was broken into small sections and I think that would help people like me who are beginners and inexperienced. I think it replaced face to face well as sometimes when I am training face to face, I get nervous and embarrassed when I cannot answer the question. The only negative was the system malfunction after completing the quizzes but that was all.

Table 27 Summary of themes from comments from the students around the e-learning package and LMS:

Positive themes from comments	Negative themes from comments
Useful resource	LMS issues
Set up and length of package	Length of access to package
Division of topics – Clear and Concise	Way package was used e.g., not in one sitting
Variety of topics	
Interactivity making enjoyable	
Very visual	

As can be seen, three students stated there were issues around the LMS platform that was out of the developer's control. NHSBT is moving to an alternative LMS, which would be used for any future projects involving e-learning. During the project, there were problems, for example, recording of scores for individual users during the project and other factors.

One student commented on information not being given in the training material which was assessed. The project underwent a full review to ensure this did not occur with the assessments being evaluated five times, so there will need to be a further review of the assessment questions and the content to rectify this before being used as part of training material nationally. This was an isolated comment, and additional comments were sought for clarification, but none received. Unfortunately, the assessment questions were randomly generated from a bank of questions created by the author and assigned to the appropriate modules within the package by the package designer. Therefore, there may have been a potential for a question from the bank to have been incorrectly allocated to the wrong module which may have resulted in this comment.

6 Discussion

6.1 Service Evaluation:

6.1.1 External Haemovigilance reports:

The SHOT report data have shown that over the last 20 years, there has been a reduction in the number of ABO incompatible events and therefore a reduction in the number of fatalities due to ABO-incompatible transfusions (Narayan et al., 2021:20; Mistry et al., 2019; Bolton-Maggs, 2019); however, it still demonstrates underlying problems with knowledge and understanding of the ABO blood group system despite it being a recommendation in 2018 that all staff involved in the transfusion pathway (including clinical staff) must be trained in ABO grouping (Ramsey, 2020; Narayan et al., 2021:20; Bolton-Maggs, 2019).

The review of the external haemovigilance reports influencing this project's content was performed between 2013-2016, which was not updated before this project went live. The e-learning package had already been developed in 2017/18 and was further delayed by the LMS not being available; however, a review of the literature as part of this discussion demonstrated an ongoing issue with ABO in both the clinical and laboratory areas (Narayan et al., 2021:20), further supporting the decision to use this as the topic.

There are now 1495 reports of near miss ABO-incompatible transfusions in the last five years (2016-2020) (Narayan et al., 2021:21) Ramsey discussed (2020) that whilst the total number of reports of ABO-incompatible transfusions administered remains low, there is still an underlying issue with knowledge and laboratory systems that is reliant on systems detecting these errors (Mistry et al., 2019). The ABO blood group system knowledge is fundamental to safe transfusion; therefore, it should not cause so many potential errors highlighting there are

still gaps in knowledge supported by the literature (Storch et al., 2020; Bolton-Maggs, 2019). There is still a requirement for ongoing education and training of the scientific workforce to prevent the errors occurring in ABO grouping and blood selection and this is being addressed at a national level as part of Transfusion 2024 (Allard et al., 2021).

6.1.2 Service User Engagement:

The service evaluation was performed by approaching the South West RTC (Sample survey), which means only twenty laboratories were invited to participate in the survey, of which eight laboratories responded giving a 42% response rate (Rindfuss et al., 2015) which was higher than a study performed in South Africa which gained a response rate of 33% (Laher and Patel, 2019). While the regional data obtained from this survey was supported by the data from national surveys performed by UKTLC and UK NEQAS (Bolton-Maggs et al., 2019), it may have provided more specific data if the survey had been distributed further to additional RTCs. The restriction in using one region and extrapolating the data had its limitations as potentially most of the staff employed at these trusts may be from a single university in some parts of the UK and also had a stable workforce which reduces the variables within the workforce potentially biasing the results obtained (Rindfuss et al., 2015). If this university had adequate training within transfusion, this might lead to a false sense of security regarding BMS knowledge overview; therefore, had more time been available, it would have been preferential to approach at least one other area reducing the university bias. Whilst university courses for BSc are all accredited with the IBMS and National School of Healthcare Science (NSHCS) (IBMS d, 2021; NSHCS b, 2021; NSHCS h, 2021), the content varies at MSc and BSc levels. Some courses may have a more comprehensive transfusion component, which would result in trainees having a greater transfusion knowledge before commencing a BMS job within the NHS.

Another bias which was introduced was personal bias as all service users were approached by the author (Cottrell and Donaldson, 2013). Research suggests that individuals may not be honest or provide the answers the surveyor wants to hear if surveyed face-to-face (Warner,

1965) and as the users all knew the author this was not appropriate and was counteracted by providing a remote survey electronically or paper copies if required to reduce bias introduced with computer literacy (Beebe et al., 2007). This aimed to reduce the bias and allow users to answer the survey honestly to gain reliable and reproducible results. This bias was unavoidable as the author works nationally and therefore communicates with laboratory managers across England. The use of transfusion practitioners or training officers was considered to avoid this bias however these roles are often a joint role with the scientist working in the laboratory alongside the additional responsibility and therefore may have resulted in a lower response rate as seen in a survey performed by the Institute of Biomedical Science in 2009 (Pitt and Cunningham, 2011). As the author only wanted a response once from each laboratory the laboratory manager was used, and an acknowledgement of the potential bias was taken on board. It was also acknowledged all data gathered from the user engagement was being compared to national existing data and therefore any results which may have occurred due to the sampling would be highlighted in the comparison.

The Southwest users and the literature have highlighted a challenge with the undergraduate transfusion training in the laboratory and the university (Bolton-Maggs et al., 2019). Whilst this project aimed to address the education post-graduation, a recent review of the national training programmes has been launched to include the PTP and STP to ensure the learning outcomes provide the knowledge required of these scientists working at BMS and CS level (NSHCS g, 2021). The curriculum review addresses the laboratory training required for these students to reduce some of the knowledge gaps seen in the SHOT reports (Narayan et al., 2020) and voiced by the TLMs (NBTC & NHSBT, 2020). Although this review and adaptation of the training programmes are underway, there is still an underlying challenge with scientific knowledge, as seen by the survey results. Therefore, the requirement for additional CPD

training opportunities to develop the workforce is required to improve the service's quality which is in part being addressed by Transfusion 2024 (Allard et al., 2021). E-learning packages such as the one developed in this project will play a pivotal role in improving scientific knowledge and allowing staff access to educational opportunities they may have previously not interacted with.

6.2 Course availability and access to training:

The service user engagement highlighted the key areas where LMs felt their staff required additional knowledge. A high percentage focusing on services routinely only offered by NHSBT, such as genotyping, reference cases, and clinical transfusion demonstrates that the current learning pathways existing within transfusion are not enough. Whilst these topics were required by more of the users, there was a requirement for training in all areas of transfusion, which is in line with the SHOT reports results (Narayan et al., 2020; Bolton-Maggs et al., 2019). The result has provided valuable information for the training department at NHSBT who can use this data to develop further e-learning courses and has also been used by the chief scientific officer at NHSBT to inform the Transfusion 2024 strategy.

The evidence in the SHOT reports and recommendations by the UKTLC have highlighted the existing mechanisms are not achieving the desired results as we are still observing mistakes occurring due to inadequate knowledge (Narayan et al., 2020; Bolton-Maggs et al., 2019). This was supported by the results seen in this project where the users have suggested that staff still require additional training however this is not possible with the current face-to-face arrangement. As has been discussed a blended approach may improve the outcomes of any educational intervention and was seen in the user engagement survey where the results showed the users wanted both face-to-face and e-learning. This is supported by research in the educational field, which shows that combination learning, or blended learning is the most effective learning form (Garrison and Kanuka, 2004; Dantas and Kemm, 2008). This is because it allows students to learn in separate ways, ensuring complete understanding and allowing the educator to adapt their mechanism if the student is not clear on a specific area (Pishva et al., 2010). Since embarking on this project, there has been additional funding from HEE for NHSBT to develop further online courses to provide courses and online learning to

NHS trusts to improve transfusion education to the BMS, CS and clinical workforce (Personal communication, 2020). Details of the funding made available from HEE are not published therefore there is no evidence to support this statement other than a personal communication from the lead for the training department at NHSBT.

TLMS expressed concerns over access to practical experience which could be overcome in a blended environment and has been seen in higher educational institutes providing MSc courses for distance learning students. These courses have comparable results with students who are full time on a similar course and was seen in a study at Nottingham Trent University by Poon (2013), provided the learning methods are appropriate, e.g., knowledge-based learning by e-learning and face-to-face for skill-based learning. Another example of blended learning is the STP MSc in haematology and transfusion run via Manchester Metropolitan University (NSHCS h, 2021). Students are employed as CS trainees and cannot spend full terms away from the workplace to undergo the academic component but still require some face-to-face learning of key skills. This could be adapted for the courses offered by NHSBT where it would be possible, for example, to ask students to attend for face-to-face learning for two/three days which would allow them an opportunity to partake in practical experiments within the training laboratory as well as face-to-face learning and continue the learning remotely using PBL allowing for application of knowledge (Tsai and Chiang, 2013).

The move to complete online learning has been applied during the recent COVID-19 pandemic where online platforms are being used to deliver face-to-face synchronous learning virtually. These are gaining positive feedback, which other educators also reported (Seymour-Walsh et al., 2020). The use of online learning has required the delivery to change and use methods not

always traditionally used in face-to-face learning, but the outcome is positive. This is further supported by the use of some e-learning packages which the training department has developed. The two e-learning packages developed within this project have not been used yet, and they can be adapted to form part of the additional learning to the current courses available. Using distance learning methods with both synchronous and asynchronous material to deliver courses provided, the educator is flexible. This has been seen by institutes offering medical and allied health profession training during the pandemic (Cleland et al., 2020).

From the service user survey results, it was interesting to see that two users would prefer not to consider using the e-learning platforms for education. It was an unexpected finding as it was thought that having distance learning would allow the workforce to be maintained in numbers whilst improving staff knowledge as described in the UKTLC reports (Bolton-Maggs et al., 2019). Upon further investigation, this was not because they do not believe e-learning does not work, but because it creates the same workforce issues as face-to-face learning. However, e-learning is seen as more disruptive to the laboratory as it usually occurs over a more extended time due to distractions and IT issues which may be a cause of failure (Azlan et al., 2020; Leu et al., 2010; Regi et al., 2020). The problem with removing staff from the clinical laboratory is not overcome by using e-learning as the staff still require the time to commit to the learning. This was seen in a study by Leu et al. (2010), where they looked at leadership management training in nurses to improve engagement and e-learning. While the study improved access to the course, the engagement was hard to achieve. This is a well-documented problem with pure distance learning and why a blended approach is often utilised (Carbonaro et al., 2008), and the Southwest users echoed this. This was a useful insight into how the managers require training to be delivered and require some development to ensure the total time commitment is reduced to allow maximum access to the courses. This was not part

of this project but will allow for future developments of courses although would require further data gathering from the nation transfusion laboratory collaborative to ensure this is required at a national level.

It was also interesting to hear the different views of senior managers and the LMs, which were different as they looked at the problem from different perspectives. This may explain some of the available literature suggesting that e-learning alone is sufficient and resolves releasing staff issues which can be seen in a paper by Al-Adwan and Smedley (2012). All the results reviewed in this project both the user engagement and UKTLC results were from transfusion laboratory managers who often do not hold the budget for additional training courses; therefore, it may be beneficial in a future project to gather data from senior management and budget holders to determine their requirements for training and education of the scientific workforce and ensure engagement at the top which impacts on the engagement in the scientific workforce and is critical for success of an intervention (Clarke et al., 2005).

One of the key areas highlighted in the survey was that there are multiple courses offered by organisations such as NHSBT that provide additional learning. However, very few of these opportunities were accredited by professional bodies; Therefore, there was no assurance that these courses provided the learner with the knowledge they required to be part of the transfusion workforce. There were no courses available in England with a sole focus on ABO grouping however there were existing courses within NHSBT which were used to inform learning outcomes for the e-learning package in this project.

One example of learning was used across most of the laboratories, which involved e-learning is the anti-D module on Learn-Pro®; however, it was acknowledged that this was heavily clinically oriented and provided little laboratory knowledge, which may in part explain why there has been minor impact on knowledge bases anti-D errors. Since commencing this project, the anti-D training package has been redesigned to involve more laboratory aspects after feedback from users. The new module provides an opportunity to apply knowledge, provide information, and use other platforms' successes to improve output. A recommendation from the NBTC is that this was an area where there is a reduction in knowledge within the workforce (E-learning for Health, 2023) which was supported by SHOT data (Narayan et al., 2020:191).

Once this module is released this should provide a solution to all laboratories for training within this area of transfusion which has been accredited by all four Blood Services. The success of the anti-D immunoglobulin e-learning package can be determined by reviewing SHOT reports which would hopefully show a decline in the number of reported errors associated with the laboratory. This development of the anti-D modules has demonstrated the change in transfusion practice since the beginning of this project and how the scientific workforce is adapting its training methods. The learning from the authors ABO blood group e-learning project was also fed into the user group for the anti-D package. This contains multiple interaction methods in the product and includes case studies to improve engagement (E-learning for Health, 2023). Whilst this package will tackle knowledge-based errors there will be errors related to storage and handing (n=3.2% in 2021) and missed prophylaxis (n=66.9% in 2021) (Narayan et al., 2022:69). These would not be impacted by an educational intervention alone and highlight how errors are not usually made by a single factor and are often an accumulation of mistakes (Linden, 1999). This would therefore need to be considered when

looking at any educational intervention in ABO grouping and using SHOT data to determine effectiveness.

Funding was also discussed by the TLMs, and this is reflected in the UKTLC report which noted funding for scientific staff reducing over the last five years which has resulted in fewer staff accessing conferences and courses (Bolton-Maggs et al., 2019). There is often a restriction on funding from the hospital for laboratory staff to access CPD opportunities or MSc qualifications which aid knowledge and development in staff. Whilst HEE provide funding for several courses at NHSBT, this does not provide enough spaces for all scientists, and there is still a requirement for hospitals to fund their own spaces. E-learning projects such as the one in this project would allow staff to access CPD opportunities whilst keeping the cost low to ensure all staff have equal opportunities. There needs to be work undertaken in standardising time for BMS staff to undertake CPD and provide adequate funding and this was a recommendation from the UKTLC in 2023 (Dowling et al., 2023).

6.3 Discussion Product design:

6.3.1 User Requirement specification:

This project was developed remotely with the author and package designer being in different countries. There were some problems encountered as a result of the international working which are not seen in other projects in the literature and therefore should not be considered a limitation (De Vries et al., 2011). Whilst face-to-face development was not part of the original URS, and at the time of employing the developer, it was known he was not based in the UK, it had not been anticipated as an issue; however, due to the package's complexity and length, there would have been significant benefits in developing this using one-to-one time. It would have significantly reduced the amount of review and correction time both parties faced and ensured the product had been made available within the original anticipated timeframe. This was a learning point, and should another project of this scale be attempted, part of the URS would now include local access to the project designer to allow for face-to-face development or a review of working arrangements to ensure there are no restrictions encountered due to remote working.

This project also highlighted how important it is to perform research on the project designer and the development platform. There was a requirement to perform a lot of research whilst the project was in development. Had this been researched before commencing the project, it would have allowed for a conversation to be started and discuss what tools within Articulate Storyline 3® would be used in the project, reducing the time spent on development. The author did not consider this, as this was thought to be within the project designer’s remit; however, this was not always the case in this project (Conole et al., 2006).

6.3.2 Funding

The project was restricted by funding, which impacted being able to procure a project designer who could fulfil all URS requirements. This was a challenge with this project as the development of e-learning packages tends to be expensive (Sandars, 2010). The budget for this project was quite restrictive and not enough money to achieve the URS. It is widely acknowledged that the cost of the set-up of e-learning is high, and costs can exceed expectations (Wentling and Park, 2002). There is often a balance between economics and the quality of learning and there may be a requirement to reduce the quality of the e-learning package to make the product economical, which was the case in this project (Weller, 2004). It may have been better to have focused on one level of the package and achieved a perfect product than have two mediocre e-learning packages where the full £10,000 budget should have allowed a professional company to develop a single package.

Going forward with this project it would help to develop one of the packages to correct any underlying problems and enhance the game component. The improved package could then be adapted with the second package's content to provide two e-learning packages. For future projects, there would be an advantage to developing a single product that could be adapted, for example, using the Articulate Storyline 3® software and then amending the content to change the level of learning.

6.3.3 Learning Management System:

The LMSX® was used in the project as an alternative to the existing LMS NHSBT used for mandatory training and other internal e-learning. The system was a trial as NHSBT was undergoing a procurement exercise for a new LMS and had an advantage as it could be distributed both internally and externally which the existing in use platform could not. This however has a limitation that the access to the platform had a defined period, as the license was only available until April 2020. This meant the release of the e-learning was defined by the access to the LMS as there was not an alternative LMS available within NHSBT which could host the package and be made available to external participants. Whilst this should not have been an issue, COVID-19 resulted in the already stretched workforce within the NHS and transfusion to become even more stretched, impacting the number of potential students willing to participate in the project (McCabe et al., 2020; Al-Riyami et al. b, 2022). It would have been best to delay this release of the project in an ideal world to allow maximum participation; however, that was not possible and had the project been delayed, there was a potential there would not have been a suitable LMS to proceed; therefore, it was released in February 2020 as planned, just before the first lockdown for COVID-19 (Johnson, 2020). As a result of low participation numbers which may have been affected by the COVID-19 pandemic this study became a feasibility study and would require further data gathering to determine the effectiveness of the intervention.

If there were a move to distribute e-learning out further, it would be wise to perform another trial to ensure the LMS is working as expected and ensuring it fulfils the user's requirements. The LMS plays a pivotal role in ensuring engagement with the system, and glitches that result in user dissatisfaction can reduce the learning's effectiveness, which has been discussed within

the university setting (Zanjani, 2017; Alenezi, 2012). There is literature discussing the impact of the LMS on the student user experience, and this was not considered during this project as the LMS fell outside of the scope of development (Imazi et al., 2005).

The restriction on the date of the LMS was a limitation of the project and alternatives were discussed within NHSBT and also university. Local IT were unable to provide an alternative LMS which could allow students from outside NHSBT to access which would have limited the number of participants invited to the trial to less than ten. As there would have been a high attrition rate often seen with e-learning within the ten students this was not felt to be a viable alternative as the numbers would have been insufficient to gain meaningful data (Martinez, 2003). The university LMS was considered as alternative but similar problems were encountered with the upload of an external e-learning package and managing the students enrolled on the project therefore this was not considered further.

There were other alternatives which could have been considered such as the e-learning for health being used however this was not practical for the timeline of this project but could be considered for future e-learning project (E-learning for Health, 2023). The advantage of using this existing platform would have been familiarity for staff however would not have had the IT control which the author had wanted for this project for example giving limited time access to a package.

The final mitigation which was considered as part of this project for the LMS timing was to consider using students from outside of England. However, was not considered appropriate for several reasons including that students who were recruited through NHSBT had been given additional learning which was the same and therefore did not give any students an advantage

but if additional students had been recruited, they would have not received these lectures and would not have been comparable to this group. The e-learning package was based on practices within England and may have not been relevant for other countries and would have required adapting and this fell outside of the remit of this project, however, could be considered for future work to increase the number of participants. The final reason for not including other countries was that the COVID-19 pandemic was not isolated to the UK and all health services were reporting an increase in patients and demands on services and therefore it was not felt appropriate to ask for them to participate in a project for a doctorate (Ashraf, 2020).

6.3.4 The E-Learning Package and Gamification component

The e-learning packages were created in collaboration with a package designer taking on board the requirements of the project from the author. As the project progressed and interaction and interactive tools were required it was discovered there were some limitations in the development. This required extensive research to overcome some of the limitations and delayed the completion of the project. It highlighted a requirement to review all development materials before embarking on a e-learning project to ensure that issues with development do not occur. Looking at other e-learning studies a review of the development prior to creating packages has not been reported in the literature (Peterson et al., 2008; Rothschild et al., 2007).

This was the second time the author had been involved in developing an e-learning package. On the first occasion, the package designer had been on site and was able to sit with the author and create the package in real-time. This project, however, was developed using an electronic storyboard on Microsoft PowerPoint®, which did not allow for additional notes to be added easily (Maestro, 2018); for example, in areas where you would like aspects of the package to be interactive. This was overcome by the addition of handwritten notes on a printed copy. This caused some issues due to difficulties in reading handwriting and the notes' interpretation and resulted in lots of amendments being required post-development delaying the package creation. This delay may have potentially been overcome by using online discussion platforms such as Google Docs® or Teams®, where clarification of comments could have been added and discussed in real-time rather than delaying the project whilst waiting for a response. Unfortunately, at the time of development, the systems within NHSBT could not use these communication techniques, which is often a problem with NHS computer systems (Richards et al., 2005; Flores, 2019).

The platform's review using a web-based system had flaws that were not discovered until after a few reviews (Maestro, 2018). For example, once a comment had been actioned in the package and set as resolved, it disappeared from the record, making it hard to ensure changes had been made, which resulted in duplicate work (Articulate, 2021). This was overcome by maintaining a hard copy of the comments; however, it was a design flaw in the system. Should a project of this scale be repeated, it would need to be incorporated into the URS, as the author had not used this version of the software before they were not aware of this design flaw. This may have been something the package designer could have informed the author about; however, as they had not used the online review platform before they were not aware of the issue either.

The project's interactive game component was not possible in the format envisaged by the author. However, the development of interactive case studies allowed the students to process a sample from start to finish and apply and enhance the knowledge they had obtained from completing the package (Nah et al., 2014). The case studies provided an interactive learning environment that was fun and allowed for competition with fellow scientists whilst ensuring retention of the new knowledge gained from the educational package (Sherry, 1995 Blakely et al., 2009). In order to obtain a game which had a laboratory simulation similar to the BTLP TACT system (NEQAS, 2021) there would need to be additional development; however, it would come at a high cost of development (Torrente et al., 2013).

UK NEQAS has utilised this with BTLP TACT® (NEQAS, 2021). The development of a game would be costly as the quotes received for this project were £20,000 plus; however, it would allow the application of knowledge, which is reported in the literature (Sherry, 1995), to be the area in which e-learning is often not sufficient on its own. If there was the game

aspect of the package, this may reduce or remove the requirement for face-to-face learning, which would allow more trainees access to these packages. This area will be looked into further by the training department to increase the distance learning they provide and could be used by other organisations also developing learning packages.

If it were not possible to invest money in providing a simulation laboratory, other solutions would have to be sought. This could include NHSBT sending samples to the student via their transfusion laboratory and providing a Zoom® based practical session where student test the samples on their technology and the group come together to discuss the results. This would allow the application of knowledge and interactivity required to engage students whilst providing them with a safe environment to learn practical skills.

Another solution may involve developing virtual reality, the training department is currently using one of the laboratory techniques in a virtual reality simulation. This has provided an excellent opportunity to have a go and see how the technology works. If this could be adapted further, this may alleviate the requirement for a game and allow virtual reality to reduce the amount of face-to-face time required (Rounding and Evans, 2021). There are, however, still limitations of virtual reality, such as the requirement for a headset to allow the use of the software; therefore, the pro and cons of developing a game which can be used online over virtual reality practical should be considered.

It was noted one user felt that the package was too basic for them as can be seen by the knowledge data. This student was at the top of the group for the basics package and saw no overall improvement in their knowledge scores which would have indicated they were on the wrong course. Looking at the student's demographic they were a band five BMS which means

they would have been suited to either course. This was a study design flaw where students were enrolled onto a course based on the NHSBT course they had completed. The literature shows two approaches when implementing an e-learning package. There is no one size fits all approach where all the information is available and learners' needs are not assessed prior to learning and this has shown good outputs in a study by Cottrell and Donaldson (2013), with nurses and transfusion training (Oster et al., 2015). The alternative approach is to take a baseline assessment and adjust the material as appropriate (Lin et al., 2016). The adjustment of the material is not possible with e-learning but where two levels of package exist a preliminary assessment to assign students to the appropriate course could be achieved.

Another way to ensure students are directed to appropriate level of learning would be to assess them by their band and the course they were enrolled on to ensure they were allocated the appropriate level training package. This would have been a simple fix that would have prevented students from feeling that the training was not at an appropriate level. Should another project be undertaken, and it is not possible to have an assessment question initially, this mechanism could be used.

6.4 Product evaluation and success:

6.4.1 Knowledge Assessment Improvements

The evaluation of the product was conducted in two ways: the actual level of knowledge improvement and the perceived knowledge using three knowledge checks which were sent to participants via email. The post-completion knowledge assessment results were not intensely followed up with the trainees (two reminder emails were sent). It was felt that there was a risk to patient safety, distracting BMS staff who were in an unfamiliar clinical area or stretched due to staff shortages because of COVID-19 (Al-Riyami et al. b, 2022). The missing data were assessed during the project; however, the post completion of the summative knowledge assessments would have been useful in interpreting the immediate success of the e-learning. It was felt the most important data was the three months follow up summative knowledge assessment; therefore, students who failed to submit the post e-learning assessment were not excluded in the project as the data available still allowed the author to determine the retention of knowledge. This method of data collection has been used by other studies within transfusion (Salter et al., 2014).

It was interesting to see, whilst the total numbers of students were low, that the project's impact was successful regarding the perceived knowledge improvement. Seven out of the eight participants felt their knowledge had increased and had been retained after three months. This was a useful finding as it has demonstrated not only had the learning been successful but that the student felt they had retained the knowledge which would have an impact upon their practice clinically. The studies discussed in the literature review marked success as retained knowledge after several months, and this has been replicated in this study, indicating in theory

this style of learning can impact knowledge (Garrioch et al., 2004; Naeem, 2016; Gallagher-Swann et al., 2011). A study by Clark et al., looked at a formal education programme with their aim to improve patient safety and they described success as an improvement of 6/7 recommendations and maintenance of the improvement after 18 months (2001). In this study we reviewed the data after 3 months as time did not permit a review after 18 months however it has demonstrated a retention of the knowledge.

The data on perceived knowledge has pitfalls. It was reliant on the student accurately assessing their knowledge and ideally having the data collected supported by another member of staff such as their senior; however, this was not possible during COVID-19. Evidence suggests that perceived knowledge is not always representative of actual knowledge, and therefore, this should be interpreted with caution (Melnyk et al., 2008). Further work with additional students would need to be conducted to provide more data before any changes to practice should occur. It would have been interesting to see if the TLMs agreed with this self-assessment, but this was not possible as the project involved multiple trusts with a single participant. There would also have been a time delay in obtaining this data due to the data collection occurring during the COVID-19 pandemic and the school summer holidays, which was not within the project deadline; therefore, these data were not obtained. It would be interesting to contact the LMs retrospectively to determine this information and provide useful data for e-learning within the transfusion workforce.

The increases in knowledge improvement and the correlation between actual knowledge improvement against perceived knowledge improvement did show significant results despite the numbers being small. Looking at the literature most of the studies looking at educational

interventions have larger participant numbers which was not possible here; however, all show success that an intervention results in an improvement in patient safety and knowledge (Sahmoud et al., 2021; Clark et al., 2001). This is not an unexpected result as you would expect if a student were given additional learning this would improve their practice and improve patient safety which is why as scientists there is a requirement to continually professionally development to ensure patient safety (Luconi et al., 2019).

6.4.2 Engagement:

The delivery of learning has resulted in many discussions within transfusion and a focus on utilising distance learning to improve access to the courses has been considered a solution which was also echoed by the user engagement results (Bolton-Maggs et al., 2019). However, when an e-learning programme was developed as in this project, there was poor engagement, with only 8/50 people engaging fully with the system. It is well documented when students are given e-learning, there is a high attrition rate, as seen in this project compared to more traditional face-to-face learning (Martinez, 2003; Angelino et al., 2007). This can be addressed by ensuring the learning is engaging, and the users are familiar with the LMS or provided with a guide (King and Boyatt, 2015). There is also documented evidence that users need to be prepared to learn in the online environment which is different from traditional methods the scientific workforce is used to. This was not performed as part of this project and would require further investment if there is a move to pure e-learning for future courses (Pintz and Posey, 2013). The e-learning would require engagement with the educators and the students, so investments from both parties are required for this to succeed in practice, and this has been described by O'Doherty et al. (2018).

Data were not collected from students around how they engaged with the system, which would have been useful for improving this for future projects. Reports from other studies have shown when there is dedicated worktime time there is improved engagement with the system (Gallagher-Swann et al., 2011; Ifediora, 2019; Bond et al., 2017). This study did not provide any allocated time at work to complete the learning, and this may have impacted the engagement. The allocation of work time was not possible with the project as students are enrolled on a voluntary basis, and this did not form any of the learning they received from the

courses from NHSBT although supported the learning outcomes. When this project is used as part of the training departments courses there would be allocated time which may improve the engagement.

The data around how a student engaged with the system could not be obtained from the log data (Henrie et al., 2018) and would have required questioning the participants. As this was not an outcome measure of this project this was not considered at the study design. In future work further evaluation of how students engage with e-learning e.g., on personal devices and when they engage would potentially improve engagement and therefore outputs.

The e-learning system's design allowed access to the system on a system that had an internet connection, therefore, not relying on the student only accessing this work on computers but also mobile devices. This was a criterion in the URS as it is recognised there are often issues with NHS IT systems which include both availability as well as access to external websites, which is often blocked by firewalls (Azlan et al., 2020; Leu et al., 2010; Regmi and Jones, 2020).

Restriction of the LMX® licence meant students had two months to complete the whole package, which was not the design of the e-learning. The package was designed in 'bite sized' sections to allow for this to be completed alongside other clinical work. The completion in one sitting would not have gained the maximum impact from the package (Stuart and Rutherford, 1978).

Two students mentioned the time they had to access the product, and some felt they rushed the e-learning package and would have liked access to the material after the time allocated. On this occasion, the time was limited as it was for a project also there were time limits on the licence available for LMSX®; however, when the product went live for educational purposes, the material would be available for longer. The trainee would be able to review the material over a more extended time (which is a considerable advantage of digital packages); allowing the student to review the material again if they wanted to revisit any sections, which can be helpful during the learning cycle process. If e-learning were to be used as part of the NHSBT training strategy, then the length of time the student would have access to the package would be stipulated by the training department; however, findings from this study can be fed-back to the team. It highlighted how different students require to go over information for a second or third time, and there was not always the time in this trial and that may have impacted the results. It was thought two months to complete eight small modules would be sufficient time. That would require a 30-60-minute commitment per week; however, maybe this was insufficient time and did not consider different learning patterns (Rodgers, 2008).

6.4.3 COVID-19 Impacting Engagement:

COVID-19 was an unexpected worldwide pandemic affecting the whole healthcare system (Johnson, 2020) and resulted in staff capacity being stretched further than usual. BMS staff are frontline workers in the fight against this virus and often supported other departments within pathology to ensure the high standard of patient care expected from the NHS (McCabe et al., 2020). Whilst COVID-19 is unlikely to be the only cause for the reduced engagement in the project; it was impossible to assess this. Therefore, it would be prudent to repeat this project with laboratory staff in a non-COVID-19 era to determine if this improves engagement.

Since completing this project, the COVID-19 pandemic has forced NHSBT to deliver all current courses interactively, using distance learning. This has encompassed both lectures and tutorials being delivered using the Zoom® platform alongside some e-learning. To overcome access to practical courses, the training department has considered using virtual reality practical to allow students a chance to have a go at some of the laboratory techniques (Rounding and Evans, 2021). This adaptive approach to learning is allowing development within the workforce in unprecedented circumstances. The project and the other packages designed by NHSBT since COVID-19 have demonstrated how e-learning can be applicable to the transfusion workforce both within NHSBT but also in the wider community and this has been seen in other studies which are reviewed in an article by Al-Riyami et al. (a, 2022).

7. Conclusions, Limitations and Future Work

7.1 Conclusion

The literature demonstrates inconsistencies with the current state of transfusion education across the UK and further afield (Bolton-Maggs et al., 2019; Narayan et al., 2020; Damanhouri, 2009). It can be established that there is no current single strategy in England for delivering transfusion education in a standardised way that is accessible to any scientist which is being addressed in part by Transfusion 2024 (Allard et al., 2021). The MSC concept in principle allows for both undergraduate and postgraduate training, which is standardised; however, this needs further development with the professional bodies to ensure the appropriate skills and knowledge are delivered as part of the course. There is also a requirement to ensure accreditation with the professional bodies and further standardisation in any CPD courses offered to scientific staff to ensure they meet the required standards and address the gaps acknowledged in the workforce (Bolton-Maggs et al., 2019).

The ageing workforce and reduction in BMS staff numbers means loss of knowledge and skills as these staff retire or leave the NHS (NHS Employers, 2017). The loss of skilled staff has been acknowledged in the UKTLC reports and has had a significant impact on the workforce (Bolton-Maggs et al., 2019). Whilst training alone would not address the reduction in staffing it would help address the loss of experienced and knowledgeable staff. Therefore, adaptive mechanisms to train the scientific staff need to be reviewed to ensure consistent safety and knowledge within the transfusion workforce. Gaps in knowledge can be assessed using data available in national comparative audits of transfusion, along with SHOT and UKTLC reports, and used to determine key focus areas for the development of training (Narayan et al., 2020; Narayan et al., 2019).

Transfusion as a discipline is fortunate to have external incident reporting available, allowing access to the data required and providing trend analysis each year with the SHOT report. The data from SHOT demonstrated there are still ongoing problems with knowledge of ABO blood grouping both in the laboratory and also the clinical area. It has highlighted that scientific staff are still finding aspects of ABO grouping confusing such as post haemopoietic stem cell transplant as there are often reported errors within the SHOT reports (Narayan et al., 2021:21). The root cause of these errors can often be attributed to ineffective training which is highlighted as an issue within the UKTLC reports (Bolton-Maggs et al., 2019). It also showed the risks or mortality and serious morbidity of an ABO-incompatible transfusion, with around third causing major morbidity or mortality (Bolton-Maggs et al., 2016:16). Alongside the data collected from the Southwest, RTC highlighted the requirement for an educational intervention with ABO.

The use of e-learning has been successful in other published studies and has demonstrated improved clinical practice (Graham et al., 2016). These studies are in various areas of healthcare and showed how healthcare has a positive response to e-learning. There are many unpublished studies in the UK currently looking at technology advances which include computer ordering for blood products, including the requirement to provide a reason for transfusion, and ensuring the order is within the correct haemoglobin (Hb) threshold, ensuring evidence-based practice is applied (Staples et al., 2020). Preliminary studies from America have shown this to be effective, especially when post-transfusion discussions help educate the clinicians when orders are not appropriate. This has used different types of education, including face-to-face and e-learning, as a combination to achieve the best outcome, which

could be replicated in the UK. These studies prove the successes of both blended learning and e-learning within the health sector (Bock et al., 2021).

It is essential not to consider e-learning as the sole teaching method as staff often find insufficient time to complete this during the working day, and restrictions in access make this impossible to complete at home when there is available time (Harun, 2001). This was replicated by the service users from the Southwest RTC who would prefer a blended learning approach to ensure time was allocated to staff for CPD. This project was broken into small sections, achievable in 10-20 minutes and can be accessed from any computer with appropriate logins. Whilst this project looked at e-learning in isolation, the training strategy would be to use a more blended approach, including face to face learning at NHSBT. The e-learning could also be used by other organisations to support additional learning with ABO if the package is made available on a platform such as e-learning for health.

The literature highlighted the importance of applied learning and using real patients and cases to learn (Petersen et al., 2008). This technique has been used in medicine for years with the implementation of PBL and the potential to develop this with scientific training revolutionising transfusion education (Pluta et al., 2013). This method is supported by existing platforms such as BTLP TACT® offered by UK NEQAS, which provides evidence for laboratory competence. This project used interactive case studies to enhance learning and offer the user an opportunity to apply knowledge. It was not possible to include the game component, which was the original aim; users had positive feedback for the case studies and felt it helped them retain the knowledge.

Overall, whilst there were development issues with the platform and the packages, the trainees' response was positive. Students engaged with the system and felt it was delivered in a way the scientific workforce appreciates. The data from the project might have been limited but has shown there was an improvement on both perceived and actual knowledge in 7/8 participants although further data collection is required. The final package and results provide an excellent resource to the training department to develop other e-learning platforms for transfusion education.

7.2 Summary of limitations:

This project had many limitations which are summarised below.

- E-learning requires IT support both at the development site and also at the user sites and therefore it is essential there is technical guidance to allow for projects such as this to occur. This project was not overcome by IT glitches however there were times where participants required assistance from NHSBT IT which could have impacted on the engagement with the system.
- LMS software needs to be available for both internal and external candidates for future e-learning projects to be successful. At the time of this project the LMS used was not able to accommodate this therefore an alternative system was used. The alternative system was limited in terms of development time and also licence time both of which had an impact on the project.
- When an e-learning package is developed this results in a file which can be stored by the local IT team and uploaded to the LMS. In this scenario the file is not currently stored on an LMS and is being held on a server and therefore is not functional currently. This is not an issue currently as NHSBT are not using the contents of this package however it had limitations on being able to gather further results from participants after the initial trial.
- The package was developed on Articulate Storyline 3® which is a current package and available for IT staff to use. If this platform were to become unavailable this product would no longer be able to be used by NHSBT and the work would have to be repeated on a new development software.

7.3 Further Work:

The completion of this project has demonstrated the success of this e-learning package within the scientific workforce; however, it has not provided sufficient evidence to completely change the methods used to train our scientists within transfusion. Therefore, there is a requirement for additional work to be completed. This is summarised in the bullet points below.

- Review of the e-learning packages. These should then be updated to take on board the feedback from the trainees who have completed the package.
- Development of a pre-assessment quiz which assigns the user to the most appropriate level of training.
- Evaluate options and include gamification in transfusion learning. Further developing the 'transfusion game'.
- Development of further interactive case studies that can allow students to apply knowledge learnt in the e-learning packages.
- Development of an LMS platform that can host material to be provided for internal and external candidates to NHSBT.
- Undergo an additional trial which includes at least 12 participants from each different group to account for differences such as location in England, agenda for change band and nationality for example. It would be essential to gain participants from each group to allow for differences in learning and understanding of the material. The data collected for the feasibility study was very homogeneous and therefore may not be representative of the wider transfusion community. A study by Bock et al., with dental students showed that the use of small number (n=12) can produce significant results and inform changes in practise (2021).

- An additional study involving international participants would also be advisable. For this data collection again a minimum of 12 participants from each country would be required to determine the significance of the intervention. Dependant on the country there may be amendments required to the package to account for differences in guidelines and testing requirements before an international trial could be initiated.
- Undergo another trial of the product, this time at a single trust to gain additional data not collated as part of this trial. This would include the managers' impression of trainee's progression and knowledge improvement, local error rates pre- and post-implementation of the training. It should also include near-miss data and results of external or internal proficiency exercises where available.
- Develop a national training programme and review external reports from SHOT and SABRE to determine if there is a downward trend in laboratory-based errors.
- Development of other topics and expansion of target staff to include clinical colleagues involved in transfusion.
- Upload the videos created as part of the project to YouTube to allow open access of the material.

As part of my continuing career within NHSBT as a Consultant Clinical Scientist I would also like to embark on further work with educating our scientific workforce. Since completing this project, I have taken part in several e-learning packages including the anti-D modules and internal e-learning projects. I would like to further this work and improve access to all scientists to training material to help improve the safety of transfusion.

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Appendices:

Appendix 1: Copy of Presentation given to the SW Regional Transfusion Committee:

NHS
Blood and Transplant

Why Transfusion Education?

- Want to reduce the number of errors which are on the increase in the SHOT report which can be directly attributed to the transfusion laboratory.

- Highlight and Correct the knowledge deficiencies described in the recent UKTLC report 2017.

- Improve the outcomes for patients by ensuring safe practice within our hospital transfusion laboratories.

NHS
Blood and Transplant

Currently Offered by NHSBT:

There are currently several courses which are available for scientists from the training department. These include:

- Practical Introduction to transfusion science
- Specialist transfusion science practice
- Advanced transfusion master class
- Blood centre tours
- Portfolio workshop

NHS
Blood and Transplant

About Me:

- Currently enrolled on the Consultant Clinical Scientist training within NHSBT.
- Undertaking a Professional Doctorate in Clinical Science.
- Required to complete a research project in a chosen subject in transfusion.
- The area which I have chosen is Transfusion Education.

NHS
Blood and Transplant

Aims:

- To introduce a distance learning platform or something similar which can be purchased from hospitals to provide transfusion knowledge to reduce the number of errors and increase staff knowledge of the subject area.

- Initially in one subject area but developed into other areas required by the hospitals.

NHS
Blood and Transplant

How can you help?

- Complete the online survey or paper based survey to inform me of the types of platform you would be interested in and the level of the knowledge you would like.

- To ascertain if you would be interested in piloting any platform which is developed as a result of this project.

- Provide me with any areas of concern you would like addressed within the remit of transfusion education.

Appendix 2 Survey distributed to the SW Regional Transfusion Committee:

1. Do you feel that current level of Transfusion education / Knowledge of new and existing staff within your laboratory is adequate for service provision?

Yes / No

2. Do you feel you are able to support knowledge training for your staff within your laboratory?

Yes /No

3. Would your laboratory be able to send a member of staff on a weeklong course for face-to-face training at NHSBT to develop Transfusion knowledge?

Yes / No / Maybe

Please provide any comments

4. Would you be able to support members of staff to undertake an E-learning package for Transfusion education?

Yes / No / Maybe

Please provide any comments

5. What subject areas would you like from a Transfusion education package? Please tick all that apply and provide any comments:

ABO

Rh / Antenatal / Genotyping / Donor Services / Clinical Transfusion / Reference Cases / Fetal Maternal Haemorrhage / Serological Techniques / Basic Immunology

Please provide any comments

6. How would you like a training package to be delivered? Please tick all that apply:

Face to Face at NHSBT Centres / E-Learning / Web based platform / App available on IOS and Android / Website / Discussion Forum / Social Media e.g. Team Haem on Twitter / Other - Please comment below

Please provide any comments

7. How long would you like each section to take to complete?

1 Hour / 2-4 Hours / 4 - 8 Hours / 1 Day / Several Days / 1 Week / Other please comment

Please provide any comments

8. Would you as the Transfusion manager require oversight of the progress of your staff within an e-learning package?

Yes / No

9. Would you be willing to pay for the service?

Yes, please specify how much per person / No

10. What level of staff would you be interested in using this service for? Please tick all that

apply (Banding was chosen for this question as various Trusts use different terminology for their scientific staff whereas banding is universally accepted).

Band 4 / Band 5 / Band 6 / Band 7 / Band 8a / BMS staff from other disciplines / Other

If you selected other, please specify:

11. Which levels of training would you be interested in? Please tick all the apply

Beginner / Intermediate / Advanced

12. Would you be prepared to partake in a pilot once the platform has been developed? This would require you to disclose the number of errors and near misses reported locally within a defined period of time. It would also require any members of staff participating in the trial to partake in 3 short knowledge assessments at defined periods to ascertain the success of the platform.

Yes / No

13. Please provide any further comments you have about the project:

14. Details of the person completing the survey to allow for contact if they participate in the trial. To include contact name hospital, contact number and email address.

Appendix 3 Specification for E-learning platform:

1. The designer should ensure that their software is compatible with development of the content in the form of a story board created in Microsoft PowerPoint or Apple Keynote.
2. The product must have the capacity to be able to run videos and allow for both sound and subtitles to be played whilst using this function. There should also be the capacity to rerun fast forward and rewind videos at the user's discretion.
3. It should also be possible for the user to be able to skip a video and continue with the rest of the module.
4. The product must allow the user to be able to select sections of the module to complete without the need to skip material.
5. The product should allow for quizzes or other examination methods to be utilised throughout the package with a variety of answer options to include matching questions to answers, multiple choice, short single word, or number answers as some of the examples.
6. The product must allow for a quiz to be undertaken initially to guide the learner to the most appropriate level of learning which will be based on an algorithm defined by the author.
7. The product must allow for the use of Hot spots (Ability to open another screen with additional information either by placing the mouse over the selected section or by clicking) or selecting information from a picture or diagram.
8. The product must allow for the use of tools to allow interactivity allowing the user to be able to define their own learning pathway within the defined module.

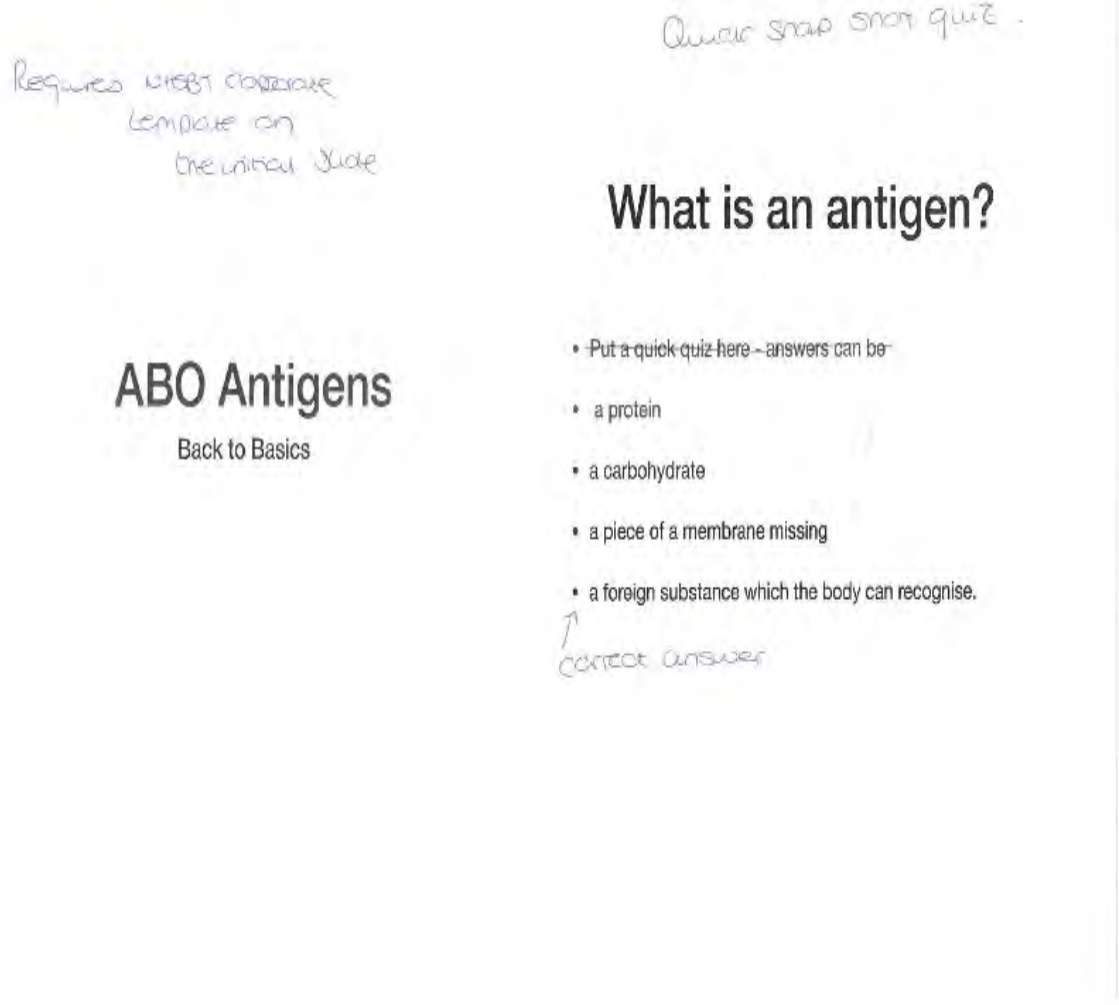
9. The product must have the capacity to allow for games and gamification to be part of the module within the e-learning package.
10. The designer must be able to support the development of games and interactivity in the package.
11. The designer must work with the author to ensure the content is produced in the expected way.
12. The designer must ensure that the package is appropriate proof-read before sending to the author for assessment.
13. The designer must ensure the format of the package is suitable for users and the format and fonts used are legible and easy to read.
14. The product must have the capacity at the end of the module once all the material is passed to have a certificate or recognition of the learning to allow this to be used for continuing professional development – this can be achieved by the LMS or by the package itself. If provided by the LMS this will be assessed in house.
15. It would be desirable if the user were able to print the content for their learning at specific points in the package to allow for continuing learning.
16. The product must allow for the user to be able stop the content halfway through a module and be able to pick up where the user left off at an alternative time.
17. The designer must be able to develop the content into a training package which is user friendly and adaptable should there be any requirement for change.
18. The package should be developed on a platform which other designers have access to, should there be a need for amendments post the design phase.
19. The designer must ensure that all changes can be made within a 1-week turnaround time to ensure there is no disruption to the service.

20. The designer must be able to complete the work before the 1st of March 2018, to allow a week of testing where any errors must be addressed within a working week for the product to go live to the customer.
21. The package must be compatible with Moodle or LMS Extra as the host site but also other learning management systems (LMS) for future developments by the organisation.
22. The designer must be able to provide appropriate IT support for the project to include the development of the package as well as post development during the implementation phase of the package to correct any identified issues with the product.
23. The designer must be able to provide IT support of the transfer of the package onto the LMS. If this is not possible discussions with local IT at NHSBT to determine how to achieve this.
24. It would be desirable if the designer could aid in professional videoing facilities as well as audio recording were defined by the author.
25. It is essential the designer can edit videos and graphics for the project as part of the product design.
26. The designer must ensure the package is functional on Internet Explorer 6 or higher, Safari 4 or higher, Firefox 3 or higher and Google Chrome.
27. The designer must ensure the system is able to operate on Windows XP or higher as well as Mac operating systems
28. The designer must ensure it is compatible with screen resolution 1026 x 768 or above and with an internet connection of 4 Mb or above.
29. It would be desirable if there was the capacity to develop the platform into an App which is downloadable on a defined platform such as IOS or Android. This could be

achieved by the downloading of the LMS onto a device and the package being downloaded onto the device.

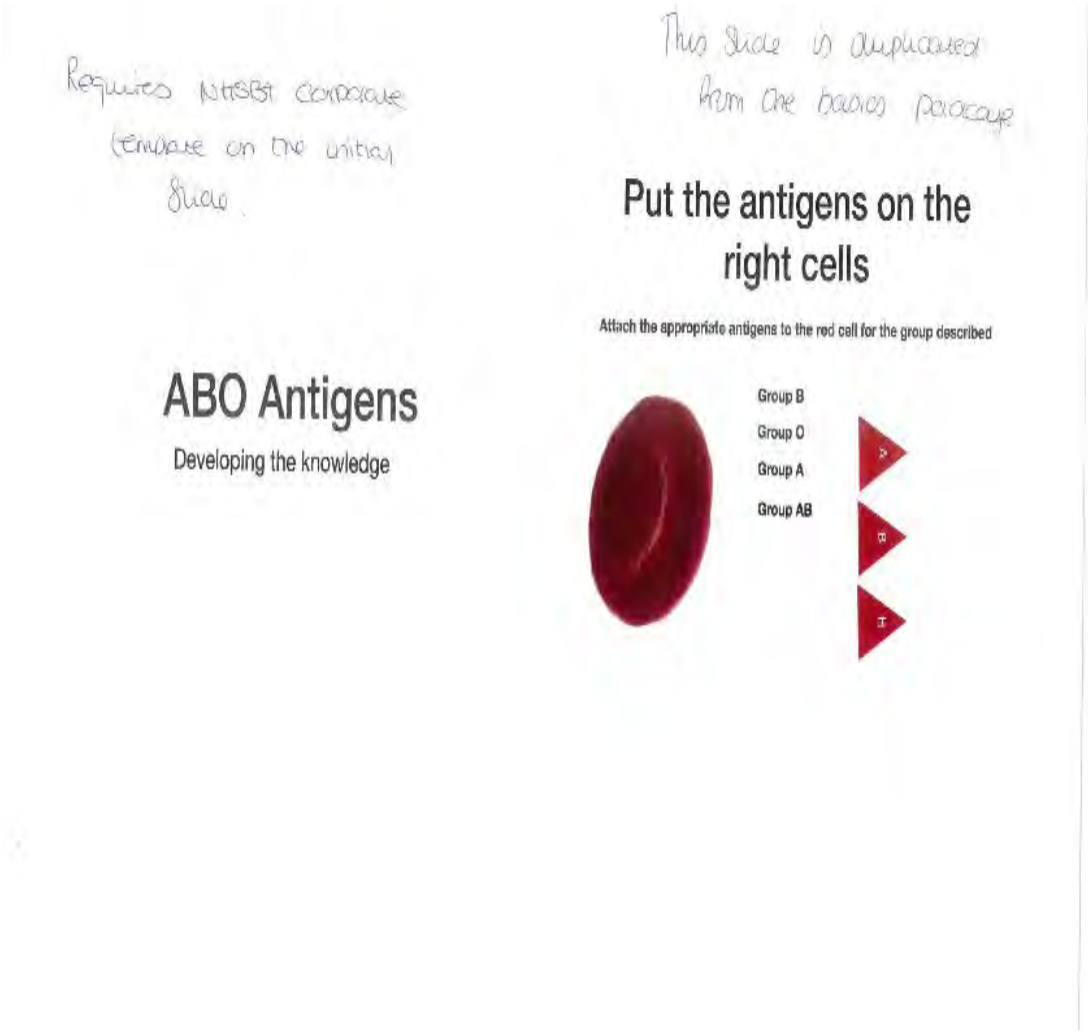
Appendix 4 ABO Basic Package Storyboard:

Click on the PDF to open the storyboard



Appendix 5 ABO Intermediate Package Storyboard:

Click on the PDF to open the storyboard



Appendix 6 ABO Package Assessment Questions:

Click on the PDF to open assessment questions

1. Mothers of infants with ABO HDFN are usually of which blood group?
   1. A
   2. B
   3. AB
   4. O
   5. Equally likely amongst all blood groups

It is usually the anti-A,B in a group O mother which is of IgG in nature crossing the placenta and able to cause destruction of the A/B fetal cells.

2. A 1 month old baby has a sample sent to the transfusion laboratory for ABO group. This was analyses on the analyser and no reverse group was obtained is this normal?
   1. Yes
   2. No
   3. Unknown

Neonatal patients can take up to 4 months to develop their reverse group as these are naturally occurring antibodies.

3. At what age would you expect a neonate to have fully developed their reverse group?
   1. 1 month
   2. 2 months
   3. 3 months
   4. 4 months
   5. At birth

Neonatal patients can take up to 4 months to develop their reverse group as these are naturally occurring antibodies.

Appendix 7: Student Participant Information Sheet:

Dear Participant,

You have agreed to participate in an education improvement tool. This tool has been created as part of a research project looking at improving transfusion education tools designed at two participant levels. I have given you this information for you to read to allow you to understand what your participation in this project would involve and how to raise any questions should you have any. There is also a short consent form which I would need you to complete to collect your data which is only being used to inform the outcome of this project and allow for future developments with e-learning in transfusion.

What is the purpose of the project - This is designed to improve access to transfusion knowledge from areas which have been highlighted nationally as weaknesses. This information has been gathered by looking at the national reports received by SHOT and SABRE and asking LMs where they feel there are deficiencies in knowledge. If you feel you would like to provide feedback on areas which need developing, please feel free to contact me on the above details. It is designed to give all BMS staff equal access to knowledge and provide a national standard.

What does being involved in the project entail? - The decision to participate is yours but will involve a commitment from you if you start. There will be three short knowledge quizzes which will be online which will need completing during the duration of the project and the module which has been developed will need completing. This will take a couple of hours to complete in total and can be accessed from any computer. There will also be option to

participate in a user group meeting to discuss the project and for you to provide feedback on the learning and how you feel this could be improved for further modules. There will be a 3-month period in which you can complete all the work involved and all results from the project will be feed back to you. This is not currently registered to provide you with CPD points however will contribute to continual learning required by the HCPC.

When will the project start? - It is anticipated the project will start in December/January time and be completed by March/April. Once this project is completed there will be no more involvement required from you; however, you may be approached when further modules are developed if you wish to test these out.

What if I do not want to participate? - If you do not want to participate that is fine if you can let me know and then there is nothing further for you to do.

Can I stop participating if I no longer want to be involved? - As with all research projects at any time you want to stop participating this is possible. I would require that you contact me to inform me you no longer want to take part and if possible, a reason behind this decision to allow me to make any changes which have informed this decision.

What do I need to do if I want to participate - All you need to do is complete the attached consent form. Once you are enrolled onto the trial there will be a short knowledge quiz to complete before accessing the e-learning. If you have agreed to be contacted, I may contact you for individual feedback on the platform.

What do I do if I have any further questions? - If you have any further questions, please contact me on the details below and I will happily answer them.

Insert - Contact Details for Sara Wright

Finally, I would like to thank you for taking the time to read this and for your help with this project.

Yours Sincerely,

Sara Wright

Consultant Clinical Scientist Trainee

Appendix 8: Student Consent Form to participate in the trial

Consent Form to participate in Transfusion Education Learning Trial:

Please Complete all the boxes below and sign this form before returning to

Sara Wright.

Email
Phone

Name	
Laboratory	
Job Title / Band	
Contact Telephone Number	
Email Address	

I give consent to participate in the project and accept that by agreeing to this I acknowledge that my results will be reviewed by the researcher and published in a doctorate thesis although these will be anonymised.

Yes / No

I give consent for the researcher to contact me for further discussion regarding the project and accept my comments may be used as part of the data collection for the project although these will be anonymised.

Yes / No

I give consent for my email address and data to be held on a database only to be used for the purposes of this project.

Yes / No

Signed	
Date	

Appendix 9: Baseline Knowledge Assessment Basics Package and Model Answer

Identifiers: hospital, email address and band

Knowledge Grading:

Based on your current level of ABO and D typing knowledge and understanding please rate yourself against the statements below. Using the grading 1 - 10 where 10 is very confident and 1 is lacking any knowledge on the subject area. Please be honest with your responses as these will not be shared with your LMs and will be anonymised for the purposes of the project. An identifier has been used to the three questionnaires you have been asked to complete for project can be linked together to determine the success of the training package.

Thank you once again and I hope you enjoy the learning package.

How confident do you feel with antigen testing for ABO?

1-10

2. How confident do you feel with the antigen testing used for the D status determination of patients?

1-10

3. How confident do you feel about testing for ABO antibodies?

1-10

4. If you were on your own and you get a discrepant forward and reverse group would you be able to perform further testing to establish the cause?

1-10

5. How confident would you feel providing advice on a D status of a lady when the results were suggestive of a weak D?

1-10

6. How well do you understand the genetics and inheritance of ABO and D?

1-10

7. How confident do you feel providing blood for stem cell transplant patients ensuring you provide the appropriate ABO group?

1-10

8. How confident do you feel with the provision of ABO compatible blood when group specific blood is not available?

1-10

9. How confident do you feel with donor ABO and D testing?

1-10

10. On the scale of 1 - 10 how do you feel your knowledge on ABO compares to colleagues in a similar position?

1-10

11. On a scale of 1 -10 how confident do you feel with the subject matter?

1-10

12. Do you feel like there is room for improvement in your knowledge?

Yes / No / Unsure

13. Do you feel there are any gaps in the following areas?

ABO Antigens

ABO Antibodies

ABO Inheritance

ABO Testing

ABO in Patients

D typing in patients.

ABO and D typing in blood donors

14. Do you have any further comments:

Thank you for completing your assessment of your knowledge. There are now 10 practical questions which you need to answer without referring to any other material.

Answers can be found in blue text and the mark scheme found in red text

1. Complete the family tree below:

Answer: Mum O -*OO* (0.16) Dad AB- *AB* (0.16) Baby 1 A- *AO* (0.16) Baby 2 A- *AO* (0.16)

Baby 3 B- *BO* (0.16) Baby 4 B -*BO* (0.16)

2. Name the antigens of the ABO blood group system for each of the blood groups below.

A	A & H (0.25)
B	B & H (0.25)
AB	A, B & H (0.25)
O	H (0.25)

3. Complete the table below:

IgM	IgG
Yes (0.06)	No (0.06)
No (0.06)	Yes (0.06)
Pentad 10 FC Fragments (0.06)	Y shaped 2 FC Fragments (0.06)
10 (0.06)	2 (0.06)

Yes (0.06)	Rarely / No (0.06)
No (0.06)	Yes (0.06)
RTP 4-20°C (0.06)	37°C (0.06)
Yes (0.06)	No (0.06)

4. Patient presents with the results seen below. List the possible causes.

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 cells	B cells	Control
4	0	4	4	0	0	0

Plasma not added to the reagent cells. (0.16)

Neonate with no reverse group yet (0.16)

Immunosuppressed or elderly patient with no reverse group (0.16)

IgG only reverse group (0.16)

Patient who has received large volumes of AB plasma. (0.16)

Patient under regular exchange transfusion with AB plasma or human albumin solution (0.16)

5. During the testing on the forward group what are we testing? What type of reagents do we use?

The forward group is looking at the antigens on the red cell surface. This is tested using monoclonal antibodies for anti- A, anti-B and occasionally anti-A, B. (1)

6. What is the ABO percentage distribution in the UK?

Group	Percentage %
A	39 (0.25)
B	10 (0.25)
AB	3 (0.25)
O	48 (0.25)

7. A patient presents post bone marrow transplant. The patient was a group A and was given a group O donor. The results show that have changed the forward group, but the reverse group is still negative. What group would you give for each of the products below?

Product	Group Suggested
Red Cells	O (0.33)
Plasma	A. AB would also be correct (0.33)
Platelets	A - AB would also be correct (0.33)

8. A patient presents to the Pre-Op clinic and has a routine group and screen performed which shows them to be O negative. The patient shows their consultant a card from the national blood service which states this patient is an O positive blood donor. Can you explain this result?

This is likely to be due to a D variant most commonly D VI where there is a potential these patients can be immunized to the D antigen and form an anti-D. (0.5) Whereas, they have the capability to sensitise a patient to the D antigen (0.5)

9. If a lady of childbearing potential cannot have a defined D group and they require an urgent blood transfusion what blood would you give them?

Women of childbearing potential should be treated as D negative until a confirmed D group can be determined. (0.5) If they require anti-D this should be given and if the need blood, then they should have D negative blood. (0.5)

10. If a patient is group O and requires four units of plasma due to a large bleed and there is no group O plasma available what other group could you give?

Group A was classified as the universal group in the BSH guidelines provided it is HT negative or if available group AB plasma can be used. (1)

Thank you for completing the knowledge aspect of the project. Now when you have time, please complete all sections of the ABO Back to Basics package. Once you have completed all the learning package, please complete the second knowledge quiz straight away. This will be in the same format but will have different questions. After this is completed there will be a 3-month gap and a final assessment will be sent out, after you complete this your participation in the project is complete.

Once again, I would like to thank you for your participation and hope you have enjoyed the project. If you have any further questions or comments, please email me on Add email and I will respond directly to you.

Appendix 10: Post E-learning Knowledge Assessment Basics Package and Model Answer

Identifiers e.g. – hospital, email address and band

Knowledge Grading:

Based on your current level of ABO and D typing knowledge and understanding please rate yourself against the statements below. Using the grading 1 - 10 where 10 is very confident and 1 is lacking any knowledge on the subject area. Please be honest with your responses as these will not be shared with your LMs and will be anonymised for the purposes of the project. An identifier has been used for the three questionnaires you have been asked to complete for project, so the answers can be linked together to determine the success of the training package.

Thank you once again and I hope you enjoy the learning package.

1.How confident do you feel with antigen testing for ABO since completing the package?

1-10

2. How confident do you feel with the antigen testing used for the D status determination of patients since completing the package?

1-10

3. How confident do you feel about testing for ABO antibodies since completing the package?

1-10

4. If you were on your own and you get a discrepant forward and reverse group would you be able to perform further testing to establish the cause since completing the package?

1-10

5. How confident would you feel providing advice on a D status of a lady when the results were suggestive of a weak D since completing the package?

1-10

6. How well do you understand the genetics and inheritance of ABO and D since completing the package?

1-10

7. How confident do you feel providing blood for stem cell transplant patients ensuring you provide the appropriate ABO group since completing the package?

1-10

8. How confident do you feel with the provision of ABO compatible blood when group specific blood is not available since completing the package?

1-10

9. How confident do you feel with donor ABO and D testing since completing the package?

1-10

10. On the scale of 1 - 10 how do you feel your knowledge on ABO compares to colleagues in a similar position since completing the package?

1-10

11. On a scale of 1 -10 how confident do you feel with the subject matter since completing the package?

1-10

12. Do you feel like you have had an improvement in your knowledge since completing the package?

Yes / No / Unsure

13. Do you feel there are still any gaps in the following areas?

ABO Antigens, ABO Antibodies, ABO Inheritance, ABO Testing, ABO in Patients, D Typing in Patients, ABO and D typing in blood donors

14. Do you have any further comments:

Thank you for completing your assessment of your knowledge. There are now 10 practical questions which you need to answer without referring to any other material.

Answers can be found in blue text and the mark scheme found in red text

1.Complete the family tree below.

Answer: Mum A – *AO* (0.12) Dad B – *BO* (0.12)

Male child A – *AO* (0.12) Partner Female O – *OO* (0.12)

Female Child B – *BO* (0.12) Partner Male B – *BO* (0.12)

Baby 1 O – *OO* (0.12) Baby 2 A – *AO* Baby 3 O – *OO* (0.12)

2. Complete the table below:

IgM	IgG
Yes (0.06)	No (0.06)
No (0.06)	Yes (0.06)
Pentad 10 FC Fragments (0.06)	Y shaped 2 FC Fragments (0.06)
10 (0.06)	2(0.06)
Yes (0.06)	Rarely / No (0.06)
No (0.06)	Yes (0.06)
RTP 4-20°C (0.06)	37°C (0.06)
Yes (0.06)	No (0.06)

3.Patient presents with the results seen below. List the possible causes.

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 cells	B cells	Control
4 mix field	0	4 mix field	4 mix field	0	4	0

Variant of group A with a Variant D (0.25)

Recent transfusion of O Neg blood (0.25)

Recent transfusion of group O blood (0.25)

Recent transfusion of D negative blood (0.25)

4. During the testing on the reverse group what are we testing? What type of reagents do we use?

The reverse group is looking at the patient's antibodies which are tested against reagent red cells with a defined expression of the ABO antigens on the surface. (1)

5. Is the ABO distribution in the world the same, can you give some examples of where this varies?

There is variation in the ABO distribution in the world. This varies from country to country - Answers for this question will be check on the internet as it is not possible to list all the distributions. Answers within 10% of state values will be accepted as there is variation in reported distributions. (1)

6. A patient presents post bone marrow transplant. The patient was a group O and was given a group A donor. The results show that have changed the forward group, but the reverse group is still negative. What group would you give for each of the products below?

Product	Group Suggested
Red Cells	O (0.33)
Plasma	A (0.33)
Platelets	A (0.33)

7. Please explain the difference in the testing regimes for new and returning blood donors.

New donors have their ABO group tested twice on two different platforms (0.25)– one full group and one short group (0.25). The D reagents are also tested with two monoclonals (0.25)

Returning donors have their ABO group tested once – short group and only use one D reagent. (0.25)

8. Describe the difference between phenotype and genotype.

Phenotype is the expression of the antigens on the red cell whereas genotype is the genes the individual has however does not mean the red cells will express them. (1)

9. Provide a list of places in the body ABO antigens can be found.

Blood cells – RBC, WBC, Platelets (0.33)

Organs (0.33)

Body Fluid – saliva, tears urine etc (0.33)

10. If a patient is group B and requires four units of plasma due to a large bleed and there is no group AB plasma available what other group could you give?

B plasma first choice (0.5)

A if there is no B or AB as this is universal provided it is HT negative (0.5)

Thank you for completing the post knowledge check aspect of the project. After this is completed there will be a 3-month gap and a final assessment will be sent out, after you complete this your participation in the project is complete.

Once again, I would like to thank you for your participation and hope you have enjoyed the project. If you have any further questions or comments, please email me on Add email and I will respond directly to you.

Appendix 11: Three-month follow-up Knowledge Assessment Basics Package and Model Answer

Identifiers e.g. – hospital, email address and band

Knowledge Grading:

Based on your current level of ABO and D typing knowledge and understanding please rate yourself against the statements below. Using the grading 1 - 10 where 10 is very confident and 1 is lacking any knowledge on the subject area. Please be honest with your responses as these will not be shared with your LMs and will be anonymised for the purposes of the project. An identifier has been used to the three questionnaires you have been asked to complete for project can be linked together to determine the success of the training package.

Thank you once again and I hope you enjoy the learning package.

1.How confident do you feel with antigen testing for ABO since completing the package?

1-10

2. How confident do you feel with the antigen testing used for the D status determination of patients since completing the package?

1-10

3. How confident do you feel about testing for ABO antibodies since completing the package?

1-10

4. If you were on your own and you get a discrepant forward and reverse group would you be able to perform further testing to establish the cause since completing the package?

1-10

5. How confident would you feel providing advice on a D status of a lady when the results were suggestive of a weak D since completing the package?

1-10

6. How well do you understand the genetics and inheritance of ABO and D since completing the package?

1-10

7. How confident do you feel providing blood for stem cell transplant patients ensuring you provide the appropriate ABO group since completing the package?

1-10

8. How confident do you feel with the provision of ABO compatible blood when group specific blood is not available since completing the package?

1-10

9. How confident do you feel with donor ABO and D testing since completing the package?

1-10

10. On the scale of 1 - 10 how do you feel your knowledge on ABO compares to colleagues in a similar position since completing the package?

1-10

11. On a scale of 1 -10 how confident do you feel with the subject matter since completing the package?

1-10

12. Do you feel like you have had an improvement in your knowledge since completing the package?

Yes / No / Unsure

13. Do you feel your knowledge has remained and changed your practice since the completion of the package?

Yes / No / Unsure

14. Do you feel there are still any gaps in the following areas?

ABO Antigens, ABO Antibodies, ABO Inheritance, ABO Testing, ABO in Patients, D Typing in Patients, ABO and D typing in blood donors

15. Do you have any further comments:

16. Please can you provide feedback on the e-learning package. What areas do you think were well developed and helped you with your learning and which areas do you think need improving? Was the package too long or do you think it was the right length? Did it take too long to complete, or do you think that because it was broken into small sections it was

manageable? Did the format suit completing whilst working in the laboratory? How do you feel this replaced face to face learning?

Thank you for completing your assessment of your knowledge. There are now 10 practical questions which you need to answer without referring to any other material.

Answers can be found in blue text and the mark scheme found in red text

1.If mum is genotyping as *AB* and dad is genotyping as *BO* can you provide the likely genotypes for any future child and the percentage probability of this occurring:

AO 25% (0.25)

BO 25% (0.25)

AB 25% (0.25)

BB 25% (0.25)

2. Can you describe the difference between IgG and IgM:

IgG has 2 FC fragments which can bind antigens (0.125) – it requires two molecules to activate complement and has a normal reactive temperature of 37°c. (0.125) There are four sub-classes of IgG. (0.125) IgG antibodies can cross the placenta. (0.125)

IgM has 10 FC fragments which can bind antigens (0.125) – it can activate complement (0.125) and has a normal reactive temperature of 4-20°c. (0.125) Due to the lack of receptors IgM antibodies cannot cross the placenta. (0.125)

3. Patient presents with the results seen below. List the possible causes.

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 cells	B cells	Control
0	0	4 mix field	4 mix field	4	4	0

Patient has had a transfusion of D negative red cells (0.2)

Large FMH D positive mum with D negative fetus (0.2)

D variant (0.2)

Chimera (0.2)

Antigen loss due to disease (0.2)

4. Describe the differences between the reverse group and the forward group to include the reagents and testing used:

The reverse group is looking at the patient's antibodies which are tested against reagent red cells with a defined expression of the ABO antigens on the surface. (0.25) This is an antibody test so can be done at room temperature, at 4°c or 37°c to enhance or remove non-specific reactions if needed (0.25). This can be performed in card, tube, or micro titre plate.

The forward group is looking at the antigens on the red cell surface. This is tested using monoclonal antibodies for anti- A, anti-B and occasionally anti-A, B. (0.25) This is done by direct agglutination and therefore can be done in card, micro titre plate or tube. If there are

non-specific reactions the cells may need washing or incubating at 37°c if there is the presence of a really strong cold agglutinin. (0.25)

5. Describe what is meant by a universal red cell donor and a universal plasma donor:

Universal red cell donor is someone who can be used for most patients without a confirmed blood group and should not cause a transfusion reaction. (0.25) This is group O as there are no ABO antigens present on the red cell surface. (0.25)

A universal plasma donor would be group AB as there are no ABO antibodies present. (0.25) Due to the low numbers of donors this is not possible and therefore group A HT negative is used as the universal plasma. (0.25)

6. A patient presents post bone marrow transplant. The patient was a group B and was given a group O donor. The results show that have changed the forward group, but the reverse group is still negative. What group would you give for each of the products below?

Product	Group Suggested
Red Cells	O (0.33)
Plasma	B (0.33)
Platelets	B (0.33)

7. Describe the differences between the reagents used to test blood donors compared to hospital blood banks.

Reagents used in hospitals and blood bank are the same for the ABO – except the ability to detect Ax in the anti-A. (0.25) Anti-A used in NHSBT must be able to detect Ax individuals as group A whereas in a hospital if they are classified as group O no patient harm will occur. (0.25)

The D reagents used are different – in a hospital they are designed to detect D VI as D negative as they should be treated as D negative as a patient. (0.25) Whereas, in NHSBT the reagents should detect these individuals as D positive to prevent sensitisation of D negative patients who receive this blood. (0.25)

8. Provide definitions for the following:

Dominant	Will express over the other gene (0.33)
Recessive	Will only express if there are two copies of the gene (0.33)
Co-dominant	Will express equally (0.33)

9. Briefly describe the process of antibody production in a human.

A foreign antigen is recognised by the hosts immune system (0.33). It leads to a primary immune response of IgM antibodies (0.33). These lead to the production of memory cells which when the antigen is presented on a second occasion will result in a faster immune response (0.33).

10. If a patient is group B and requires one unit of platelets due to a large bleed and there are no group B platelets available what other group could you give?

Group A or O in pools provided HT negative would be ok (0.33). If not AB (0.33) or A HT negative apheresis platelet would be universal. (0.33)

Thank you for completing the 3 month follow up knowledge check aspect of the project. You have now completed the project.

Once again, I would like to thank you for your participation and hope you have enjoyed the project. If you have any further questions or comments, please email me on Add email and I will respond directly to you.

Appendix 12: Baseline Knowledge Assessment Intermediate Package and Model Answer

Identifiers e.g. – hospital, email address and band

Knowledge Grading:

Based on your current level of ABO and D typing knowledge and understanding please rate yourself against the statements below. Using the grading 1 - 10 where 10 is very confident and 1 is lacking any knowledge on the subject area. Please be honest with your responses as these will not be shared with your LMs and will be anonymised for the purposes of the project. An identifier has been used to the three questionnaires you have been asked to complete for project can be linked together to determine the success of the training package.

Thank you once again and I hope you enjoy the learning package.

1. How confident do you feel about ABO Subgroups?

1-10

2. How confident would you feel with patients presenting with additional or missing ABO antigens and how to deal with these results?

1-10

3. How confident would you feel in dealing with a patient with unexpected ABO antibodies on your own?

1-10

4. How confident do you feel regarding the genetics and inheritance of ABO subgroups?

1-10

5. How confident do you feel regarding the different ABO testing methodologies?

1-10

6. How confident do you feel regarding molecular testing of ABO and D in patients?

1-10

7. How confident do you feel regarding the ABO subgroups distribution in the UK?

1-10

8. How confident do you feel with dealing with stem cell transplant patients?

1-10

9. How confident do you feel providing blood for patients with complicated ABO groups?

1-10

10. Do you feel confident dealing with patients with a variety of D variants invidious clinical scenarios?

1-10

11. On the scale of 1 - 10 how do you feel your knowledge on ABO compares to colleagues in a similar position?

1-10

12. On a scale of 1 -10 how confident do you feel with the subject matter?

1-10

13. Do you feel like there is room for improvement in your knowledge?

Yes / No / Unsure

14. Do you feel ether are any gaps int he following areas?

ABO Antigens
ABO Antibodies
ABO Inheritance
ABO Testing
ABO in Patients
D typing in patients.
ABO and D typing in blood donors

15. Do you have any further comments:

Thank you for completing your assessment of your knowledge. There are now 10 practical questions which you need to answer without referring to any other material.

Answers can be found in blue text and the mark scheme found in red text

1. Please complete the family tree with the probable genotypes.

Answers Mum A1 *A1O* (0.125). *Dad* A2 *A2O* (0.125)

Son O *OO* (0.125) Partner of Son O *OO* (0.125)

Daughter A1 *A1O* (0.125) Partner of Daughter B *BO* (0.125)

Baby 1 & 2 O *OO (*0.125) Baby 3 A1 *A1O* (0.125)

2. What happens when the H antigen is not present in a patient?

The H antigen is required as a precursor to allow for expression of the ABO antigens (0.25)– if there is no expression of H (0.25) there can be no expression of the A/B antigen (0.25) which would result in the Bombay phenotype (0.25).

3. A patient preset with these results what are the possible causes?

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 cells	B cells	O Cells
2 mf	0	4	4	1	4	0

A Variant with an anti-A1 present (0.25)

Cold reacting antibody (0.25)

Transfusion of group O cells (0.25)

Antigen loss (0.25)

4. A patient presents with these results with the clinical details of myeloma what could be the possible cause and how could this be overcome?

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 cells	B cells	O Cells
4	0	0	0	4	4	4

This would potentially be due to interactions with monoclonal therapies used to treat myeloma (0.33) particularly anti-CD38 (0.33). This could be overcome using DDT treated red cells (0.33).

5. a) If you suspect a patient was the subgroup A2 how would you test for this?

You would type the patient with anti-A1 which would be negative (0.33). You would then put the patient's plasma up with both A1 and A2 cells (0.33). to determine if there was the presence of a naturally occurring anti-A1(0.33).

5. b) If blood is required what would you provide?

Patients who are A2 can receive group A blood (0.5) however if the group was unclear, it would be best to provide group O until this was clarified. (0.5)

6. What actions should you consider if a D negative woman of childbearing potential is given 2 units of D positive blood by mistake?

This would be above the limit of just being able to give anti-D to prevent sensitization and therefore double or single blood volume exchange transfusion should be considered (0.33). This would need to be followed up to give anti-D to remove any residual cells (0.33) and this can be done by using the fetal maternal hemorrhage test by flow (0.33).

7. A patient presents post BMT. They were given a bidirectional ABO transplant. The patient was group A but was given a group B donor what blood products should you provide?

Product	Group Suggested
Red Cells	O (0.33).
Plasma	AB (0.33).
Platelets	AB (0.33).

8. List the different methods for D typing and give a reason when this may be useful?

Phenotyping using polyclonal reagents or monoclonal reagents (0.25)– easy to perform and can ultilise solid phase technology and can be performed by all blood transfusion laboratories (0.25).

Genotyping / Sequencing (0.25)– Allows for the detection of variants of any issues with the gene. Can only be performed in specialised settings (0.25).

9. A male patient 46 presents after a road traffic collision. These are his results. He has been given two units of emergency blood. If he needed further blood provision, what would you provide him and why presuming he has had two samples taken which show the same results.

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 cells	B cells	O Cells
4mf	0	2	1	0	4	0

This looks like this is a group A patient with a Weak/variant D (0.25). As the ABO group cannot be determined clearly group O should be used unless local policy states otherwise (0.25). Whilst the D group is investigated, they could provide D positive blood to conserve D negative (0.25) – unless policy states the use of D neg is required (0.25).

10. What is the difference between the phenotype and the predicted genotype?

Phenotype is the expression of the antigens on the red cell whereas (0.33) genotype is the genes the individual has (0.33) however does not mean the red cells will express them (0.33).

Thank you for completing the knowledge aspect of the project. Now when you have time, please complete all sections of the ABO Developing the Knowledge package. Once you have completed all the learning package, please complete the second knowledge quiz straight away. This will be in the same format but will have different question. After this is completed there will be a 3-month gap and a final assessment will be sent out, after you complete this your participation in the project is complete.

Once again, I would like to thank you for your participation and hope you have enjoyed the project. If you have any further questions or comments, please email me on Add Email and I will respond directly to you.

Appendix 13: Post E-learning Knowledge Assessment Intermediate Package and Model Answer

Identifiers e.g. – hospital, email address and band

Knowledge Grading:

Based on your current level of ABO and D typing knowledge and understanding please rate yourself against the statements below. Using the grading 1 - 10 where 10 is very confident and 1 is lacking any knowledge on the subject area. Please be honest with your responses as these will not be shared with your LMs and will be anonymised for the purposes of the project. An identifier has been used to the three questionnaires you have been asked to complete for project can be linked together to determine the success of the training package.

Thank you once again and I hope you enjoy the learning package.

1.How confident do you feel about ABO Subgroups after completing the package?

1-10

2. How confident would you feel with patients presenting with additional or missing ABO antigens and how to deal with these results after completing the package?

1-10

3. How confident would you feel in dealing with a patient with unexpected ABO antibodies on your own after completing the package?

1-10

4. How confident do you feel regarding the genetics and inheritance of ABO subgroups after completing the package?

1-10

5. How confident do you feel regarding the different ABO testing methodologies after completing the package?

1-10

6. How confident do you feel regarding molecular testing of ABO and D in patients after completing the package?

1-10

7. How confident do you feel regarding the ABO subgroups distribution in the UK after completing the package?

1-10

8. How confident do you feel with dealing with stem cell transplant patients after completing the package?

1-10

9. How confident do you feel providing blood for patients with complicated ABO groups after completing the package?

1-10

10. Do you feel confident dealing with patients with a variety of D variants in various clinical scenarios after completing the package?

1-10

11. On the scale of 1 - 10 how do you feel your knowledge on ABO compares to colleagues in a similar position after completing the package?

1-10

12. On a scale of 1 -10 how confident do you feel with the subject matter after completing the package?

1-10

13. Do you feel like there is still room for improvement in your knowledge after completing the package?

Yes / No / Unsure

14. Do you feel there are still any gaps in the following areas after completing the package?

ABO Antigens
ABO Antibodies
ABO Inheritance
ABO Testing
ABO in Patients
D typing in patients.
ABO and D typing in blood donors

15. Do you have any further comments:

Thank you for completing your assessment of your knowledge. There are now 10 practical questions which you need to answer without referring to any other material.

Answers can be found in blue text and the mark scheme found in red text

1. Please complete the family tree with the probable genotypes.

Answer: Mum A2 *A2O* (0.125) Dad O *OO* (0.125)

Son A2 *A2O* (0.125) Sons partner O *OO* (0.125)

Daughter O *OO* (0.125) Daughters partner A2B (0.125)

Baby 1 O *OO* (0.125) *Baby* 2 A2 *A2O* Baby 3 B *BO* (0.125)

2. Please provide five reasons why the ABO antigens may not be present in a patient?

- Premature / Neonate (0.166)
- Antigen loss because of disease (0.166)
- Transfusion (0.166)
- Not adding appropriate reagent (0.166)
- Elderly (0.166)
- Post red cell exchange with group compatible (0.166)

3.A patient presents with these results what are the possible causes?

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 Cells	B Cells	O Cells
4	0	2	0	0	4	0

This would likely be a D variant which would need further investigation using different anti sera or confirmation using molecular techniques. (1)

4.A patient presents with these results what could be the possible cause and how could this be overcome?

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 Cells	B Cells	O Cells
4 mix Field	0	0	0	0	0	0

- Subgroup of A with no reverse group (0.33)
- A neonate with no reverse group who has had an intra uterine transfusion or a top-up or exchange. (0.33)
- An immunocompromised or elderly person who has received group O blood with no reverse group. (0.33)

5.a) If you suspect a patient was the subgroup what testing could be performed

Test with a variety of anti-sera to look at the reaction pattern as well as testing with different reagent cells to determine if a reverse group could be obtained (0.5). You could also perform A1 typing (0.5).

5. b) The patient is group Ax. If blood is required, what would you provide?

Group O would be the safest blood group to provide to these patients. (1)

6. What actions should you consider if a D negative woman is given two units of D positive blood by mistake? Is there any other information you would require?

This would be above the limit of just being able to give anti-D to prevent sensitization and therefore double or single blood volume exchange transfusion should be considered (0.33). This would need to be followed up to give anti-D to remove any residual cells (0.33) and this can be done by using the fetal maternal hemorrhage test by flow (0.33).

7. A patient presents post BMT. They were given a bidirectional ABO transplant. The patient was group B but was given a group A donor what blood products should you provide?

Product	Group Suggested
Red Cells	O (0.33)
Plasma	AB (0.33)
Platelets	AB (0.33)

8.Describe the issues which can be faced when a female patient is described as a D variant?

These women require D negative blood to prevent sensitisation to the D antigen which has been reported (0.33). They also require anti-D immunoglobulin during pregnancy which may

get missed due their D variant status (0.33). It can become challenging if they need flow to determine a fetal bleed as this uses the D antigen as a discriminator (0.33).

9. A female patient 46 presents after a road traffic collision. These are her results. If she needed further blood provision, what would you provide her and why presuming he has had two samples taken which show the same results.

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 Cells	B Cells	O Cells
4mf	0	2	1	0	4	0

This looks like this is a group A patient with a Weak/variant D (0.33). As the ABO group cannot be determined clearly group O should be used unless local policy states otherwise (0.33). Whilst the D group is investigated, they should provide D negative blood as this is a woman of childbearing potential (0.33),

10. Describe the reasons molecular methods are not used in ABO testing?

Molecular methods are not used for ABO as there are lots of polymorphisms which result in expressions of the ABO antigens (0.33). Therefore, genotyping can be extremely difficult to interpret (0.33) and is not performed in England for use in clinical management of a patient (0.33).

Thank you for completing the post knowledge check aspect of the project. After this is completed, there will be a 3-month gap and a final assessment will be sent out, after you complete this your participation in the project is complete.

Once again, I would like to thank you for your participation and hope you have enjoyed the project. If you have any further questions or comments, please email me on Add Email and I will respond directly to you.

Appendix 14: Three-month follow-up Knowledge Assessment Intermediate Package and Model Answer

Identifiers e.g. – hospital, email address and band

Knowledge Grading:

Based on your current level of ABO and D typing knowledge and understanding please rate yourself against the statements below. Using the grading 1 - 10 where 10 is very confident and 1 is lacking any knowledge on the subject area. Please be honest with your responses as these will not be shared with your LMs and will be anonymised for the purposes of the project. An identifier has been used to the three questionnaires you have been asked to complete for project can be linked together to determine the success of the training package.

Thank you once again and I hope you enjoy the learning package.

1.How confident do you feel about ABO Subgroups after completing the package?

1-10

2. How confident would you feel with patients presenting with additional or missing ABO antigens and how to deal with these results after completing the package?

1-10

3. How confident would you feel in dealing with a patient with unexpected ABO antibodies on your own after completing the package?

1-10

4. How confident do you feel regarding the genetics and inheritance of ABO subgroups after completing the package?

1-10

5. How confident do you feel regarding the different ABO testing methodologies after completing the package?

1-10

6. How confident do you feel regarding molecular testing of ABO and D in patients after completing the package?

1-10

7. How confident do you feel regarding the ABO subgroups distribution in the UK after completing the package?

1-10

8. How confident do you feel with dealing with stem cell transplant patients after completing the package?

1-10

9. How confident do you feel providing blood for patients with complicated ABO groups after completing the package?

1-10

10. Do you feel confident dealing with patients with a variety of D variants in various clinical scenarios after completing the package?

1-10

11. On the scale of 1 - 10 how do you feel your knowledge on ABO compares to colleagues in a similar position after completing the package?

1-10

12. On a scale of 1 -10 how confident do you feel with the subject matter after completing the package?

1-10

13. Do you feel like there is still room for improvement in your knowledge after completing the package?

Yes / No / Unsure

14. Do you feel your knowledge has remained and changed your practice since the completion of the package?

Yes / No / Unsure

15. Do you feel there are still any gaps in the following areas after completing the package?

ABO Antigens
ABO Antibodies
ABO Inheritance

ABO Testing
ABO in Patients
D typing in patients.
ABO and D typing in blood donors

16. Do you have any further comments:

17. Please can you provide feedback on the e-learning package. What areas do you think were well developed and helped you with your learning and which areas do you think need improving? Was the package too long or do you think it was the right length? Did it take too long to complete, or do you think that because it was broken into small sections it was manageable? Did the format suit completing whilst working in the laboratory? How do you feel this replaced face to face learning?

Thank you for completing your assessment of your knowledge. There are now 10 practical questions which you need to answer without referring to any other material.

Answers can be found in blue text and the mark scheme found in red text

1.If mum is genotyping as *A2B* and dad is genotyping as *A1O* can you provide the likely genotypes for any future children and the percentage probability of this occurring:

A2A1 (0.25)

A2O (0.25)

BA1 (0.25)

BO (0.25)

There is a 25% chance of any of these genotypes

2. Please provide five reasons why the ABO antigens may not be present in a patient?

- Premature / Neonate (0.2)
- Antigen loss because of disease (0.2)
- Transfusion (0.2)
- Not adding appropriate reagent (0.2)
- Elderly (0.2)
- Post red cell exchange with group compatible (0.2)

0.2 for each correct answer up to the value of 1

3. A patient presents with these results what are the possible causes?

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 cells	B cells	O Cells
4	4	4	4	4	4	4

- Cold reacting antibody (0.33)
- Pan reactive auto antibody (0.33)
- Patient on a monoclonal therapy effecting result (0.33)

4. A patient presents with these results what could be the possible cause and how could this be overcome?

Anti-A	Anti-B	Anti-D1	Anti-D2	A1 cells	B cells	O Cells
4	0	0	0	4	4	4

- Cold reacting antibody which may be removed by performing the test at 37°c. (0.25)
- Patient on DARA and the use of DTT treated cells (0.25)
- Combination of cold reacting antibody and a strong anti-A1. (0.25)
- Patient with the Bombay phenotype with a naturally occurring anti-H (0.25)

5. a) If you suspect a patient was Bombay phenotype what testing could be performed to confirm this?

- ABO group forward and reverse (0.33)
- H typing of the red cells (0.33)
- Antibody panel with Bombay neg cell included (0.33)

5. b) If blood is required, what would you provide?

Bombay blood would need to be provided to these patients as any other group may lead to an immediate acute transfusion reaction. (1)

6. Provide the blood in terms of D type which should be given with the following scenarios:

Patient type	Blood provision
D II	D positive (0.14)
D VI	D Negative (0.14)
Male DVI patient urgently	Negative if possible but can use D positive (0.14)
Unknown female 36	D Negative (0.14)

Unknown female 76	If urgent D positive if routine D specific (0.14)
D IV	D Negative (0.14)
DAR	D Negative (0.14)

7. A patient presents post BMT. The patient was group AB but was given a group O donor what blood products should you provide?

Product	Group Suggested
Red Cells	O (0.33)
Plasma	AB (0.33)
Platelets	AB (0.33)

8. Describe the three different molecular techniques used to determine the D status of a patient.

- Fixed Assay PCR (0.33)
- Multiplex Assay (0.33)
- Single Allelic Discrimination (0.33)

9. A female patient presents to A&E and the only clinical details you get is trauma. They require urgent red cells, plasma and platelets and cannot wait for the samples to be processed what groups would you provide for each product and why?

Red Cell O D negative (0.33)

FFP A HT negative (0.33)

Platelets A D negative – If not possible A positive with anti-D immunoglobulin cover if required (0.33)

10. Provide a list of Pros and Cons for molecular testing for ABO?

Pros	Cons
Can be automated (0.2)	Expensive (0.2)
Can be performed using a kit (0.2)	Lengthy process (0.2)
Zygosity can be established without extensive family studies (0.2)	Specialised equipment and laboratory space required (0.2)
Not affected by previous transfusion (0.2)	Genotype does not always reflect phenotype in ABO (0.2)
Can allow for detection of variants in the blood group (0.2)	Genotype can be complex in ABO due to all the polymorphisms (0.2)
Can be used in patients where there are complications using traditional serological methods (0.2)	Could result in questions regarding paternity (0.2)

Up to a maximum of one point

Thank you for completing the 3 month follow up knowledge check aspect of the project. You have now completed the project.

Once again, I would like to thank you for your participation and hope you have enjoyed the project. If you have any further questions or comments, please email me on Add email and I will respond directly to you.

Appendix 15: Thank you letter for students who completed the e-learning package

Dear Participant,

Thank you for your participation in an education improvement tool project for ABO blood group system. I hope you enjoyed using the tool and it provided you with some new knowledge on ABO and D and also allowed you to apply your knowledge both academically as well as in practice in the laboratory.

I would really appreciate any feedback you have of the product, or the content and you will be invited to participate in a focus group but if you are unable to provide feedback for that please feel free to contact me using the details provided above.

Finally, this project was not registered for CPD points however this letter provides assurance that you completed the ABO and D training package as part of a doctorate project. This entailed a structured learning programme with frequent assessments. This can be used as part of your continuing professional development, and I would encourage you to reflect on this for your own records.

Once again thank you for your participation and I hope you enjoyed it.

Yours Sincerely,

Sara Wright

Consultant Clinical Scientist Trainee

Appendix 16 Ethics Approval Letter from NHSBT R&D Office:

NHS
Blood and Transplant

Dr Nicholas Watkins
Assistant Director – R&D
NHS Blood & Transplant

Mrs Sara Wright
Filton Blood Centre

4th December 2017

Dear Sara,

NHSBT ID: PhD-17-12
Title: Improvements in transfusion science education for scientists
Dates: October 2017-October 2019

Following review of the above named project, I can confirm your project proposal is approved by the NHSBT R&D Office. Your project will develop a training package which can be implemented to support transfusion knowledge for scientists working within the hospitals using new ways of learning to engage users.

The Organisation and Workforce Development team have reviewed your application and has no additional comments on your proposed work. You therefore have operational support to proceed with your project.

This approval is granted on the basis that you do not require ethical approval as it has been determined as being purely service evaluation. The project must follow the agreed protocol and be conducted in accordance with all NHSBT policies and procedures, especially those relating to research and data management.

As a condition of your approval, please ensure that the R&D Office is sent a copy of the report for this project once it is complete. If you have any questions relating to this approval please contact the NHSBT R&D Office (research.office@nhsbt.nhs.uk) quoting the Reference Number: PhD-17-12.

Yours sincerely

N. Wk

Dr Nick Watkins
Assistant Director – Research & Development

Cc: Ruth Evans (NHSBT Supervisor)

Appendix 17 Storyboard for Video Component of E-learning Package:

IMG 5580:

This is a card ABO video. This is currently using two videos. The steps are highlighted below which would require either audio or subtitles to be added to the video. This would also need speeding up would like this to be no more than 1 minute if possible.

Initially the reverse cells are added to the appropriate well in the card and the patient's plasma is added to the top. This should be in a 1:1 ratio and are incubated at room temperature for ten minutes.

The forward group which is utilising the patient or donor red cells in a defined suspension in the media recommend by the manufacture. This does not require an incubation or addition of other reagents as there are monoclonal antibodies present in the gel matrix.

The card is then spun in a centrifuge - there is currently no video footage of this.

IMG5584 shows the final card which can be read. The positive results will be seen as a band of red cells in a well and a negative result will be seen as a button of cells at the bottom of the well in the card.

The results seen in this case shows positive reactions with anti-A and B cells and negative reactions with anti-B, anti-D reagent, the control well and the A1 cells.

IMG5581

This is a tile blood group video. The steps are highlighted below which would require either audio or sub-tittles to be added to the video. This would also need speeding up would like this to be no more than 1 minute if possible. This is not a routine method used within a laboratory but provides a very good visualisation of how the process works within the accepted techniques.

The tile is split into four sections therefore allow you to test the forward group and the reverse group. The methodology for testing the D would be the same as the forward group.

The reagents for the tile group are added at a one-to-one ratio.

The monoclonal anti-A and anti-B are added to the appropriate areas of the tile.

The plasma was added to the appropriate area of the tile.

Red cell suspension from the patient is added to the antisera.

A1 and B cells are added to the plasma wells.

Mix the tile with gentle agitation in a swirling action.

Observe direct agglutination which is where the antibody and the antigen interact directly with each other and do not require any additional reagents to allow agglutination to be visualised.

Negative results are seen as fluid cells and positive reactions are seen as red cell clumps or agglutinates.

The results seen in this case shows positive reactions with anti-A and B cells and negative reactions with anti-B and A1 cells.

IMG 5583

Tube grouping video. The steps are highlighted below which would require either audio or sub-tittles to be added to the video. This would also need speeding up would like this to be no more than 1 minute if possible.

Patient plasma is added to the last three tubes - A1cells are added to the A1 tube, B cells are added to the B tube and O cells are added to the O tube. This is performed first as this requires a 10-minute incubation at room temperature.

The forward group is performed next with the appropriate antisera being added to the correct tube. Once all the antisera are added equal volumes of patient red cells are added to each tube.

The tubes are gently mixed.

The tubes are centrifuged.

The tubes are removed from the centrifuge.

The tubes are read using a tip and roll technique. A positive result is where there is agglutination which is often seen as a single lump of cells in the tube whereas a negative result is seen as free flowing cells.

The results seen in this case shows positive reactions with anti-A, anti-A, B and B cells and negative reactions with anti-B, both anti-D reagents, the A1 cells and the O cells.

A note needs to be added to each video regarding how each technique should be controlled on each occasion to ensure its validity.

There may be additional videos which are required but these do not have story boards available but there are directions in the PowerPoint.