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Medical Imaging Interpretation Courseware

Course Management and Interactive Medical
Imaging Applications

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Abstract

An important field within medical technology is medical imaging. Medical imaging is the process of creating visual representations of internal structures. These visual representations can be used to set a diagnosis, to decide upon a treatment, or as a tool during surgery. Medical imaging is widely used, and it is thus important that those use such images has adequately knowledge and skills for using and interpreting them.

The use and interpretation of various medical imaging modalities is often a part of different courses held at hospitals and educational institutes. To help assist those courses, a course and test administration system was developed as a web application, named *Medical Imaging Interpretation Courseware*.

The application contains features for course, user and test administration. Users can be organized into groups, and be added to a course, either through the group or as single users. A course can consist of different tests. The tests can contain various test types, including text questions and questions that interactively use medical images.

The application was tested by an appropriate audience and the results show a promising indication that the application can train and assess medical imaging interpretation skills in a visual and interactive manner.

Sammendrag

Innenfor medisinsk teknologi er medisinsk bildebehandling et viktig felt. Medisinsk bildebehandling er prosessen ved å skape en visuell reprensentasjon av strukturer på innsiden av kroppen. Disse visuelle representasjonene kan brukes under diagnosering, for å avgjøre behandling, eller under en operasjon. Medisinsk bildebehandling er mye brukt, og der er dermed viktig at de som skal begynne i jobber der de benytter seg av dette har tilstrekkelig med kunnskap og ferdigheter til å bruke og tolke slike bilder.

Tolkning og bruk av forskjellig typer medisinske bilder er ofte en del av kurs som holdes ved sykehus og utdanningsinstitusjoner. Som et hjelpemiddel under slike kurs, ble et kurs og test administreringssystem utviklet som en web applikasjon, og fikk navnet *Medical Imaging Interpretation Courseware.*

Applikasjonen inneholder funksjoner for kurs, bruker og test håndtering. Brukere kan om ønskelig organiseres i grupper. Og enkelt brukere eller grupper av brukere kan legges til et, eller flere, kurs. Et kurs kan inkludere flere tester. Testene kan inneholde forskjellige test typer, inkludert tekst spørsmål, og spørsmål som aktivt bruker medisinske bilder.

Applikasjonen ble testet av en passende brukergruppe, og resultatene viser en positiv indaksjon på at applikasjonen kan bruks for trening og evaluering av kunnskaper og ferdigheter innen medisinsk bildetolkning.

Preface

This is the Master's thesis as part of study program Computer Science at the Norwegian University of Science and Technology. The work was carried out during the spring semester of 2016, in collaboration with SINTEF and St. Olavs Hospital.

I would like to thank my supervisors Frank Lindseth, Senior Researcher Scientist at SINTEF medical technology and Associate Professor at NTNU, and Cecilie Våpenstad, SINTEF researcher and PhD student at NTNU, for their help and guidance during this project.

I would also like to express my gratitude to the employees of SINTEF, as well as students taking the *Ultrasound in Neurosurgery* course June 2016, for participating in the user test. Finally I would like to thank the clinicians who has provided material and solutions to the tests.

Marte Nordrik Hallan
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Chapter 1

Introduction

The modern society is dependent on technology, it impacts virtually every industry. The field of medicine being no exception, where advancement of technology results in better treatments and diagnosis. Medical technology is an important subset of medicine, that aids to use technology to improve the quality, or reduce the cost, of health care. An important field within medical technology relates to medical imaging.

Medical imaging is the process of creating visual representations of structures inside the patient. The visual representations are created without opening up the patient or through minimal invasive surgery. To create the representations, different imaging technologies exists, revealing different structures and abnormalities. The images created are not intuitive for the untrained eye, but if interpreted correctly they can hold important information needed for setting a diagnosis, deciding upon a treatment plan or as tools during surgery.

Each year a new generation start their process to become workers within the medical field. It is important that those who will encounter the different medical imaging technologies later in their career, obtains adequately

knowledge and experience on how to interpret the images. To ensure so hospitals and medical institutes teaches a numerous courses related to use and interpretation of medical imaging.

A challenge faced when teaching medical imaging interpretation is the need for visual interpretation skills. There is a demand for the development of educational applications that both train and assess such skills in a visual and interactive manner. Digital exams either during courses or as part of e-learning packages are important aspects of technology enhanced learning.

This can be obtained through a set of different examination modalities. Some modalities focusing at general knowledge, while other looks at specific cases related to medical imaging. Use of existing medical images will let the course participants get first hand experience in medical imaging interpretation, such as pointing out important structures and finding abnormalities.

1.1 Problem Definition

The objective of this thesis is to develop a web application that can help assist courses related to medical imaging interpretation. The emphasis of the web application will be test administration. Where the teacher can create a test consisting of different testing modalities. The testing modalities will vary from familiar testing units, such as multiple choice questions, to other testing modalities that targets interpretation of medical images. The tests should be able to be used as:

- **Precourse test:** to ensure familiarity to the subject.

- **Open test during the course:** to provide an area to practice.

- **After course examination:** to assess the obtained knowledge and skills.

The intention of the web application, named *Medical Imaging Interpretation Courseware* or *MIIC*, is to encourage the course participants to learn about medical imaging, and practice their interpretation skills. While the teachers or course administrators will get an opportunity to assess the obtained skills and knowledge of the course participants.

The main stakeholders for the application are the teachers, the course administrators and the course participants. The teacher or course administrator will create courses, upload material and create tests and exams. The course participants will by answering the tests get practice interpreting medical images, and a chance to prove their skills and knowledge.

1.2   Theses Goal

The main goal of the thesis is to develop a web application prototype that can be used during medical imaging interpretation courses. The application should be able to do user and course management, as well as testing. The testing part should include text testing and imaging testing. To test both general knowledge and skills related to interpreting medical images. The application should also be tried out by appropriate audience.

1.3   Research Questions

The main goal of this theses were presented above, but in addition the following research question will be answered:

1. **RQ1**: Is the application useful in assisting courses related to medical imaging?

2. **RQ2**: Is the application able to visually train and assess medical imaging interpretation skills?

1.4 Structure of the Report

The report is structured as follows.

Chapter 2 gives an introduction to the background material used and research done before implementation of the application.

Chapter 3 gives an introduction to courses and testing, stating the novelty of approach for the application.

Chapter 4 presents an overview of the application, the methods used to implement it as well as the methods used during the user test.

Chapter 5 describes the implementation details, including the various features implemented.

Chapter 6 presents the the developed application and the results from the user test.

Chapter 7 discuss the results from the user test, and answer the research questions.

Chapter 8 presents the conclusion of the project.

Chapter 9 gives recommendations for further work.

Chapter 2

Background

This chapter will present the background information needed to develop a course administration system that is tailored for medical imaging interpretation courses. The tests will interactively be using medical images, so the first section, section 2.1, will give an introduction to various medical imaging techniques. The application will be web based and section 2.3 present issues related to web development. The final section, section 2.4 will present some of the existing solutions to related problems.

2.1 Medical Imaging

Medical imaging is the process of creating an image of internal structures inside a patient. The images may be created without opening up the patient, or through minimal invasive surgery. These images can be important tools for the doctor when treating, monitoring or diagnosing a patient or be used as a tool during open surgery. Early use of medical imaging might even reduce the time a patient is admitted to hospital [29].

There are various imaging modalities that can be used to create the image. Some of the most common ones will be described in sections 2.1.1 to 2.1.5. The different imaging modalities can give different information, different images, about the same area. The type of imaging modality to be used depends on the patients symptoms, as well as the part of the body and structure to be examined.

Some of the imaging modalities can produce images that can be viewed live on a video screen, creating a live stream of whats happening inside the patient. This video stream can be viewed on a computer monitor, printed or transferred to an external storage unit. Some of the images uses gray scale to symbolize certain structures, while others inserts a camera into the body to produce pictures.

2.1.1 Ultrasound technology

Ultrasound are high frequency sound waves issued from an ultrasound transducer. The sound waves can penetrate trough soft tissue in the human body. When an internal organ is hit by a sound wave, an echo wave is bounced back to the transducer. Based on the echo wave, the ultrasound machine creates images [36]. The image will be in grey scale, where lighter areas represent the structures where more of the sound waves are bounced back as echo, such as bones. The ultrasound machine can intrepid the echo waves in real time, creating an ultrasound video. From the video snapshots can be created.

Ultrasound imaging is often used as a diagnostic tool, and is often associated with prenatal ultrasound. Prenatal ultrasound is used to create an image of a fetus, placenta or associated structures during pregnancy. The images can be interpreted to check for physical abnormalities, determine the number of fetuses and more. Studies has not found any risks or harm associated to the

use of prenatal ultrasound [22].

But ultrasound technology also provides usages to other fields of medicine, such as anaesthesia and neurosurgery. Real time ultrasound guidance may enable anaesthetists to accurately position the needle when distributing local anaesthetic for regional anaesthesia [35], and intraoperative 3D ultrasound can be applied to improve surgery of brain tumours [45].

2.1.2   X-Ray

X-ray imaging use electromagnetic waves to create an image of internal structures. An x-ray image use a grey scale, where light areas on the image represent structures which absorbs most of the radiation. Darker areas represent structures which do not absorb as much of the x-rays. Air does not absorb x-ray, so air filled structures, such as lungs appear black, while the calcium in bones absorb x-ray well, and will appear white [27].

Important usages of x-ray imaging includes checks for broken bones, checks for pneumonia and mammograms. While the benefits of using x-rays are huge, doctors has to consider a risk-benefit ratio seeing as high doses of radiation is carcinogenic, both for the patient and the radiologist. The carcinogenic risk associated with the use at x-ray is at worst low, but carcinogenic risks is found at higher doses [44].

2.1.3   CT-scan

A CT-scan, or a computed tomography scan uses x-ray equipment to create cross-sectional images of internal structures. The image can be given at different planes inside the body to create an image of a specific structure. The image can be 2 or 3 dimensional. CT-scans generally provides a better

image of the soft tissue than traditional x-rays. Usages of CT-scans includes checking for broken bones, cancer, blood clots and internal bleeding [5].

2.1.4 MRI scan

Magnetic resonance imaging (MRI) scans uses a strong magnet and radio waves to create an image of internal structures. The magnet is based on the fact that the the nucleus of atoms, protons, contain a positive electric charge. When the MRI machine is turned on, the otherwise randomly assigned fat and water molecules will align. MRI scans are beneficial for examining the brain and the spinal cord [16].

2.1.5 Endoscopy

Endoscopy is the procedure of inserting a strong light and camera inside the body to examine internal structures. The camera can be moved inside the body through openings and passageways. The use of endoscopy may be for diagnosis, or during surgery [8]. There are different kind of endoscopy, depending at the part of the body to be examined.

- Arthroscopy: endoscopy of the joints

- Bronchoscopy: endoscopy of the lungs

- Colonoscopy: endoscopy of the large intestines

- Laparoscopy: endoscopy of the abdomen and pelvis

2.2   Image-Guided Therapy

Image-guided therapy is the use of medical imaging for planning and performing surgeries. Image-guided therapy can be used to improve existing surgeries, by making them more precise, or new procedures utilizing medical imaging techniques can arise. The use of image-guided therapy may lead to less invasive surgeries and shorter hospital stays for the patient [25].

2.3   Web Development

Web development is a term used for all the work related to developing a web page, or a web application. When developing web applications there are multiple issues to consider, including everything from how the information should be presented to the user to which devices it should be accessible from. This section presents some important issues that should be considered when developing a web application.

2.3.1   The User Interface

A user interface (UI) is the part of the application that is visible to the users. The design of the UI will greatly affect how the application will be received when published. If the application is too difficult to use, the users might even completely reject it.

Users are more comfortable with systems and web pages that are easy to use and understand, and where they can obtain their goal with minimal frustration. A good user interface will result in happier users and a higher productivity. On the other hand can a poor UI result in dissatisfied, angry and frustrated users [42].

A good UI will provide a higher usability, where ISO 9241 part 11 [13] defines usability as *"The effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments."* Where the definitions of *effectiveness, efficiency* and *satisfaction* are as follows:

- **effectiveness**: the accuracy and completeness with which specified users can achieve specified goals in particular environments.

- **efficiency**: the resources expended in relation to the accuracy and completeness of goals achieved.

- **satisfaction**: the comfort and acceptability of the work system to its users and other people affected by its use.

Guidelines for a Good User Interface

To ensure a good UI a set of guidelines and principles for best practices has been developed over the years. Some widely used guidelines are Jakob Nielsen's 10 usability heuristics for UI Design [1].

These focuses on how to make system easy to use for the end user, and emphases the importance of trying to prevent errors from happening. By trying to be flexible, only including actions and information that serves a purpose, being consistent and letting words and actions have the same meaning throughout the system, errors are less likely to occur. A help system should be included, as the entire system might not be intuitive to all of its users.

If however an error were to happen, the system should try to help through relevant error messages, using the users natural language. If appropriate a solution to the problem might be presented as well. Including cancel and go back buttons might help the user feel in control of the system, and that it is less likely that they're doing something wrong.

When designing the UI, another set of principles that might be considered are the *Gestalt Principles* [9]. They are theories about visual perceptions developed by German psychologists in the 1920s. The principles describes how humans organizes elements to create an entirety, gestalt being the German word for shape.

In visual perception humans form groups of visual impressions to organize complex scenes. Groups of objects, or singe standing objects are highlighted and differentiated from the surrounding area. The surrounding area is less interesting and filtered out as an often mere and less interesting background.

The groups are segregated from each other, and elements within a group creates a unity, or a whole. The principles states that elements placed close to each other in distance, elements with similar colors or elements of the same shapes normally creates such a group. Objects might also be thought of to be in the same group if the objects align, creating a continuity between the objects.

2.3.2   Devices

The most common way to access the Internet is through a PC or laptop, according to GlobalWebIndex [2] does 91% of Internet users in the ages 16-65 own such a device. However mobile devices such as smartphones and tablets are becoming increasingly popular, where 80% of Internet users owns a smartphone and 47% a tablet.

This means that a high percentage of the Internet users has the possibility to access the web application through other devices than a PC or laptop. Based on this it is important to at least consider if the application, or parts of it, should be supported by those other devices.

A web application that has been designed only for laptops are often difficult to use at smartphone, which has a smaller screen. The smaller screen results in the content being extremely small, and the user has to zoom in at parts of the page to be able to read the information. That is if the web page is loading at all. This could be a frustrating experience for the user.

A simple way to transform the web application to better fit smartphones and tablets, is to change the organisation of the content. The content should be organised in a manner that is better suited for the smaller screens that comes with the smartphones and tablets. The user could however still run into problems, as there are certain elements that are not viewable at most smartphones and tablets. To create a smartphone friendly version of those web applications would require some more work. The benefits of creating the web page for smartphone and tablets must be viewed against the extra work of creating it.

2.3.3 Browsers

The web page may need to be loaded to different browsers, running on different operating system. It also is wise that the web page can run properly in previous versions of the browsers, seeing as all of the users may not have updated the browser to the most recent version.

Figure 2.1 displays the top 5 desktop browsers between May 2015 and April 2016 [41]. With nearly 60% of the market share, Google Chrome dominates throughout the entire period. Mozilla Firefox and Internet Explorer take turns being the second most used browser, with about 15% each of the market share. Sharing the final market share is Safari, Opera and other browsers.
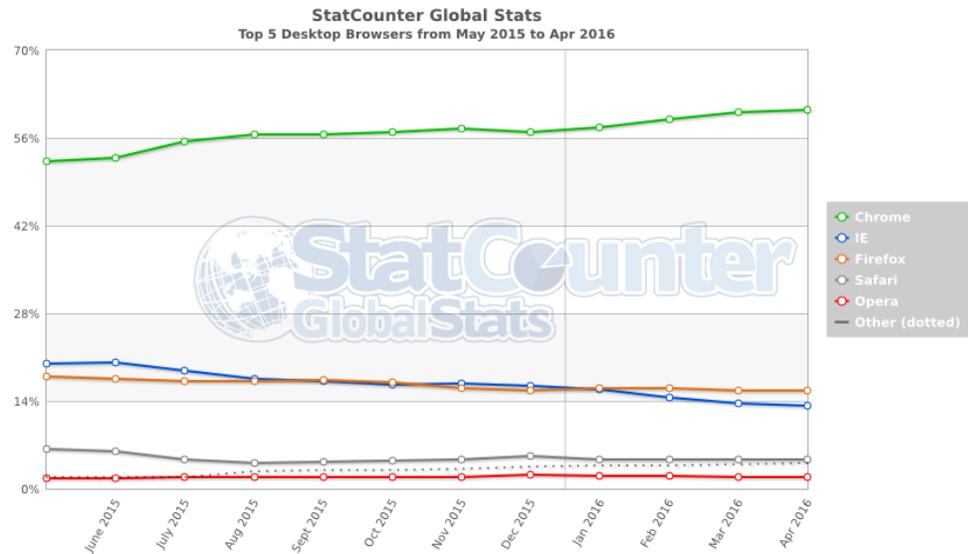
Figure 2.1: Top 5 desktop browsers from May 2015 to April 2016

2.3.4   Screen Resolutions

The most common resolution from May 2015 to April 2016 was 1366 x 768 pixels (see figure 2.2). The higher resolutions were also increasing in popularity throughout the time period. However designing a web page based on high resolution may result in a poor experience for a user who has lower resolution. A low resolution may result in some of the content not being displayed properly, or it might not be displayed at all.

It is also worth to notice that the resolution for smartphones and tablets often are lower than those for desktops (see figure 2.3), where the most common resolution for the same time period was 360 x 640 pixels.
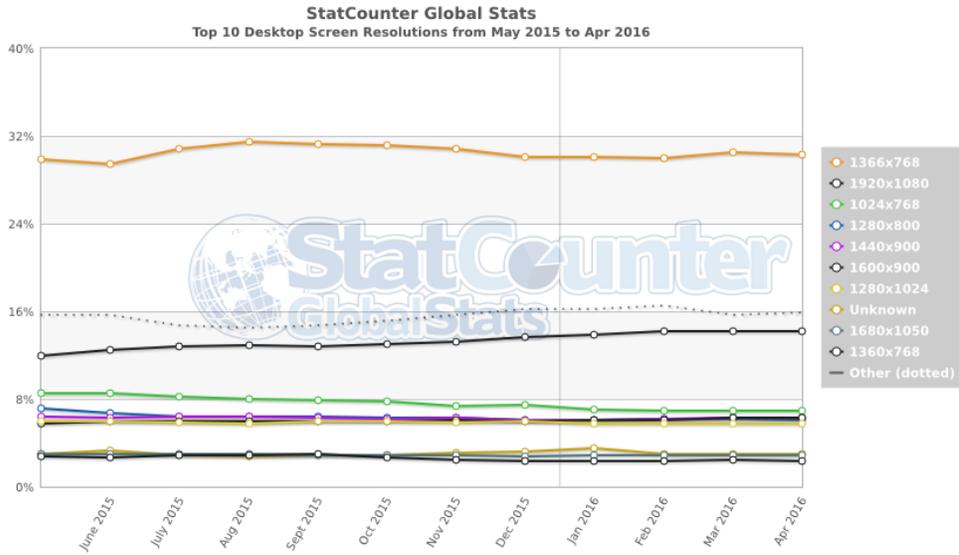
**Figure 2.2:** Top 10 desktop screen resolutions from May 2015 to April 2016
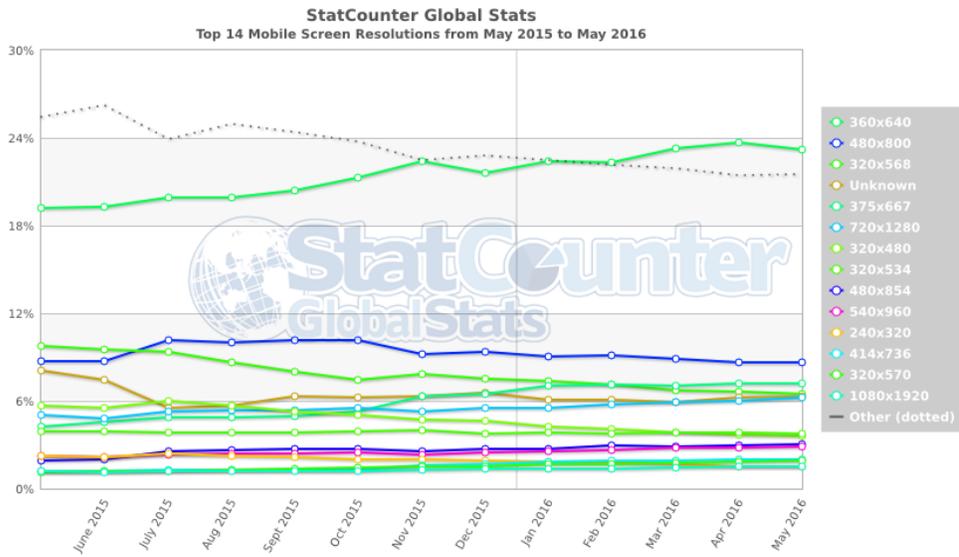
Figure 2.3: Top 10 mobile screen resolutions from May 2015 to April 2016

2.3.5 Tools and Frameworks

When designing a web page there exists a numerous tools and frameworks that might help better the quality to the web application. Finding the correct tools and framework might save the developer a massive amount of time, leaving more time for implementation of new features rather than reinvention of the wheel.

There are a numerous tools and frameworks to chose between, each with their different strong point and drawbacks. Some might even pose a potential risk for accessibility for some users, where not all tools are supported by all browser etc.

2.4 Existing Solutions

There are multiple existing systems that handles course administrating and testing. Some of the systems will be presented in this section. A drawback of these system is that they are generalized for all types of courses, lacking questions that train and assess medical imaging interpretation. This section will also present educational games, or other educational systems, that has some of the desired testing types, but lack the general course or testing ability.

2.4.1 NerveBlocker

Kamperud and Hellan [34] created a prototype version of a mobile application, named NerveBlocker, for teaching ultrasound-guided regional anesthesia. The application consists of different game modes to help the user learn to interpret ultrasound images and videos used for regional anesthesia. It

aims to gamify the learning experience, and is supposed to be open for anyone to use. An expert has to upload images or videos as well as the solution to the games. Any uploaded material will be accessible for anyone. It does not offer any course related material, or ways to create specific tests for a course.

2.4.2 WeBSurg

WeBSurg [46] is a virtual surgical university for minimally invasive surgeries. It provides online, worldwide surgery training as well as information about the latest surgical breakthroughs. WeBSurg focuses at minimally invasive surgeries through the use of web-based multimedia technologies.

- **Surgical videos:** Videos from actual surgeries, complemented with an audio explaining the techniques being used.

- **Lectures:** Different lectures on various subjects have been videotaped and published.

- **Operative techniques:** Textual or audible explanations of different operative techniques. The techniques are presented with animation showing the technique.

2.4.3 Its Learning

ItsLearning [33] is a digital learning platform used at different teaching places in Norway, varying from primary schools up to higher educations such as the Norwegian University of Science and Technology (NTNU). It includes tools for administrating a course, communication, teaching and evaluation of students. Students can deliver papers or take tests. The tests can include multiple choice, answer question or fill in the blank.

Introduction to Courses and Testing

This chapter introduces the courses that are currently interested in the MIIC. Section 3.2 will give an introduction to some of the research related to testing, giving an overview of benefits courses and course participants can experience by using a testing system. Finally section 3.4 will state the novelty of approach.

3.1   Courses

The national competence center for ultrasound and image-guided therapy is a collaboration between three institutions in Trondheim, Norway: SINTEF, NTNU and St. Olav University Hospital [17]. Each year the centre holds different courses related to ultrasound and image-guided therapy.

The web application is initially thought to be used during courses related to laparoscopy and neurosurgery, and their use of medical imaging. It is however desirable that the application could be made general enough to be used by other branches of medicine as well.

3.1.1 Laparoscopy

Laparoscopy is used to examine organs inside the abdomen. A small incision is made just bellow the bellybutton, and a CO2 gas is inflated into the abdomen, making it easier for the doctor to insert instruments without injuring organs, as well as to see the organs when the camera is inserted (see figure 3.1) [38].

Small incisions are made, and small tubes are placed in the incisions. The instruments and the camera are inserted though the tubes. Images from the camera are sent to a video screen in real time. Laparoscopy is a low-risk and minimally invasive procedure. Images from the camera can be stored as either snapshots or videos.
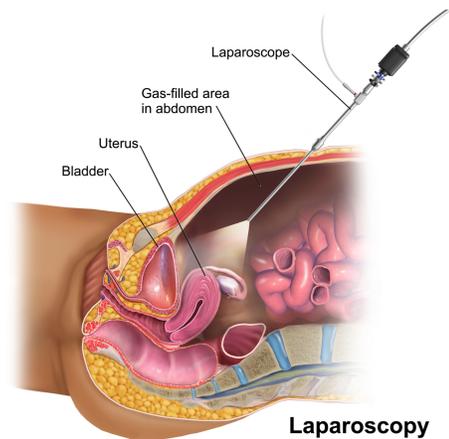
Figure 3.1: Laparoscopy [30]

NSALK

Nasjonal Kompetansetjeneste for Avansert Laparoskopisk Kirurgi, NSALK [20], is the national expert service for advanced laparoscopic surgery in Norway, located at St. Olav University Hospital. One of the services NSALK

provides is training of minimal invasive surgeries. The training is often conducted as a part of a laparoscopic course.

NSALK is equipped with multiple virtual reality (VR) simulators, that can be used to exercise surgical skills outside of the operating room (OR). The VR simulators use their own course administration system and challenges that simulate situations surgeons can face in the OR. After finishing a challenge, data such as time used and mistakes made, are stored in the simulator. These data are often anonymous.

3.1.2   Neurosurgery

The courses related to neurosurgery are dealing with diseases to the nervous system. The nervous system transmits signals to and from various parts of the body. This can result in voluntary or involuntary movements. Neurosurgery includes resection of brain and spinal tumors.

Equipment used during surgical resection of tumors can be navigated with high precision when using 3D ultrasound imaging [18]. A live stream of ultrasound images gives updated descriptions of the brain during the surgery, making it easier to locate and remove tumours without damaging healthy brain tissue.

3.2   Testing

There are multiple reasons for administrating a test at some point during the course. Amongst the benefits a course can experience from a test are ways to communicate important parts of the curriculum, motivate course participants to study, find possible weaknesses to the course or curriculum

and get an overview of the course participant's knowledge or skills after completing the course [43].

Using an online testing system provides benefits over tests performed on paper. It reduces the need for manually grading the tests, as well as the need for printing papers. The answers from each test can be saved for later examination, or comparison. Methods for presenting statistical analysis of test score can be created for easier examination of the results, and overall performance from the course participants.

Using tests that are tailored to medical imaging interpretation, creates new possibilities with regards to the need for visually displaying interpretation skills. To obtain interpretation skills is it important to practice interpretation of medical images. By tailoring a test system, a test can consist of various tasks that interactively use existing medical images in a visual manner.

When the test should be taken might influence the test itself, and the main purpose of the test. The following subsections will contain a brief discussion of this topic.

3.2.1 Precourse Testing

It may be desirable that the course participants have completed some home studying before they participate in the course. By having to complete a test before participating in the course, the course participants has to go trough some home preparation. Studies shows that prepared students follows the teaching more easily [39].

Course participants who has participated in a prelecture quiz performs better at final exams, compared to course participants who has not taken such quiz. The course participants who has taken the prelecture quiz also asks more relevant questions during the lectures [37]. A precourse test might have

to be passed before the course participant is allowed to participate in the course.

As part of the precourse test, there can also be material that the students should read, or watch. This can be text paragraphs or videos between the tasks. Doing this would ensure that the students are familiar with some of the material before the course begins. A precourse test might have to be passed before the student is allowed to participate in the course.

3.2.2   After Course Testing

At the end of the course it might be desirable to get an overview of what the course participants have learned during the course. That might be for grading purposes, or to get an overview of their obtained knowledge to help evaluate the course. Statistical presentations of answers and test scores might help reveal parts of the curriculum that needs deeper explanation during later courses.

3.2.3   Open Tests During the Course

Since practicing interpretation of medical imaging is important to become good at interpreting such images, it might be desirable to create a practice area for the course participants to use during the course. This can be done by creating non mandatory tests, consisting of various cases. This way the course participants has a place they can use for practice.

The questions used for the open practice tests might be the same, or different, to the cases used for a grading exam after the course. Reusing some of the cases might encourage course participants to use the practice tests. If cases are to be reused, it should be possible to prevent the course participants from

seeing the correct solution after submitting a test, in that case should they only receive a score giving an indication at how they performed.

3.2.4 Testing for Comparison

At some point it might be desirable to compare the answers that two, or more, course participants have submitted to the same test. Showing the different answers in a manner that allows for easy comparison might open up for a dialog on how the different course participants thought while answering.

This functionality could be desired by other than the course participants. Experienced surgeons who wants to collaborate or discuss a case, may upload images without any solutions, and create a test consisting of these images where the test takers are asked to outline an abnormality. Afterwards they would answer the test by themselves, before getting together to compare and discuss their results.

3.3 Tests

A medical imaging interpretation test is an assessment that is intended to measure the test takers knowledge and skills regarding medical imaging interpretation. The test can be made up of various question types, where the questions can vary the level of a static or interactive response required. The test can be thought of as a question set containing individual questions to make up the total assessment.

3.3.1   Multiple Choice Questions

One type of testing assessment is Multiple Choice Questions (MCQs). An MCQ includes a question or statement and a list of possible answers. The course participant is asked to identify the correct, or best possible answer from the list. It is important that the question or statement is clear and unambiguous. Especially when the answers are true or false, is it important that they are absolutely true or absolutely false, with no shades of grey [43].

An MCQ can include other media as well, such as an image or a video. With these types of MCQs the question or statement are related to the included media. This creates a wider range for the types of questions that can be asked. MCQs with medical images or videos can be used to test course participants in tasks related to medical imaging.

3.3.2   Imaging Questions

An imaging question will consist of various tasks related to an image, used to create a visual representation of the interpretation. The course participant may be asked to draw at the presented image or to point and click at named structures. The imaging questions should be of more interactive manner than a standard statement-option question. An interactive question may enable a more complex reasoning by the course participant than a static question [32].

The imaging task will in some cases be interpretation tasks without one true answer. Different clinicians may have slight variations in how they interpret the same image. By using an imaging question type intended for the teacher, a solution may be created as a collaborative effort.

3.4 Novelty of Approach

There are many existing solutions when it comes to course management and test administration. However the existing solutions are made to cover a variety of courses and tests. The MIIC application tries to tailor a solution for medical imaging interpretation, by creating tests that visually trains and assess interpretation skills.

Many of the courses wish to have full anonymity for the course participants. That requires the application to have a user management system that does not save any information about the course participants. Instead it should generate a username and password for each participant. This way only a username is associated to the various answers submitted, the answers might however be saved for later analysis.

The test modalities should be tailored to test medical imaging interpretation skills. A test might be designed where the course participants has to use existing medical images, to practice, learn and prove their knowledge and interpretation skills. Various imaging questions can be made, requiring the course participants to interactively use the images, by drawing at the image and pointing out important structures.

The application should give the teacher full control of their data. When using medical images there are laws and regulations regarding who you can share the images with and how they are stored. And even if it was legal it's not always desirable to share the material with everyone. By letting the teachers add users to the application, opposed to systems where anyone can register to the course, the teacher obtains more control over who has access to the various uploaded material.

Different teachers, or clinicians, have different methods of performing a procedure or interpreting a medical image. By letting the teacher create the tests

and the solution to the imaging questions, they can merge their methods into the tests.

It should also be possible to extend the application when needed as medicine is an always evolving field. New techniques and equipment are constantly being researched. The application should be able to adapt to this evolving state, by making it easy to add new tasks.

Chapter 4

Methods

This chapter will present the requirements and basic construction of MIIC. It will give an overview of how the MIIC is structured, including implementation pattern and various architectural views. Section 4.1 presents the functional and non-functional requirements for MIIC. Section 4.2 and section 4.3 presents the chosen technology and the software architecture while section 4.4 gives an overview of the various architectural views. The final section will discuss the methods used for the usability test.

4.1 Application Requirements

Table 4.1 gives an overview of the functional requirements of the application. A functional requirement is a required or desired feature of the application. Each requirement comes with a level of priority, either low, medium or high. Where high priorities are considered a must have for the application, while a low priority is considered a desired but not crucial feature.

Id	Functional Requirements	Priority
FR1	The teacher or administrator should be able to create new courses, users and user groups	High
FR2	The teacher or administrator should be able to add users and/or user groups to courses	High
FR3	The teacher or administrator should be able to create new tests	High
FR4	The application should support multiple choice questions, optionally with image or video	High
FR5	The teacher or administrator should be able to upload images, and mark and name structures	High
FR6	The application should support questions where the goal is to outline structures at an image	High
FR7	The application should support questions where the goal is to point out structures at an image	High
FR8	The teacher or administrator should be able to create new questions or choose between existing questions when creating a test	Medium
FR9	The students should only see courses and tests that they are taking	High
FR10	The students should be able to submit answers to tests	High
FR11	The application should generate a score based on the students answers	High
FR12	The teacher or administrator should be able to set test score to different test modalities	Medium
FR13	Only teachers should be able to see admin pages	High
FR14	The teacher or administrator should be able to see, edit and delete all courses, users and user groups	High
FR15	Both teachers and students should be able to log in	High
FR16	The teacher or administrator should be able to see, edit and delete all tests	High
FR17	The teacher or administrator should be able to see all answers submitted by a user	High
FR18	The teacher or administrator should be able to see all answers submitted to one question for easier comparison of the answers	Medium
FR19	The application should support duplication of tests	Low
FR20	The teacher or administrator should be able to set a maximum allowed time and/or attempts for each test	Low

| FR21 | The teacher or administrator should be able to upload non test related material | Low |
| FR22 | The teacher or administrator should be able to set a threshold for how close one has to draw to the solution to obtain full score when outlining structures | Medium |

<div align="center">

Table 4.1: Functional Requirements

</div>

The application also has a set of non-functional requirements. These are presented in table 4.2. Non-functional requirements are quality goals of the application, how the application is supposed to be.

Id	Functional Requirements	Priority
NFR1	The application should be easy to use	High
NFR2	The application should be able to be used by multiple users simultaneously	High
NFR3	The application design should have a simple and tidy appearance	Medium
NFR4	The application should be appropriate in an educational setting	High
NFR5	The application should run on the most used browsers	High
NFR6	The application should be able to run at mobile phone and tablets	Low

<div align="center">

Table 4.2: Non-functional Requirements

</div>

4.2 Chosen Technology

The application will be developed using various existing technologies. The application server layer will be implemented using the programming languages JavaScript [14] and Python [23]. The Bootstrap framework [4], and jQuery plugin [15] will be used, as well as the Django framework [7]. The application will be running on an Ubuntu 14.04 server [24]. The web server will be using Nginx [19] and Gunicorn [10], a WSGI binding between web server and application server. The database will be using the PostgreSQL

database management system [21], which is ACID compliant [3].

4.3   Architecture

This and the following sections, will present the architectural aspects of the
Medical Imaging Interpretation Courseware. This section will focus on the
chosen implementation pattern and the context of the application.

4.3.1   MVC (Model View Controller)

For the MIIC the Model View Controller (MVC) pattern were chosen. The
MVC pattern divides the application into three parts:

- **Model:**   the data

- **View:**   what is shown to the user

- **Controller:**   the in-between component used to communicate between
  the model and the view

The benefit of using this pattern is that changes to the view will not affect
how the data is handled, and vice versa (see figure 4.1).

4.3.2   Context Diagram

The context diagram is a high level diagram that provides a basic overview
of the system and the entities it interacts with. There are three primary
entities that will interact with the application (see figure 4.2):

1. **Administrator:**   The administrator is the person responsible for
   handling the course administration. That includes creating the course,
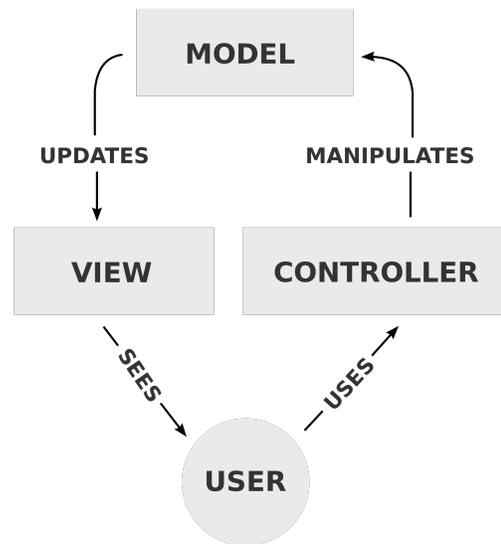
Figure 4.1: Illustration of the MVC pattern

users and user groups. The administrator will also assist the teacher in creating tests if needed.

2. **Teacher:** The teacher is the person who teaches the course. The teacher can decide if he wants to use existing material during the tests, or if he wants to upload his own.

3. **Course Participant:** The course participant is a person following the course. Each course participant gets its own user that he can use to log on to the MIIC. A course participant user is unique, so that when a test is submitted, the teacher or the administrator can see his specific test results.
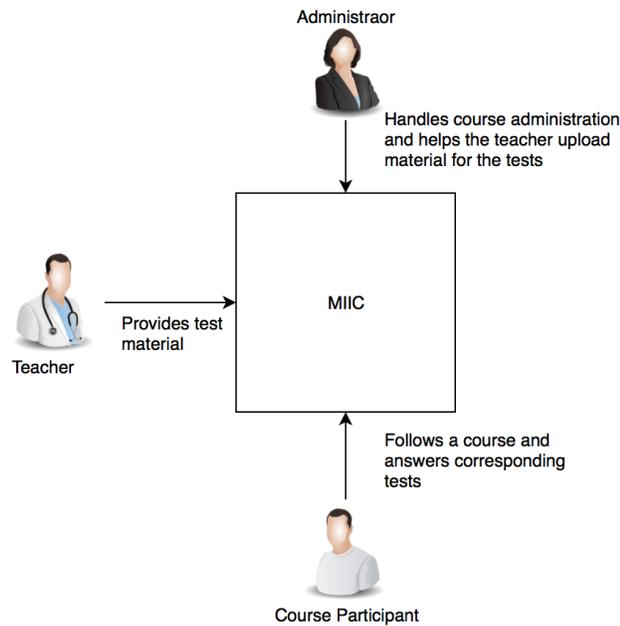
Figure 4.2: The context of the Medical Imaging Interpretation Course

4.4   Architectural Views

This section presents the application's functional viewpoints. Those are used to describe the primary interactions between the user interfaces.

4.4.1   Primary Architectural View

Figure 4.3 shows the primary context for the MIIC.

Web Browser Browser software installed on the users device.

Internet A global system that links computer networks.

MIIC The log-in page for the course administration system.
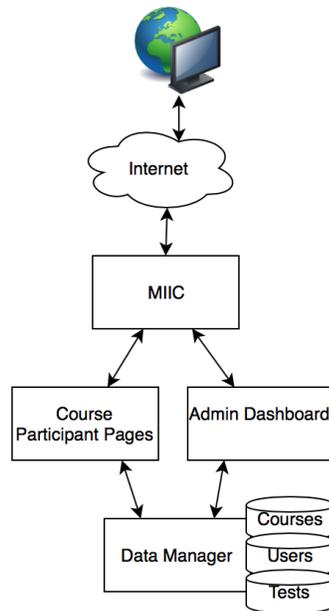
Figure 4.3: The context of the course administration system

Course Participant Pages This is the pages that the course participants will be redirected to when logging in.

Admin Dashboard This is the pages that administrators and teachers will be redirected to when logging in.

Data Manager This is the back-end component responsible for handling all data.

4.4.2   Admin Dashboard

Figure 4.4 shows the context of the admin pages.

Add New Course The page for creating a new course, and adding it to the application.
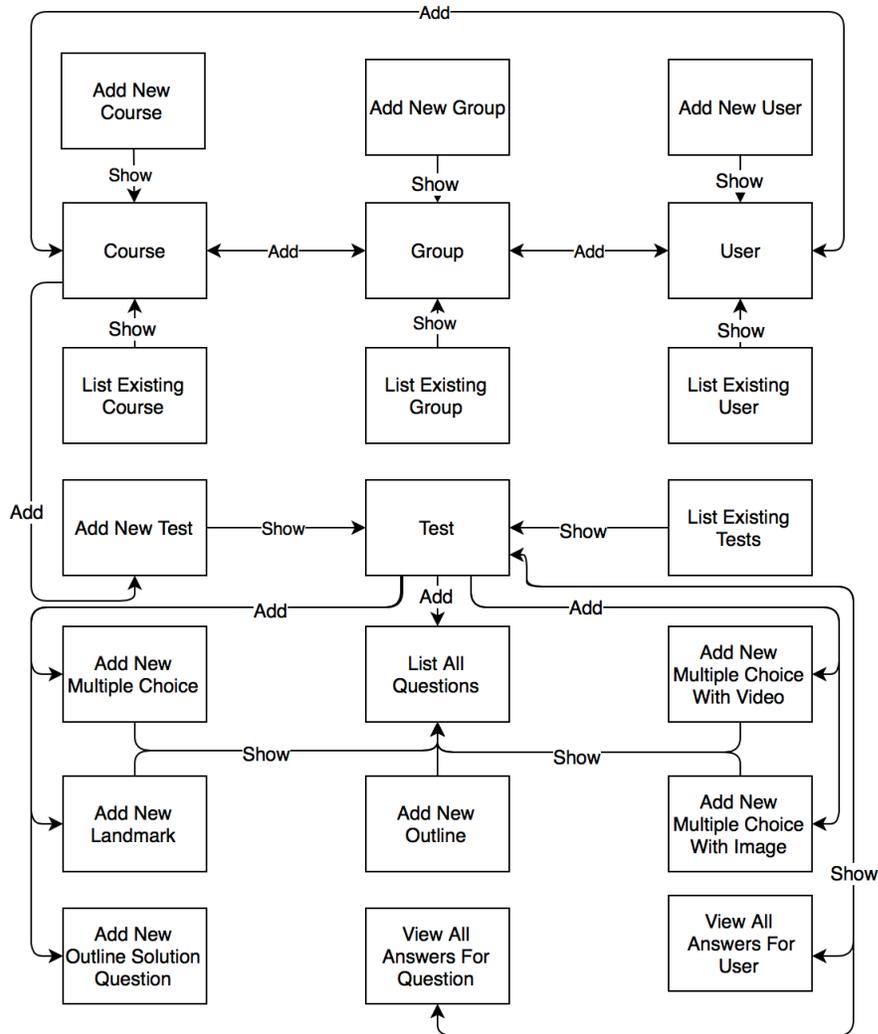
Figure 4.4: The context of the admin pages

Course The page for editing a specific course and adding tests, users and
user groups to the course.

List Existing Courses An overview of all existing courses.

Add New User The page for creating a new user, and adding it to the

application.

User The page for editing a specific user and adding the user to a course or a group.

List Existing Users An overview of all existing users.

Add New Group The page for creating a new user group, and adding it to the application.

Group The page for editing a specific user group, adding a user to the group or the group to a course.

List Existing Groups An overview of all existing user groups.

Add New Test The page for creating a new test, and adding it to the application.

Test The page for editing a specific test and adding different testing assessments to it.

List Existing Tests An overview of all existing tests.

Add New Multiple Choice The page for creating a new multiple choice question, and adding it to the application or test.

Add New Multiple Choice with Image The page for creating a new multiple choice question with an image, and adding it to the application or test.

Add New Multiple Choice with Video The page for creating a new multiple choice question with a video, and adding it to the application or test.

Add New Landmark The page for creating a new landmark question, and adding it to the application or test.

Add New Outline The page for creating a new outline question, and adding it to the application or test.

Add New Outline Solution The page for creating a new outline solution question, and adding it to the application or test.

List Questions An overview of all existing multiple choice questions, standard or with image or video, landmark and outline questions and outline solution questions.

View All Answers For Question An overview of every answer submitted for a question in a test.

View All Answers For Question An overview of every answer submitted by a user in a test.

4.4.3   Course Participants pages

Figure 4.5 shows the context of the course participant's pages.
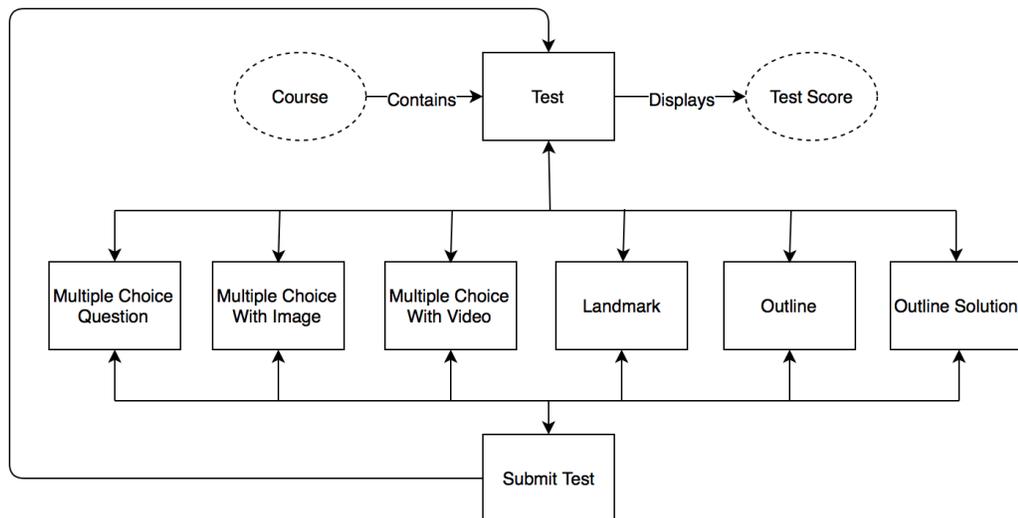
Figure 4.5: The context of the course participants pages

Course A box for each course, displaying any available tests.

Test A test containing a question set, created by the teacher for the corresponding course.

Test Score The test score the course participant achieved for the corresponding test, hidden if test has not been answered yet.

Multiple Choice Question A multiple choice question included in the corresponding question set.

Multiple Choice Question with Image A multiple choice question with image included in the corresponding question set.

Multiple Choice Question with Video A multiple choice question with video included in the corresponding question set.

Landmark A landmark question included in the corresponding question set.

Outline An outline question included in the corresponding question set.

Outline Solution An outline solution question included in the corresponding question set.

Submit A submit page that lets the course participant submit the test after completion.

4.5 Testing and Evaluation

After the application has been developed, a user test[1] will be conducted to get an indication at how the MIIC will be received by an appropriate audience. The user test will consist of multiple users trying out the application, either as an administrator/teacher or as a course participant. After they have tried the

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[1]Not to be confused with a test used in the application as a part of a course.

application, they will be redirected to a page containing a questionnaire. The questionnaire has two sections, the first related to usability and the second to get an indication of the participants background and their perception on the functionality of the application.

4.5.1   System Usability Scale

The first part of the questionnaire is related to the usability of the system, and to test that the System Usability Scale (SUS) has been chosen [31]. The SUS form consist of 10 statements related to usability. Each statement has 5 response options. The response options should be used to state how much the test user agree to the statement, ranging from *strongly disagree* to *strongly agree*.

A SUS score can be calculated from the answers. All answers are given a score of 0-4. For all odd statements (statement 1,3,5,7 and 9) a *strongly disagree* is given a score of 0, while a *strongly agree* is given a score of 4. For all even statements (statement 2,4,6,8 and 10) a *strongly disagree* is given a score of 4 while a *strongly agree* is given a score of 0. The options between *strongly disagree* and *strongly agree* are given a score that is gradually distributed between 0-4.

For each test participants a total score is calculated by summing up all scores from the individual statements, resulting in a score of 0-40. The original score should be multiplied by 2.5, to convert the score to a score of 0-100. An average SUS score is approximately 68, meaning all scores above 68 is considered higher than average. The SUS score has been translated to adjectives, called the Adjective Rating Scale, for easier interpretation of the score [28] (see figure 4.6).

The SUS score should only be used to classify the ease of use of the application. If a low SUS score is obtained it does not say anything about where
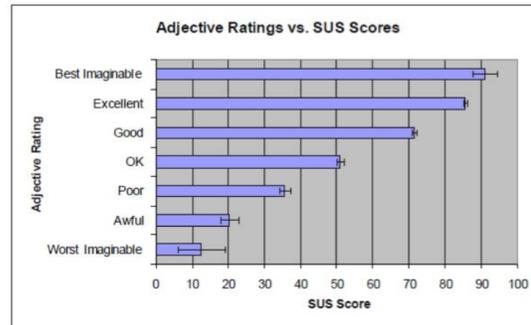
Figure 4.6: The Adjective Rating Scale

the actual problem lies. However it is good at differentiating systems with a high usability from a system with poor usability.

The SUS form is included in Appendix B.

4.5.2 Questionnaire

Since the SUS primarily focuses on the usability of the system, an extra section of questions are added to the questionnaire. This set has more focus at the test participants background and reason to use the system, as well as the usefulness of the system. This question set includes questions with options as well as questions where it is possible to write short answers

This questionnaire is included in Appendix C

4.5.3 The number of test participants

The ideal number of participants included in a user test varies based at test type. A quantitative study that aims at statistic, such as SUS, should include at least 20 test users [11]. While a usability test that aims at discovering problems with the systems, manages with at least 5 test users. Studies show

that the more test users that take the usability test, will result in each new test user uncovering less new problems [26].

That means that the first few users will uncover most of the usability problems, and that the benefits of adding a new test user decreases based on how many test users that has already taken the usability test. About 15 users, will uncover almost every usability problems. However 5 test participants will uncover about 85% of the usability problems, and in many cases have a better resource-benefit ratio.

Implementation

This chapter presents the implementation details regarding MIIC. Section 5.1 discuss login and user authentication, while section 5.2 presents the details regarding courses, users and user groups. Sections 5.3 and 5.4 discuss the tests, including the different testing modalities implemented. Section 5.5 presents the application for mobile devices and section 5.6 discuss the design choices made. Finally sections 5.7 and 5.8 presents known bugs and supported browsers of the MIIC.

For easier overview of the relevant functionality, the images from the application has been cropped. All admin pages comes with a menu bar at top, and a menu bar at the left side for navigation between the different pages. The menu bar at the side can, if desired, be hidden for a more minimalistic presentation. The dashboards for the course participant's pages and the admin pages are included in Appendix D.

The application was first hosted on a private server, and was later moved to a server at NTNU under the address http://miic.idi.ntnu.no.

5.1   Login

As mentioned in chapter 4 the Django framework was used. Django comes with some existing functionality. It handles creation of users with different authentication level, such as regular users and admin users, as well as login and log out features. Django also comes with an authentication check that can be placed at the beginning of each method. Doing so makes it possible to state which methods should only be accessible by admin users or regular users logged into the application, and which methods is available for everyone, even those who are not logged in.

Django also comes with security features, such as the CSRF middleware and template tag, to protect against Cross Site Request Forgeries [6]. Using a CSRF token prevents an attacker from logging in and sending forms using someone elses credential.

5.2   Courses, Users and Groups

Even if the emphasis of the MIIC is testing, a certain level of course and user administration is necessary. This section will present how the application handles the various parts related to courses, users and groups.

Users

A user is in this sense a course participant. The user should get a unique username, used for later identification. The user will by default have the username set as password. However the user is free to change this password when logging onto the application. All the users can be anonymous by giving the course participant a fictive username. If it is not desirable or needed to

use anonymous data, the username may be set as equal to the real name of the course participant.

User groups

A user group is a set of users. When creating a user group up to 99 users can be auto generated and added to the group (see figure 5.1). If chosen to auto generate users, it is an option to give all n users the same prefix for the user name. The users will then get the prefix followed by *-01, -02, ... , -n.* If no prefix is chosen, the name of the group will be the chosen as default prefix.
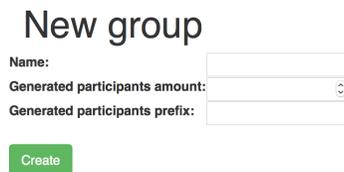
Figure 5.1: The new user group creation page.

Additional users can be added to a group after creation. Already existing users can be added, and new users can be generated. If a new user is generated, the user will get the same prefix for username, followed by the next available digit.

Courses

A course is considered the collection point between users and tests. For each course various tests, users and user groups may be added. If a user group is added to the course, will all the individual users in the group automatically follow the course as well. Only the users who follows the course, either as

an individual user or through a user group, has access to the corresponding tests.

5.3 Testing Modalities

A test can consist of different testing modalities. There are primarily three different testing modalities implemented, one of them with different sub-versions. The different testing modalities and how they are implemented will be presented in this section.

5.3.1 Multiple Choice Question

The three different version of MCQs, presented in section 3.2, are implemented. That includes standard MCQs, MCQs with images and MCQs with videos. Since the three variations of MCQs does not differ as much, the creation page of the three versions were made quite similar (see figure 5.2).

At the creation page for standard MCQs both the question and the answers are text fields where the teacher or administrator can fill in the needed information (see figure 5.2a). A label next to the text field states if the text field should be used for the question, the correct answer or an incorrect answer. All MCQs are added to the database, and can be accessed and reused for other tests.

Creating MCQs with media is relatively similar to uploading standard MCQs, but a button to upload an image or a video is included (see figure 5.2b and figure 5.2c). MCQs with other media are also stored in the database for later access and use.

(a) Standard MCQ (b) MCQ with image (c) MCQ with video

Figure 5.2: How to create different types of MCQs

Evaluation of Multiple Choice Questions

The evaluation of a multiple choice question is relatively straight forward. If the user has chosen the correct answer, a full score is returned. If however the user has chosen an incorrect answer, a score of 0 is returned. By default the score returned when the correct answer is chosen is 1, but the teacher or course administrator has the opportunity to change the score returned upon correct answer.

5.3.2 Landmark

For a landmark question the main goal for the user is to identify important structures or regions at a medical image. Multiple regions may have been identified and named by the teacher or the course administrator, and at the test the user is asked to set a mark at one of these regions.

When creating a landmark question the teacher has to upload a medical image. The image can be named for easier identification, or it can get the file name as a default name. After the image has been uploaded one will be redirected to the page where the question is created (see figure 5.3). At

default only one landmark region will appear, however up to six landmark regions can be drawn onto the picture. At the figure an extra two landmark regions are added for illustration.
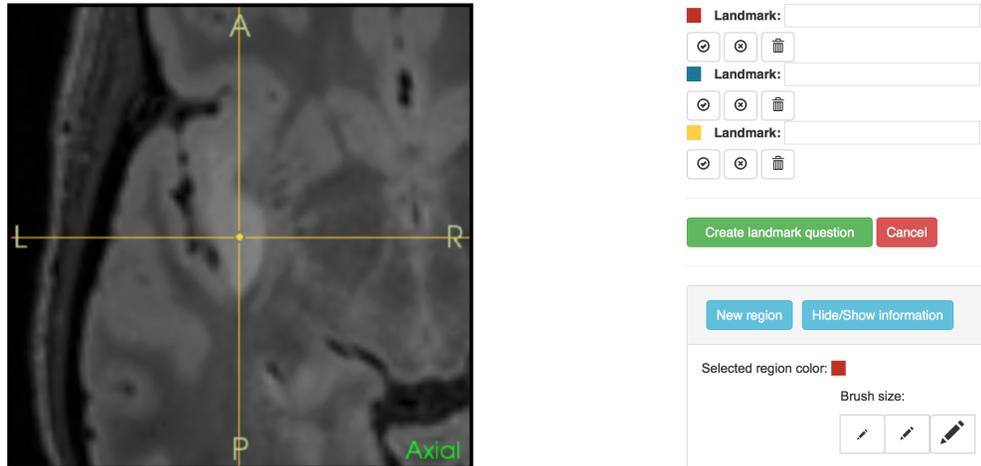
Figure 5.3: Landmark creation page, right after redirection

A landmark region is a structure the course participants should correctly identify and mark during a test. Each landmark region has to have a unique name, and will get assigned a color. This color is used to mark the correct region. The region should be completely covered by the color (see figure 5.4). This way different types of regions can be created, such as lines, closed regions or points. There are also 3 different brush sizes to choose between, to help create different sized regions.

If the teacher has made an error drawing the region, or decides that the region should not be part of the question anyway, a clear or delete region button can be used. A clear button will remove everything drawn with the color corresponding to the region. If the teacher decides not to include the region at all, a delete button will remove the region as well as any of the corresponding color.
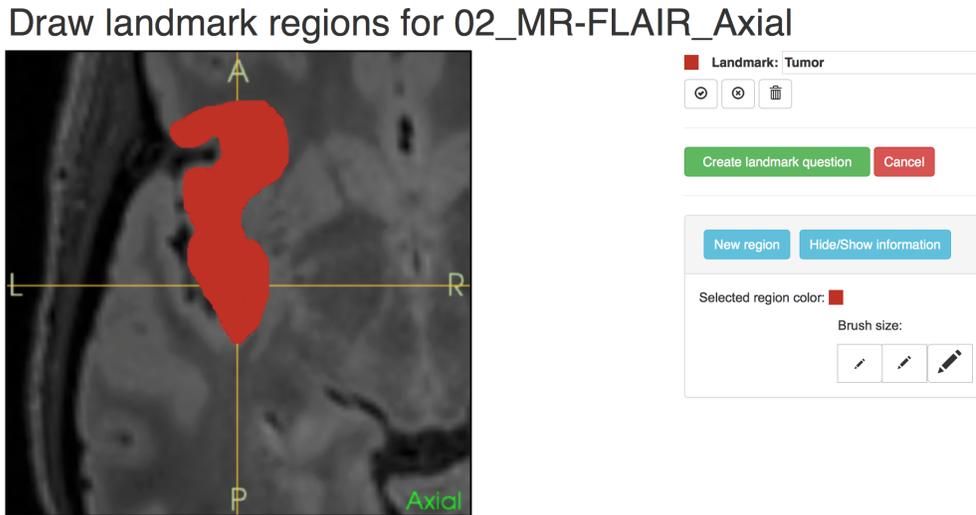
Figure 5.4: Landmark creation page where one region is drawn

At the top of the uploaded image there is an HTML canvas [12], with transparent background. When drawing the landmark regions they will appear at this canvas. This way the landmark regions can be stored as its own separate image. The parts of the image without any color are treated and stored as transparent. The new image will contain as many RGBA points as the original. Later the image can be traversed to find the colored regions.

RGBA points

To represent the medical images, as well as any images created to make an assessment, the RGBA (Red, Green, Blue, Alpha) color space will be used. The first three letters, the RGB-triplet, are used to represent different colors. For each of the colors red, green and blue an integer between 0-255 is used to represent the amount of the primary color included in the color.

The alpha channel [40] is used to represent the opacity, or the transparency of the color represented by the RGB-triplet. The alpha can represent 256

levels of transparency. Level 0 being full transparency, and level 255 being no transparency. Using the RGBA color space, images can be treated as an XY-coordinate of RGBA points. Where X represents the points along the horizontal axis, and Y the points along the vertical axis.

Evaluating a landmark question

To check if the user has placed the mark in the correct region, the application compares the placement of the mark to the image with the landmark regions. The RGBA point at the image with the regions are found using the XY-position to the mark. These two XY-positions are the same, due to the images being the same size. If the RGBA point represents the correct color, the user receives full score. If however the RGBA point represents an alpha or a colored region of another color, the user receives a 0 score.

It does not matter where in the region the mark is placed. As long as the mark is placed in the correct region, the user receives full score for the assessment. The same goes the other way, if the mark is not within the correct landmark region a score of 0 will be given, no matter how close the mark is to the correct region. The default score for a correctly placed mark is 1, but the administrator has the option to change this.

5.3.3 Outline

For an outline question the main goal for the user is to identify and outline important structures or regions at a medical image. As with the landmark question a teacher has to upload and name an image, and identify, outline and name up to 6 outline regions.

The outline regions are given a name and a color the same way as for the landmark questions. However the region should not be completely covered

in color (see figure 5.5). Only the outline of the region should be drawn at the HTML canvas. If a mistake is made while drawing, the teacher has the same clearing or deleting options as for the landmark question.
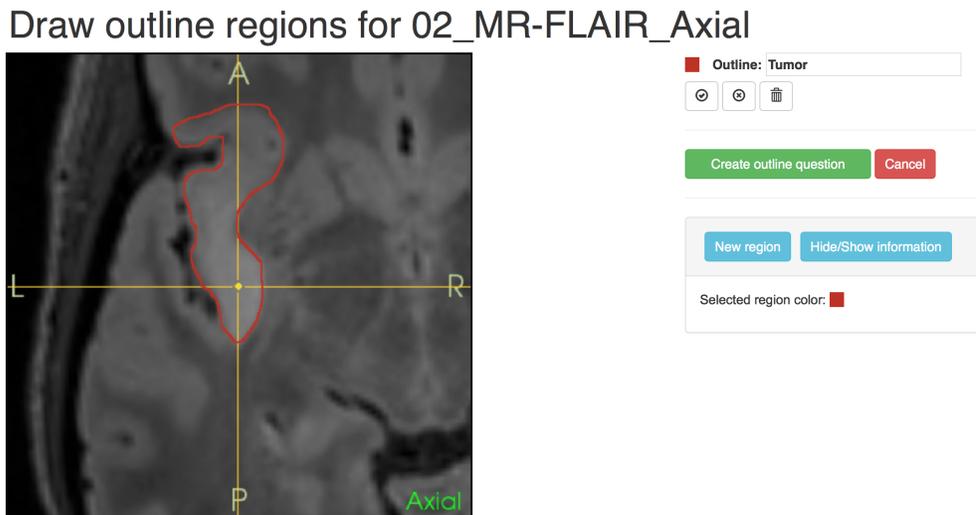
Figure 5.5: Creating an outline assessment

There is also an information box, with description on to how create the question (see figure 5.6). This information box is hidden by default, but can be viewed by clicking the show information button. A similar information box exists for the landmark creation page.

Both landmark and outline questions are stored in the database upon creation. This way the questions can be accessed and used in later courses and tests. However if a teacher only wants their material, especially medical images, being used at this specific course, the individual questions can be deleted after the course is finished.
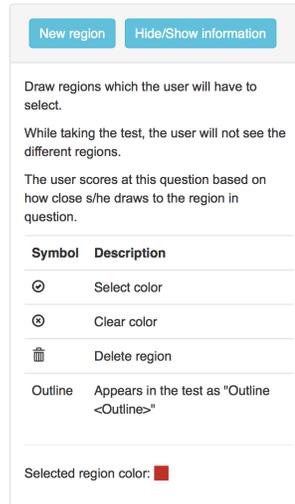
Figure 5.6: The outline information box.

Evaluating an outline question

The goal for the user is to draw their outline as close as possible to the outline solution created by the teacher. The score returned for an outline question is based on the average distance between each point in the user's solution, and the closest point in the outline solution of correct color.

To find the lowest distance between a point in the user's answer and the outline solution, the Euclidean distance is used (5.1). The Euclidean distance between a point in the user's answer and each point in the outline solution is calculated. The distances are then compared to find the lowest. This is repeated for all n points in the user's answer. To find the average distance between the two regions, the n distances are averaged (5.2).

$$dist((x,y),(a,b)) = \sqrt{(x-a)^2 + (y-b)^2} \qquad (5.1)$$

$$avgDist = \frac{\sum_{i=1}^{n} minDist(x,y)(solution)_i}{n} \tag{5.2}$$

The average Euclidean distance between the user's answer and the outline solution is used to determine the score. If the average distance is within a set threshold, the course participant will receive maximum score. If the average distance is higher than another threshold, a score of 0 will be returned. An average distance between the two thresholds, will return a gradual distributed score, where lower average distance will return a higher score.

5.3.4   Outline Solution Question

Since medical imaging interpretation is about interpretation, there is not necessarily one answer that is exactly correct. To take this into account, a question type to create solutions as a collaborative effort was included. The clinicians who are collaborating, should each draw a suggestion for solution by them selves, before getting together for discussion.

To ensure that the submitted answers are presented in such a way that they are easily comparable, all the answers are presented on top of eachother over the original photo. This way it easy to see the small, and perhaps larger, differences between the submitted answers (see figure 5.7). A toggle button for each answer is included next to the image, to make it possible to hide, or show, the different answers. A create outline button is included for creating an outline question using the original image with the corresponding solution suggestion as solution.
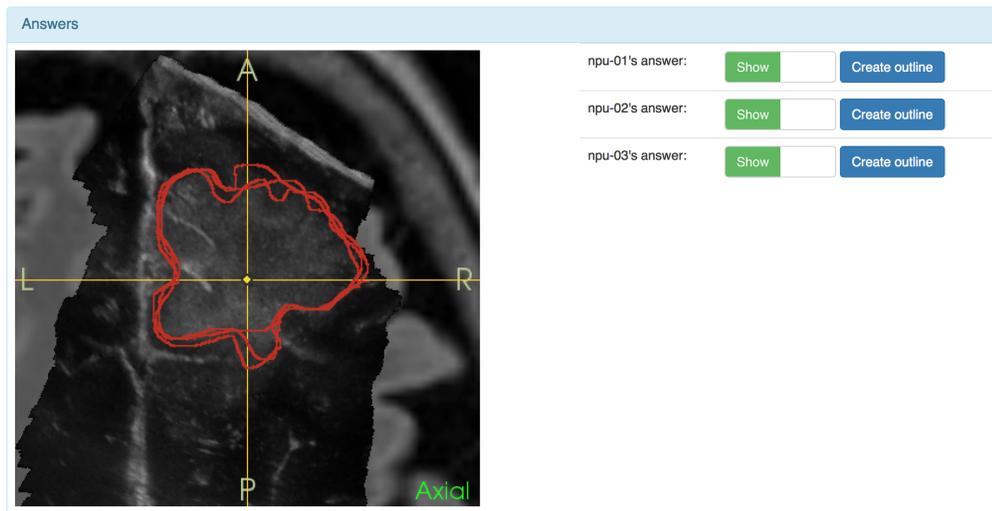
Figure 5.7: The on top comparing for outline solution questions.

5.3.5   Adding a New Testing Modality

To add a new testing modality, the new test type must be implemented, and it would have to communicate with the database. But as well as the implementation directly related to the new testing type, some changes must be made to the existing code. The changes has to be made at at the model, the view and the controller level:

- **Model**: There is a base class named *testUnit* that all testing types extends, so the new testing type would also have to extend this class.

- **Controller**: The mapping of the data coming from the view, to the model to be saved, would have to be done through a form.

- **View**: The HTML code for presenting the new testing type would have to be implemented. This should preferably be done in a manner matching the existing view. The new testing type would also have to be added to the list of existing questions, and test scores should be able to be set at the settings page.

5.3.6 Settings

The default score returned for a question that is answered correctly is 1 for all question types. This however might not always be desirable. Some times may an imaging question be worth more than an MCQ, this should be reflected by giving a higher score for the imaging questions.

This can be done at the settings page (see figure 5.8). The minimum and maximum thresholds for outline can be set at this page as well. The minimum threshold is used to determine how close the user's answer has to be to get full score, and maximum states at which distance the user should get a 0 score. Both thresholds are set to 5 at default.

Figure 5.8: The settings page.

This is global values, and will be applicable for all test taken after the update. It will not affect answers that is already submitted. It is not possible to set values just for one test, so the administrator has make sure everyone

has answered existing tests, or the users might be scored based on different values.

5.4   Tests

A test is, by the application, considered to be a collection of individual questions. The test also includes a set of optional variables such as whether or not the course participants will be presented with the correct solution after submitting an answer and if the course participants can delete their submitted answer to get a new attempt.

For each tests there are different options, including viewing and editing the test, viewing or clearing the submitted answers and deleting the test (see figure 5.9). Some of these options will be further described in the following subsections.

Tests

Test name	View and edit test	List users taking course	Compare test results	Clear test results	Delete test
TumorDelTest	👁 View	☰ View users	☰ Compare results	🗑 Clear	✖ Delete
NeuroCourseQuiz	👁 View	☰ View users	☰ Compare results	🗑 Clear	✖ Delete
NeuroCourseOutline	👁 View	☰ View users	☰ Compare results	🗑 Clear	✖ Delete

Figure 5.9: The *list all existing tests* view.

5.4.1   View Test Results

When the course participants has finished their tests, the teacher or administrator has the opportunity to see their obtained test score, as well as the submitted answers. There are two primary ways of viewing the results, to

view all the answers submitted by one person or to view all the answers submitted to one question.

To make it easier to compare the answers submitted to one question, it is possible to view all answers submitted to the question at the same page. For this view the original question with the correct solution will be presented at the top of the page, while all answers given from the course participants will be presented underneath with corresponding username.

For the outline question the average Euclidean distance between the answer outline and the solution outline is also presented for each course participant. And for both outline and landmark questions it is possible to add the solution on top of the answer for each user, for easier visualisation of the distance between the two regions (see figure 5.10). The thicker line is drawn by the user, and the thinner line is the solution created by the teacher.

If the teacher has chosen that the users will be presented with the solution after an answer has been submitted, the user will get the same compare view as in figure 5.10. They will however only be able to see their own answers, not the answers to the other users.

5.4.2   Delete Tests Results

At some point it might be desirable to delete submitted answers. That might be due to changes in the test, or due to technical problems. Either way test scores, and submitted answers, must be cleared to give the user a chance to retake the test. It might be that all answers submitted to a test should be cleared, or just the answer submitted by one specific user.

To do so two clear test results buttons are included. To clear all answers submitted to a test a *clear test results* button is included for each test, this button can be found at the *list all tests* view. The button for clearing a
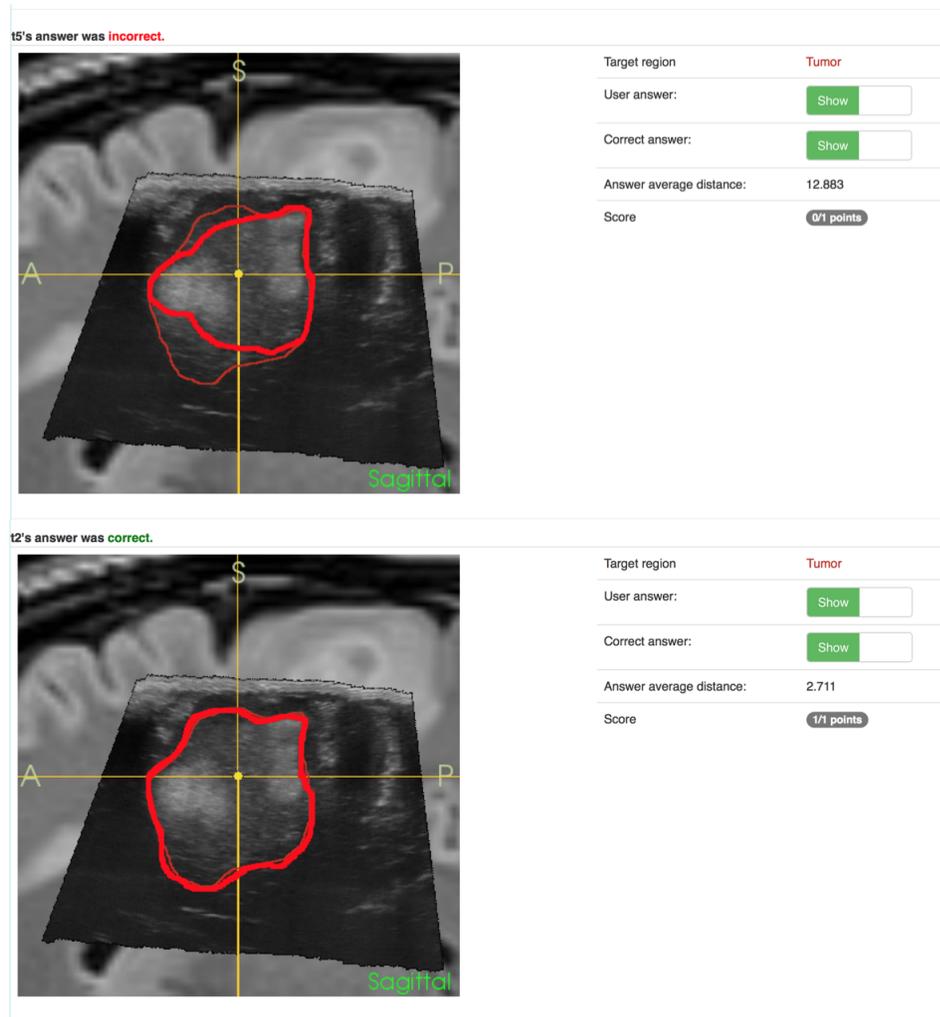
Figure 5.10: Comparing submitted answers for an outline question.

single user's submitted answer is found at the *list all users taking course* view. A *clear test result* button is included for each user that has answered the test. If a user has not answered the specific test, the button will be gray and unclickable, opposed to red and clickable for users who has answered the test (see figure 5.11).

Figure 5.11: The *list all users taking a course* view, including the *clear test results* button.

5.5 Mobile Devices

The application is also able to run at mobile devices (see figure 5.12 and figure 5.13). The first figure includes the course participants view for answering an MCQ with image (5.12a), a landmark question (5.12b) and an outline question (5.12c). Some of the functionality from the admin pages are presented in the second figure, that includes the test overview page (5.13a), the list all questions view (5.13b) and the compare submitted answers for question view (5.13c).

5.6 System Design

This section will focus on the design choices for the application, with emphasis on the usability guidelines presented in chapter 2 section 2.3.1.

As presented in chapter 2 section 2.1 there are a numerous different imaging modalities that might be used in the various courses. The different imaging modalities will result in different types of images, using different color palettes. For instance will an ultrasound image be primarily black and white, while a laparoscopic image often will be varying scales of pink or red. To avoid heavy contrasts to any of the imaging modalities, a limited color palette, with

(a) MCQ   (b) Landmark   (c) Outline
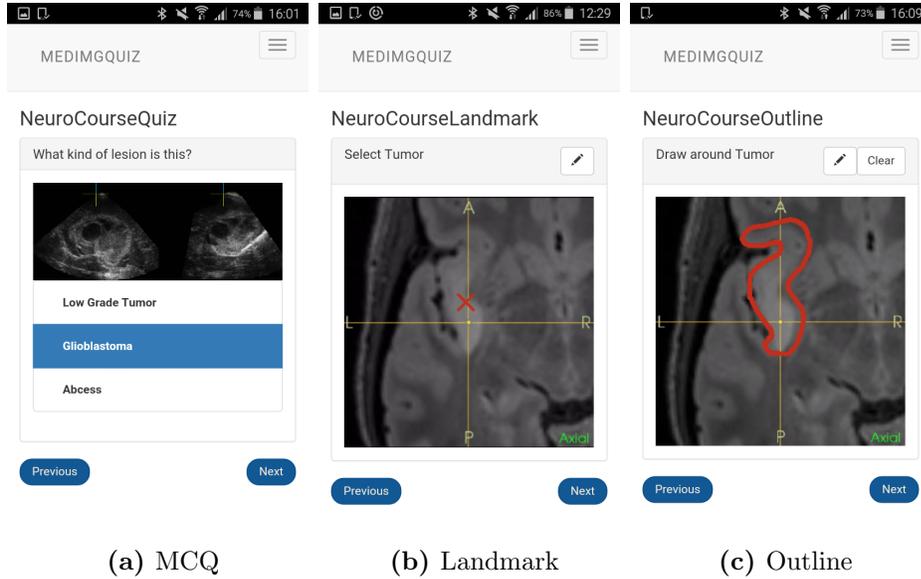
Figure 5.12: Course participants pages on mobile devices

(a) Test overview   (b) List questions   (c) View answers
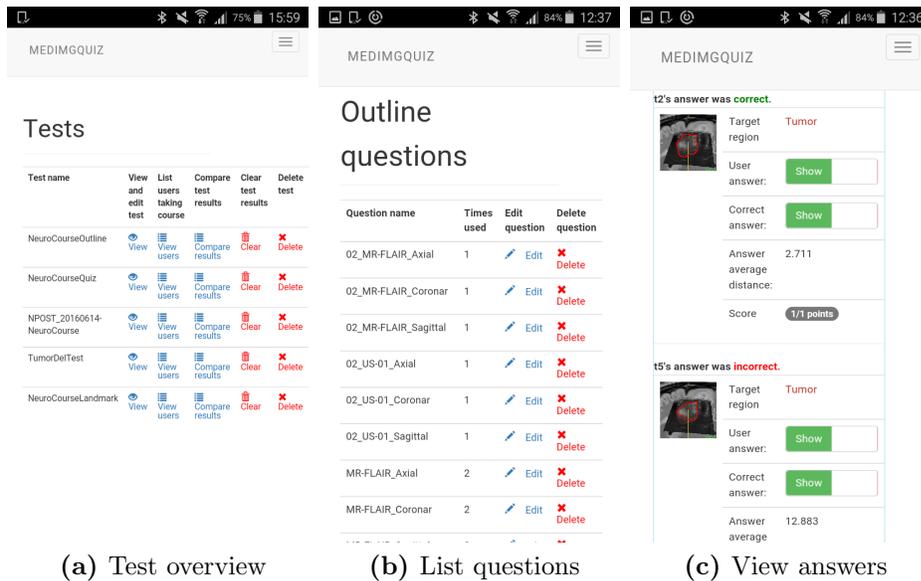
Figure 5.13: Admin pages on mobile devices

(a) Feedback for success

(b) Feedback for minor errors

(c) Feedback for fatal errors

Figure 5.14: The different feedback given from the application.

a white background was chosen.

The primary colors used for the system was grey, white and blue. These colors were used to create a consistency throughout the system. The navigation bars are presented with a light grey background. Two shades of blue were used. A darker blue when hovering over the navigation bar and when choosing correct options during a test. This color was also used at informational buttons such as *Take this test*, *Next* and *Previous*. And a lighter blue at informational buttons on the admin page, such as *Show information*. This blue was also used in tables.

Often will red signify error, while green signifies okay. To draw on this association to the real world, red and green was chosen for create and cancel buttons, and feedback presented to the user (see figure 5.14). The background color of the feedback shows the success status of the action, red for fatal errors, yellow for warnings and green for success.

As well as presenting an example of the colors used, figure 5.14 also presents an example of how the application gives appropriate feedback, and lets the user know the system status after performing various actions. To let the user feel in control of the application, most parts of the application comes

with cancel, edit or delete buttons. Everything that the user has created or uploaded can be deleted or edited. If the user has gone in into a page for uploading new material or edit some of their existing material, a cancel button is provided in case of need.

The parts of the application which might be troublesome, primarily how to create landmark and outline assessments comes with an information box, as presented in section 5.3.3. This information box is thought to help with parts of the application that might not be intuitive, in hopes of preventing both frustration and errors. The information box is hidden by default, as it will most likely not be needed the majority of time. But can become visible in any moment of need.

Since the application is to be used by different fields, to different courses it is important that the users of the application can leave their mark, by using naming conventions that corresponds to their daily practices. To ensure this most of the naming are left to the users. Some places the user can chose between a default name, or to name the material themselves. For easier navigation are related items placed within a relatively short distance of each other. Confirmation buttons, as well as any next buttons are placed under, or at the lower right of the objects.

5.7 Known bugs

- Only one region from each image will be presented as a question during the tests, the region will be chosen randomly.

- Video on mobile devices does not work properly for all browsers.

- Admin pages on mobile devices scales images too small for comparison views.

5.8 Supported Browsers

The application is tested for all of the five most common browsers presented in section 2.3.3. All the browsers could run the application without any problems. That includes *Chrome*, *Internet Explorer* versions 8 and up, *Firefox*, *Safari* and *Opera*. Other browsers may be able to run the application as well, but it has not been tested.

Chapter 6

Results

In this chapter the results from this project will be presented. The results are divided into two parts, where the first part, presented in section 6.1 will be devoted to the application developed, and the needs it meets. The second part, presented in sections 6.2 to 6.4 is the results from the user test.

6.1 Medical Imaging Interpretation Courseware

The main goal of this thesis was to develop a web application to be used as a tool during medical imaging interpretation courses. This section will present the application through sequence diagrams, presenting the intended way of using the application. The application contains primarily four different usages: (1) creating courses, users and tests, (2) answering tests, (3) viewing submitted answers and (4) establishing an outline solution.

6.1.1 Creating Tests

Figure 6.1 presents the sequence diagram for creating a test and figure 6.2 presents the views corresponding to the sequence diagram. To get access to the admin pages the teacher or administrator has to log in with an admin user (6.2a). After successfully logging in can a new course be created (6.2b), as well as users and user groups(6.2c and 6.2d). The user or user group may then be added to the course. A combination of users without groups and user groups can be added to the same course.

To create a new test the teacher or administrator has to name the test, choose which of the courses the test should be available to, whether or not the course participants will be presented with the correct solution after submitting an answer and if the course participants can delete their submitted answer to get a new attempt (6.2e). Any of the choices made at this step can be edited later.

After creating the test, different questions can be added to the test (6.2f). This may be done in two different ways. A new question can be created, or an existing question can be added from the database. If a new question is created, it will be added to the database, so it can be reused at later tests. Questions can also be created without being related to a test. The teacher or administrator also has the option to update the global settings for scores given to a question, as well as thresholds used by the outline question.

6.1.2 Answering Tests

Figure 6.3 present the sequence diagram for answering a test, while figure 6.4 presents the sequence diagram as views. When logging onto the application the user will be presented with the courses they are following, and any available tests for the corresponding courses. If the user has not answered the
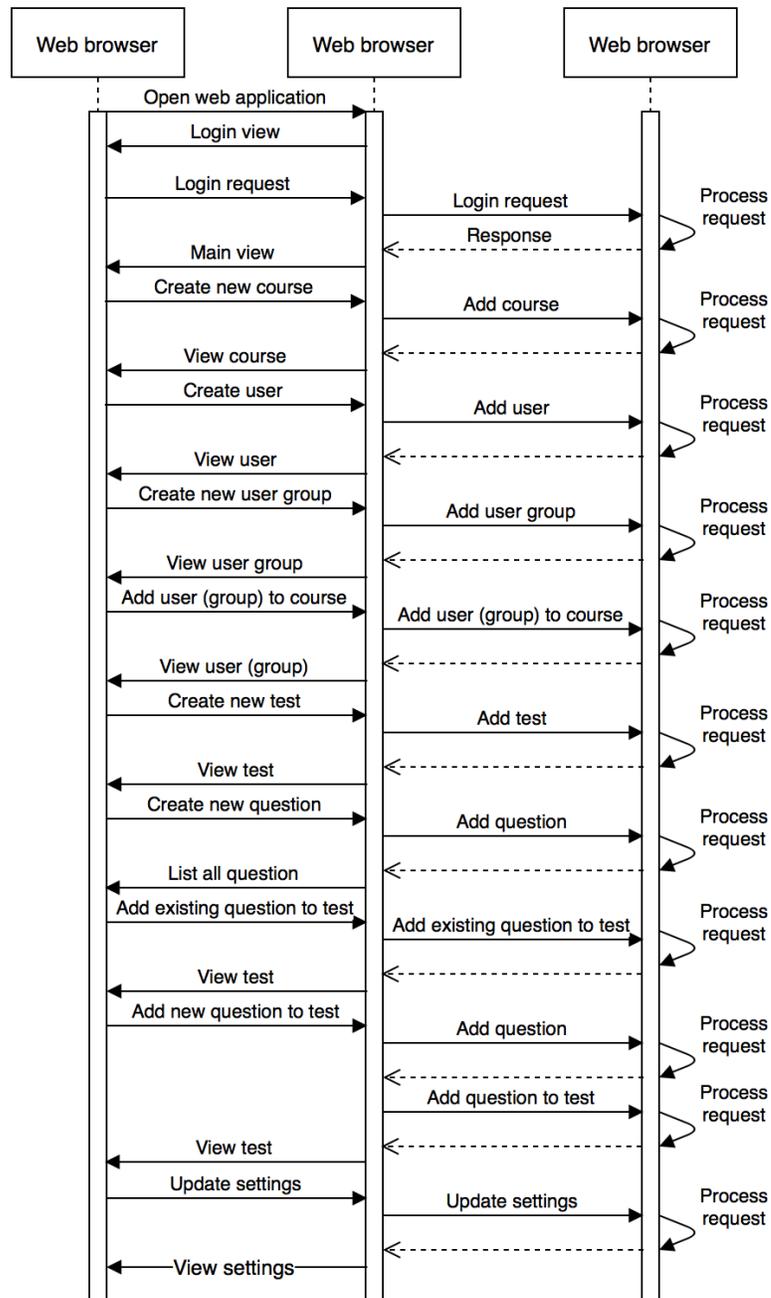
Figure 6.1: The sequence diagram for creating a test

(a) Login view

(b) Course view

(c) User view

(d) User group view

(e) New test view

(f) Test view

Figure 6.2: The views seen when crating a new course with users and tests

test, a blue *take this test* button is available (6.4b). This will change to the
test score when the user has submitted an answer to the test (6.4f).
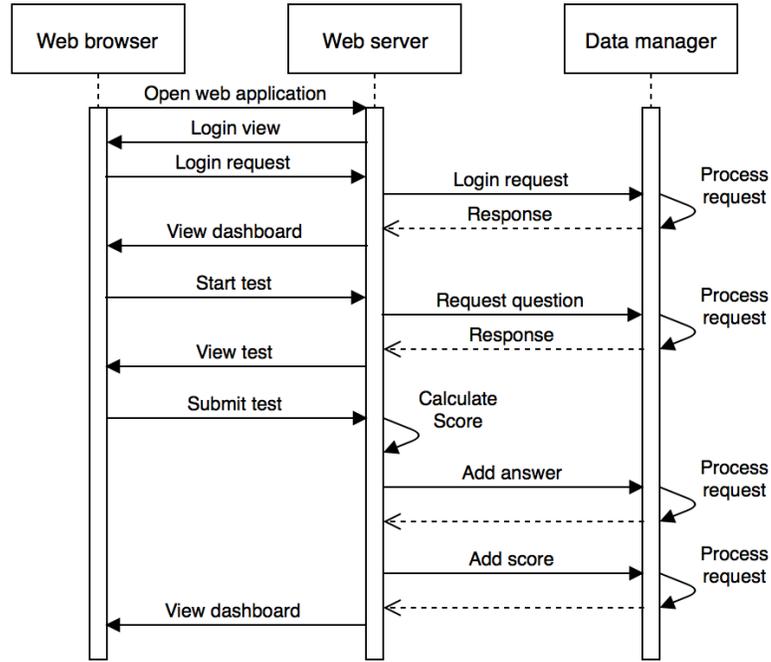
Figure 6.3: The sequence diagram for creating a test

For the landmark and outline questions will the users be presented with the
original image as it was uploaded. No regions will be shown during the test.
For landmark questions should the users place a mark in one of the landmark
regions associated with the image. The mark can be placed by clicking at
the image (6.4c). There can only be one mark at the image, so if the user
re-clicks at the image the mark will be moved to the newest position. For
an outline question should the user draw around one of the outline regions
associated with the image (6.4d).

When answering an MCQ, the users will be presented with the statement,
possibly including an image or video, and the answer options. The user is
however not informed which of the answer options that is correct. The user

should try to identify the correct answer option (6.4e). Only one option can be chosen for each question, so re-clicking at another option will change the chosen option.

6.1.3 Viewing Test Results

Figure 6.5 present the sequence diagram for answering a test, while figure 6.6 presents the sequence diagram as views. The teacher or administrator has to list all tests, and find the test for which they want to view the results (6.6b). The results can either be viewed for each question (6.6c) or for each user (6.6d and 6.6e).

6.1.4 Establishing Outline Solution

The final use case for the application is establishment of an outline solution as a collaborative effort. This use case will be a combination of the three sequence diagrams presented above. A series of images can be uploaded. To each image, the name of an outline region should be included, but not the actual solution region. These images can be included in a test, where the test takers are asked to create the solution.

After each test taker has submitted an answer by them selves, they can get together to analyze and discuss the results. Based at the discussion one of the submitted answers can be chosen as the solution for the region. If however the discussions concludes that non of the submitted answers where satisfying enough, one of the participants may be assigned to create a new solution based at the discussion and the submitted answers.

(a) Login view

(b) Dashboard view

(c) Answering a landmark question

(d) Answering an outline question

(e) Answering an MCQ

(f) After submitting tests
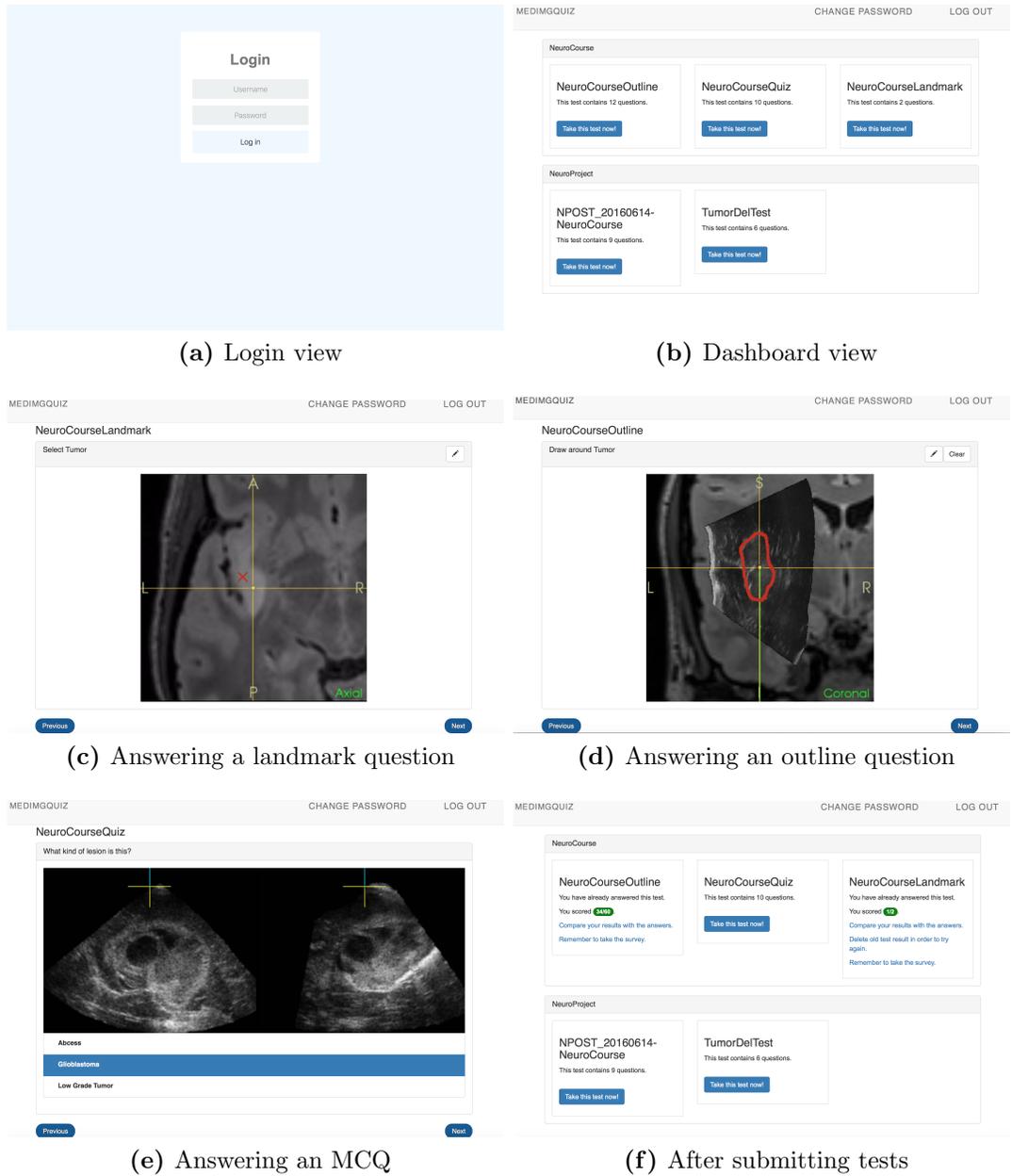
Figure 6.4: The views seen when answering and submitting a test
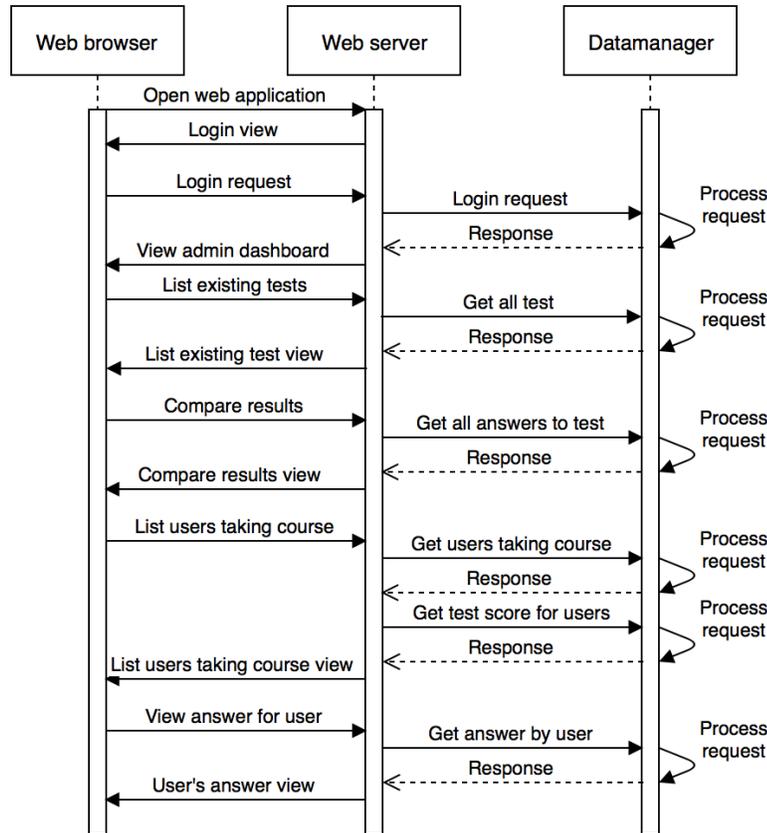
Figure 6.5: The sequence diagram for viewing test results

6.2 Usability Test

In June 2016 *The National Advisory Unit for Ultrasound and Image-guided Therapy* arranged the course *Ultrasound in Neurosurgery*. During the course the course participants received a user for MIIC. The users were following a course that had two tests, one consisting of 12 outline questions and one consisting of 3 standard MCQs and 7 MCQs with images. The tests where not mandatory and the course participants could choose if they wanted to take the tests. After submitting a test they where given a link to the feedback
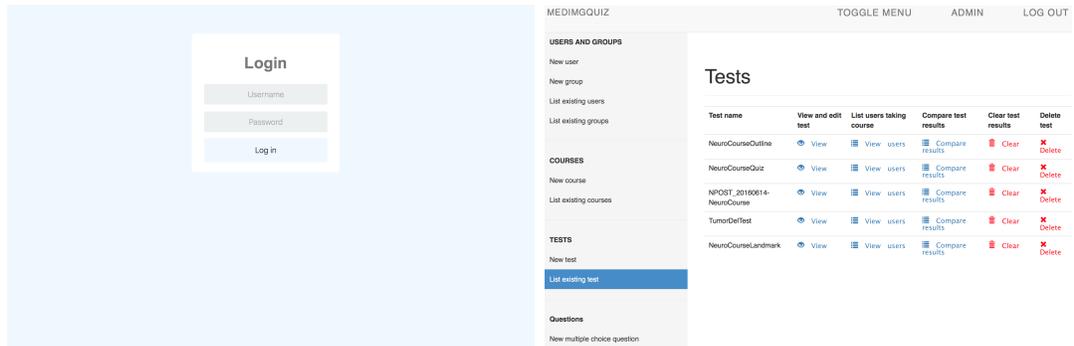
(a) Login view

(b) List all tests view
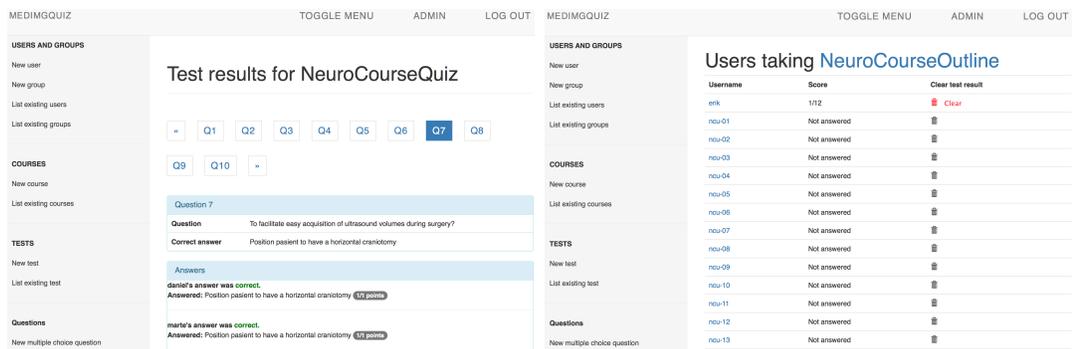
(c) View all answer to each question

(d) View users taking course
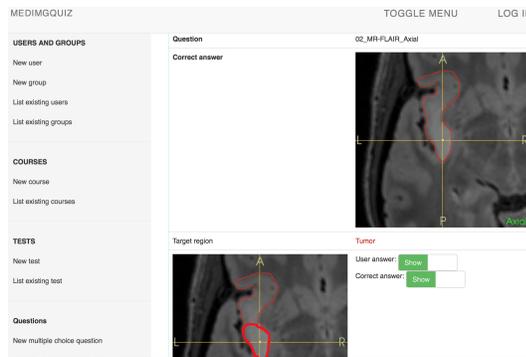
(e) Viewing a single users answer

Figure 6.6: The views for viewing and comparing test restults

form.

An other group that participated in the user test was some of the employees of SINTEF. They were given a user, and followed the same course, and hence had access to the same tests as the participants of the *Ultrasound in Neurosurgery* course. All though the employees of SINTEF were not the target audience for this part of the system they were included as it was difficult to requite a satisfactory amount from the target group. The employees of SINTEF where also given a chance to test the outline solution question. A test consisting of 9 outline solution questions was created, and the participants got to answer the test. They also got access to the compare views in the admin pages.

Answering the feedback form after trying the application was not mandatory, and not all the users submitted the feedback form after trying out the application. The rest of this chapter will be based at the 5 users who submitted the feedback form.

6.2.1 Test Participants Background

The test participants had different backgrounds, knowledge and reasons to use the application. According to the questionnaire 60% of the test users had a background as technician workers, while 40% was medicine students. All of the technicians answered that they use medical imaging in their profession, while the students answered that they are currently learning about it. 80% said they only tried the course participant's pages, while 20% tried the administration pages as well.

Id	Item	Score
1	I think that I would like to use this system frequently	3.2
2	I found the system unnecessarily complex	3.8
3	I thought the system was easy to use	3.8
4	I think that I would need the support of a technical person to be able to use this system	3.8
5	I found the various functions in this system were well integrated	3.2
6	I thought there was too much inconsistency in this system	3.2
7	I would imagine that most people would learn to use this system very quickly	3.6
8	I found the system very cumbersome to use	3.8
9	I felt very confident using the system	2.8
10	I needed to learn a lot of things before I could get going with this system	3.8
		SUS Score = 87.5

Table 6.1: The SUS score of the individual items.

6.3   SUS Score

The SUS Score was calculated as presented in section 4.5. The scores for the individual items are presented in table 6.1. In the *score* column the SUS score of the items are calculated and the final SUS score is presented at the lowermost row. The application received a SUS score of 87.5, out of a 100 points. This corresponds to the rating *excellent* at the Adjectove Rating Scale.

6.4   Questionnaire Results

The second part of the questionnaire consisted of both statement-option questions, and textual feedback questions. This section will present the results from both of those question types.

Id	Question	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree
1	I think that the system might be useful in courses related to medical imaging.	0%	0%	0%	20%	80%
2	I think using the system will help me learn medical imaging interpretation.	0%	0%	20%	40%	40%
3	I felt I got to prove my skills and knowledge about medical imaging interpretation.	0%	0%	20%	20%	60%

Table 6.2: The results from the questionnaire.

6.4.1 Statement-Option Questions

The results from the rest of the statement-option questions are presented in table 6.2. The feedback is generally very positive to the fact that MIIC would be a useful tool during medical imaging interpretation courses. For these questions the average response was between *somewhat agree* and *agree*.

The response was not that positive in regards to whether they felt as if they had a chance to prove their knowledge. However some of the participants explained this as being due to the outline thresholds being to low, and the application returning a score of 0, even though they were still rather close to the ground point.

6.4.2 Textual Feedback

The final two questions of the questionnaire gave the test takers an opportunity to give a short written answer as feedback. The first question asked if the test takers felt that some functionality was missing from the application, and the second question asked if they had any suggestions for improvements.

This sections provides a summary of the textual feedback given in the questionnaire.

Progress bar during the test

The teachers are free to add as many, or as few, questions as they like to each tests. The test takers however does not get informed of how many questions a test consists of. So multiple of the test takers suggested that some sort of progress bar would be a nice feature during the tests.

The progress bar could be as simple as showing which question the user is currently at, and how many questions the test consist of in total. Or a more advanced progress bar, where the user could navigate between each question, such as the one used for comparing tests results. For the last progress bar, color coding could be used for showing the user which question has been answered, and which remains.

Outline thresholds was too low

For the usability test, both of the outline thresholds was set to 5 pixels. That means that a full score would only be received if the test participant's answer was less than 5 pixels away from the solution on average. Some of the test participants complained that this was too difficult, and points should be awarded even with a greater miss compared to the solution.

The functionality for setting the outline thresholds is already implemented, so it is possible change the settings to award points even with a greater miss. A 5 pixel threshold is just the default value chosen for the test. This feedback is however valuable for when conducting real tests. Different default values for outline might also be considered.

Make the three MCQs as one

The three MCQs, standard multiple choice questions, multiple choice questions with images and multiple choice questions with video are all part of the same question type. In the application they are however treated as three completely different question types in the admin pages.

Present comparing answers using different colors

For the comparison of the outline solutions it would have been useful to present the different outline solution regions in different colors. By adding the user name in the corresponding color next to the image, it would have been easier to see which answer each user had contributed with.

Chapter 7

Discussion

This section will discuss the research questions presented in chapter 1. The discussion and evaluation will primarily be based on the feedback given in the questionnaire.

RQ1: Is the application useful in assisting courses related to medical imaging?

As table 6.2 presents, were the test users very positive when asked about the applications usefulness in courses related to medical imaging interpretation. For statement 1, all except 1 user answered that they *agreed*, the last user answered *somewhat agree*. And for statement 2, 80% answered that they *agree* or *somewhat agree* that this application would help them learn about medical imaging interpretation.

Even though the group that answered the feedback form was limited to 5 users, the results show a promising indication that the application can be useful in assisting medical imaging interpretation courses. Others who tried the application without answering the feedback, also expressed positive

comments and said that they saw potential and usefulness in the application.

RQ2: Is the application able to visually train and assess medical imaging interpretation skills?

Statement 3 in table 6.2 asked the user if they felt they had the opportunity to prove their skills and knowledge about medical imaging interpretation. The feedback here was also mostly positive, all except one user answered *agree* or *somewhat agree*, where the last user answered *neutral*.

One of the issues presented by the users in regards to proving their skills was the fact that the outline thresholds was set to low, as discussed in section 6.4. It is important to do more testing and evaluation to find the optimized outline thresholds, to satisfy both the teachers and the course participants in regard to how close an answer has to be to the solution to achieve a score.

As with RQ1 this is based at statistical feedback, and hence the number of test users should ideally been around 20, however the results do show a promising indication that this application can train and assess medical imaging interpretation skills.

Chapter 8

Conclusion

The motivation behind this thesis was to develop a web application that could be helpful when teaching courses related to medical imaging. The reason behind being the important role medical imaging plays within the field of medicine. To ensure proper education of medical imaging interpretation, hospitals and medical institutes teaches various courses related to the practice.

One of the best ways to acquire medical imaging interpretation skills is by practicing interpretation of such images. Based on that it was decided that the application was to contain various tasks for interactively use medical images to train and assess interpretation skills in a visual manner.

The application got the name *Medical Imaging Interpretation Courseware*, and handles course, user and test administration. Since medical imaging interpretation was the main motivation behind the thesis, the emphasis of the application was at the testing modalities used for testing medical imaging interpretation skills and knowledge.

All the users can be anonymous by giving the course participant a fictive user-

name, or non-anonymous by giving the course participant their real name for username. Fictive usernames can be auto generated to a user group for easier creation of large quantities of users. The tests can consist of different types of questions, varying from standard text questions using multiple choice, to questions where the answer is given by clicking or drawing at a medical image.

The application comes with administration pages where the teachers or administrators can create courses, users, user groups, tests and the various questions. For the questions can different types of data be uploaded, and solutions can be drawn directly at the image where that is suitable. Since there rarely are one true answer to interpretation tasks, a question type to create solutions as a collaborative effort was included to the application.

The web application was tried out by a small user group, consisting of both medical workers and students. Their evaluation of the application was that it was easy to use, educational and showed potential for being a valuable tool when teaching medical imaging interpretation courses.

Since the application was only tested by a small test group, the results may only be used as a promising indication of the usefulness and usability of the application. A test performed by a larger test group, consisting of more users from the main target group, may present a different result.

Chapter 9

Future Work

There are many possibilities for improving the application. Doing so may enhance the MIIC usage as a teaching tool. Some of those possibilities will be presented in this chapter, and are based on discussions throughout the implementation phase, that would have been implemented if there was more time, and feedback from the user test.

9.1 Courses, Users and Groups

The application as it is now only contains a small amount of administration related to courses, users and groups. So this part of the applications contains many opportunities. Some possible features includes:

- **Communication**: Communication between teacher and course participants, either through instant messaging between teachers and individual user or group, or between teacher and everyone who follows the course.

- **User information**: Make it optional to save more information about

the course participants, such as name, studies etc.

- **Publish non test related material:** Make it possible for teachers to publish material that is not related to a test.

9.2 Testing

There are some improvements that should be made for the existing application. In addition to improvements to the existing application, new features may be added to expand the areas of use.

9.2.1 Improvements to Existing Solution

This section contains improvements that could be made to the existing test modalities.

Zooming when drawing

To be able to create more accurate solutions a zooming feature may be implemented, making it possible to zoom in at areas of the medical image. This feature should be included for both the administration pages, when drawing solution regions, and for the course participants, when answering tests.

Upload multiple files

When uploading material it would be beneficial to be able to upload multiple images at one time. This could be time saving for the teachers.

Timing

Some tests should be answered within a certain time. It might be that the test should only be open for answers within a given time period, or that the course participants has to submit the test within a given time after starting the test.

Set local settings

The application contains a settings page that gives the teacher the possibility to change various variables for the tests, such as the scores given for each test type and the different thresholds for the outline question. These settings will however affect all the tests. This feature may be made local for each tests, so that different tests could have different settings.

9.2.2   New Testing Modalities

New testing modalities may be included to expand the area of knowledge and skills that is being tested. Other testing modalities that was discussed, but not implemented due to time limitations was video testing and equipment testing.

Video testing

There are different ways to include video testing. A possibility is to ask the course participants to find the most optimal part of the video for performing various procedures, or to stop the video when a certain structure is visible. When the video is stopped, the course participants may be asked to locate or outline visible structures.

Equipment Testing

There are many different equipment used during various procedures. Some of that equipment may require some adjustments before use. One discussed testing modality was to use an image of the screen from an equipment, and let the the settings be adjustable. The course participants would then be asked to correctly adjust the settings depending on the given case.

9.3 Connection to Virtual Reality Simulators

After the course participants has completed a challenge at the VR simulators, various scores are being calculated as to how the course participants performed at the different tasks. A feature recommended for future work would be to find a way to present these scores to the course participant when logging in with a corresponding user. The VR simulators creates a file consisting of various scores, this file, or parts of it, could be uploaded to the application, presenting the scores in an orderly manner.

9.4 Expanding the Area of Use

Even though the application was developed with courses related to laparoscopy and neurosurgery in mind, it was made quite general to make it possible to use for other fields as well. Any images can be uploaded for the imaging test types. This makes the application applicable for other areas of use, such as:

- **Dental**: Locating holes, wisdom teeth or nerves.

- **Eye care**: Identifying various eye diseases, and the areas they cover.

- **Veterinarian**: Learning anatomy and interpreting medical imaging used at animals.

- **Laboratory technicians**: Analysing microscopical images.

However no clinicians from other areas was included during the development process. So for the application to be optimized for them, other testing modalities might have to be included. The application was also developed with medical courses in mind, but courses related other fields might also be applicable, such as:

- **Geographical**: Locating or outlining countries or other geographical structures.

- **Radar imaging**: Interpreting position and movement of highly reflective objects, such as aircrafts and ships.

- **Astronomy**: Interpreting astrological images.

Appendix A

Acronyms

NTNU Norwegian University of Science and Technology

MIIC Medical Imaging Interpretation Course

NSALK Nasjonal Kompetansetjeneste for Avansert Laparoskopisk Kirurgi

VR Virtual Reality

CT-scan Computed Tomography scan

MRI Magnetic Resonance Imaging,

MVC Model View Controller

RAMS Reliability, availability, maintainability, and safety

MCQ Multiple Choice Questions

RGBA Red, Green, Blue, Alpha

ACID Atomicity, Consistency, Isolation, Durability

SUS System Usability Scale

CSRF Cross Site Request Forgeries

Appendix B

SUS Form

System Usability Scale

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Appendix C

Questionnaire

What is your background?

○ Student

○ Doctor

○ Other...

Which part of the system did you try?

○ Admin pages

○ Test pages

Are you familiar with medical imaging interpretation?

○ I use it in my profession

○ I am currently learning about it

○ I don't use it in my profession

○ Other...

I think that the system might be useful in courses related to medical imaging

○ Disagree

○ Somewhat disagree

○ Neutral

○ Somewhat agree

○ Agree

I felt I got to prove my skills and knowledge about medical imaging interpretation

○ Disagree

○ Somewhat disagree

○ Neutral

○ Somewhat agree

○ Agree

○ Other...

I think using the system will help me learn medical imaging interpretation

○ Disagree

○ Somewhat disagree

○ Neutral

○ Somewhat agree

○ Agree

Is there something you think could improve the system?

Long answer text

Is there some functionality you feel were missing from the system?

Long answer text

Appendix D

Dashboard

D.1 Admin pages
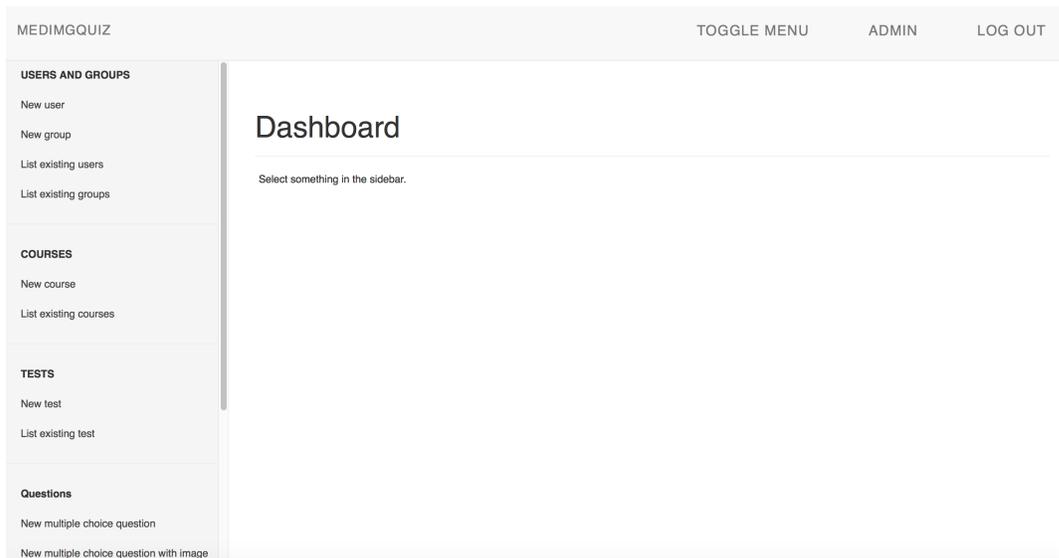
MEDIMGQUIZ   TOGGLE MENU   ADMIN   LOG OUT

USERS AND GROUPS

New user

New group

List existing users

List existing groups

COURSES

New course

List existing courses

TESTS

New test

List existing test

Questions

New multiple choice question

New multiple choice question with image

Dashboard

Select something in the sidebar.

MEDIMGQUIZ   TOGGLE MENU   ADMIN   LOG OUT

New test

List existing test

Questions

New multiple choice question

New multiple choice question with image

New multiple choice question with video

New landmark question

New outline question

List existing questions

TEST RESULTS

Delete all existing test results

OTHER

Survey

Settings

Dashboard

Select something in the sidebar.

D.2   Student pages

MEDIMGQUIZ   CHANGE PASSWORD   LOG OUT

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