De Montfort University

Training System for Enhancing/reinforcing the Learning Experience of Model-based Systems Engineering.

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MSc. Mechatronics

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Declaration

I, Guillermo Alfredo Mosquera Canchingre, declare that all the content in this paper entitled “Training System for Enhancing/reinforcing the Learning Experience of Model-based Systems Engineering “is my own work and it has not been submitted to this or any other Academic Institution for any award, and all the sources to other materials have been acknowledged.
Acknowledgement

First, I am grateful with my parents Guillermo Mosquera and Elizabeth Canchingre because without them I would not be who I am and would not be able to be where I am now.

I would like to express my gratitude to my supervisor Dr. Chi-Biu Wong for helping me to develop this project, and supervising its progress.

I wish to express my sincere gratitude to Sarah Mills for all her help and support during the development of this written report.
Abstract

This paper reviews the styles of teaching and learning of engineering education, defining the most appropriate way engineering students learn. It covers concepts from model-based systems engineering and how this knowledge is currently delivered to students as well as how they receive it. In addition, it presents the concept of an idea to develop a training system to enhance the learning experience of learners of model-based systems engineering.

It demonstrates how the Model Based Systems Engineering approach and methodology is used to address this project as well as the advantages that adopting this approach and methodology provides.

Additionally, it contains the design and implementation of the MBSE training platform and a case study, which are the main elements of this project. Unfortunately, due to the time constraint only part of the implementation on these two elements is presented in this work.

As results of this work, an architectural framework for the development of the MBSE training platform is defined which would be useful for further development. It also presents part of the design of the case study, which could be used as a guide for future development as well. The evaluation performed to the implemented part of the MBSE training platform, indicates that the contents need to be clearer in order to improve the learners experience.
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1. Introduction
1.1. Motivation

Mechatronics Engineering is defined as: “the synergistic combination of mechanical and electrical engineering, computer science, and information technology, which includes control systems as well as numerical methods used to design products with built-in intelligence” [1].

Moreover, Krishnan suggests that a mechatronics system can be properly designed only when engineers with the expertise in the different areas that form mechatronics intervene in the process[2].

Usually, some academic institutions, potential students and people in general tend to think that mechatronics engineering would form engineers that should master the different disciplines that comprise it, including mechanical, electronics and software engineering; nevertheless, it is not possible to train mechatronics engineers to obtain the same amount of knowledge in all the disciplines that comprise it as it were for example, a pure electronic or mechanical engineer in the same period of time. This does not mean that a mechatronics engineer should spend more time studying in order to master multiple disciplines.

The role of a mechatronics engineer should be interpreted as the engineer that has a general understanding of multiple disciplines in order to cooperate and integrate the knowledge of engineers from other disciplines. Indeed, Model Based Systems Engineering approach offers a great opportunity for mechatronics engineers to address this purpose.

1.2. Problem Statement

Nowadays, industry requires professionals who can manage complex systems because the products or systems being produced are getting more and more sophisticated and complex with much shorter lead time; therefore, the principles of systems engineering plays a key factor to tackle these issues.

Unfortunately, systems engineering approach is too complex to gain a good grasp just based on lectures with examples and case studies only on paper.

1.3. Aim

The aim of the project is to develop a training system for learning Model-Based Systems Engineering that enhances the learning experience of learners who are studying this methodology for engineering systems.
1.4. Objectives

- To identify the difficulties that arise from learning Model Based Systems Engineering.

- To develop a training platform to enhance the learning experience of Model Based Systems Engineering.
  
  o To develop a case study to support the learning of Model Based Systems Engineering concepts and methodology.

- To implement the training system.

1.5. Scope

This project is focussed on developing a training system to enhance the students learning experience of Model Based Systems Engineering.

It has to be clear that this system is learners – oriented, but not teachers – oriented, which means that students should be able to use this system by themselves as a complement to the concepts reviewed in lectures in order to reinforce them and further discuss with lecturers and classmates any doubt that may arise while using the system.

The resulting developing platform is meant to be a supporting tool that provides hands-on material to reinforce the content reviewed in lectures. However, it is not meant to replace the instructor since it cannot give valuable feedback to the students as a human being would do.

This training platform is going to be designed for learners with an education level equivalent to 3rd year undergrad students and masters’ levels due to the complexity of this topic, and regarding the pre-required knowledge of Model Based Systems Engineering, it would be for users with a basic knowledge of the topic.
2. Literature Review

2.1. Evolution of Systems Engineering

Systems Engineering started to be recognised as a branch of engineering during World War II; however, some authors mention that systems engineering has existed since the time in which Egyptians built the pyramids.

The necessity and the will of developing complex systems which required knowledge of multiple engineering disciplines, as well as being successfully delivered in the shortest possible time in order to win the military and space race made humanity start thinking of a way to handle these kind of projects not only in the technical, but also in the time management and cost aspects.

One of the tools used with this purpose by the U.S Navy was PERT (Program Evaluation & Review Technique) while developing the Polaris Submarine weapon system. PERT is a statistical tool that is useful to manage the time of complex projects completion. It permits to forecast the impact on delivering time according to the task completion of the project.

The main cause for systems engineering evolution is the formalisation of concepts and methodologies that would help to understand how to deal with systems adequately.

According to Brill the key contributions for increasing the knowledge about systems engineering were made between 1950 and 1995. Figure 1 provides a graphical representation of them[3].

![Figure 1. Increasing Systems Engineering knowledge and practice[3]](image-url)
Bell Laboratories were the first one to use the term “systems engineering” in 1940[3]. More industries started to adopt this discipline when they realised that it was more effective to identify and modify properties of systems as a whole.

Goode and Machol agreed that with the purpose of understanding systems engineering it was necessary to implement a new method through systems design, systems analysis and systems approach[4].

Hall established the concept of “process of systems engineering”. This concept involved three significant elements. First, it was necessary to understand that systems engineering definition had several facets. Second, engineers had to analyse systems from three main environmental aspects the physical or technical, business and economic, and social. Third, in order to fulfil customer needs efficiently all available knowledge had to be use according to the Total Quality Management principle[5].

In order to solve systems-oriented problems, Shinners and Chestnut developed a methodology which suggested that the best way to solve these problems was to understand them first[6],[7]. They also studied different forms to generate feedback process to define ways to meet customers’ needs. Furthermore, Chestnut proposed that the answers to the three following questions were important to formulate the problem:

1. What is the system to do (performance, cost, time and reliability)?
2. What environment does it have to operate in (home, commercial, or military)?
3. What environment is the product to be made in (engineering/manufacturing, skills and facilities)?

Similarly, Miles edited and published ten lectures about “Systems Concepts for the Private and Public Sectors” presented at the California Institute of Technology by different experts. Miles holds that it is more convenient to focus on the analysis and design of system as a whole instead of doing it by components or parts. In addition, he recognised that to apply the systems approach it was necessary to have a broad knowledge of different engineering team disciplines and how they interact with each other. He described that the systems approach was comprised by the following six steps[8]:

1. Goal definition or problem statement.
2. Objectives and criteria development.
5. Systems selection.

Chase realised that the systems concepts and approach could not be taught properly due to the deficiencies of the current state of the language[9]. Consequently, Wymore declared that systems analysis and design should be carried out by an interdisciplinary team and be driven by three musts: modelling human behaviour, dealing with complexity and largeness of scale, and dealing with a dynamic technology. This work was focussed on formalising the methodology to allow the interdisciplinary group to organise itself, cooperative and effectively communicate systems concepts and approach. This methodology was based on a mathematical theory of systems design which is fundamentally a way of thinking, talking and writing about systems concepts and design; in addition, it allows to define the problem as accurately and completely as possible[10].

Afterwards, Blanchard and Fabrycky introduced the term “system-life-cycle-engineering” as essential to practice systems engineering because it would ensure that systems engineering would consider every single aspect of systems. The systems life cycle was defined as initial identification, planning, research, design, production, evaluation, consumer use, field support, and system phase-out. The following questions were proposed in order to consider the systems life cycle satisfactorily[11]:

1. What is the system to accomplish in terms of operations and performance characteristics?
2. When is the system needed? What are the consumer requirements? What is the expected operational life of the system?
3. How is the system to be utilised?
4. How is the system to be distributed and deployed? Where are the various elements of the system to be located and for how long?
5. What effectiveness requirements should the system exhibit?
6. What are the environmental requirements for the system?
7. How is the system to be supported throughout its life cycle?
8. When the system becomes obsolete and/or when items are removed from the inventory, what are the requirements for disposal? Can specific items be reclaimed and recycled? What are the effects on the environment?

Correspondingly, Sage continue with the formalisation of systems engineering and suggested “systems engineering is the management technology that controls a total lifecycle process, which involves and which results in the definition, development, and deployment of a system that is of high quality, trustworthy, and cost effective in
meeting user needs”. In addition, definitions of systems engineering in terms of its structure, function and purpose were introduced[12].

Moreover, some organisations contributed to the development of systems engineering by publishing handbooks, standards and guides; nevertheless, these publications were focussed on the different organisations fields. Table 1 provides a summary of these publications.

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Publications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defence Systems Management College (DSMC)</td>
<td>Systems Engineering Management Guide (SEMG)</td>
</tr>
<tr>
<td>Electronics Industries Association (EIA)</td>
<td>Interim Standard 632</td>
</tr>
<tr>
<td>National Aeronautics and Space Administration (NASA)</td>
<td>Systems Engineering Handbook</td>
</tr>
<tr>
<td>Institute of Electrical and Electronics Engineers (IEEE)</td>
<td>PI220</td>
</tr>
</tbody>
</table>

Table 1. Organisations contributions to Systems Engineering

In 1990, different sectors including the United States government, industry and academia decided to create the National Council on Systems Engineering, which was an organisation committed to the studies of systems engineering; nonetheless, due to the increasing numbers of overseas members, it was renamed as International Council on Systems Engineering (INCOSE).

2.2. Systems Engineering Process Models

Several process models of systems engineering have evolved in addition to the formalisation of the concepts and methodology. These process models have the purpose to illustrate the methodology applied to the process of developing systems engineering projects. Among all the process models developed, Chang, Perng and Juang asserts that the most commonly used are the Waterfall, Spiral and Vee models[13].

In order to manage the increasing complexity of systems software Royce proposed the waterfall model, which consists of five to seven steps of systems software development[14]. The idea of this model is that each step is completed in sequence until the system is finished; however, when errors are detected in a certain phase, some of them should be repeated until the system is delivered properly. Figure 2 illustrates the waterfall model.
Boehm suggested a spiral process model which is an iterative process that goes through its phases every time a different prototype is developed[16]. This model has built-in risk evaluation process before continuing to the next phase. Figure 3 shows the spiral model.

Figure 2. Waterfall model [15]

Figure 3. Spiral model [15]
Forsberg and Mooz proposed the Vee process model, which captures the complete systems life cycle. On the left hand side, it has the decomposition and definition activities, and on the right hand side, it has the integration and decomposition activities. The Vee process model allows to verify and validate from component level up to system level to ensure that all the system specifications are met[17], [18].

![Vee model diagram](image)

**Figure 4. Vee model [15]**

### 2.3. From Document Based to Model Based Systems Engineering

Traditionally, systems engineering has been performed by using a document-based approach, which relies on producing hard copy or electronic format of textual specifications, design documents and drawings containing all the information regarding a system under development. The system and its subsystems specifications are organised in a hierarchical tree which is used to implement traceability between the design and system requirements by identifying a part or subsystem that satisfies the requirement [19].

Nevertheless, the fact that the systems information is spread among many documents makes it really hard to evaluate the completeness, consistency, relationships between requirements, design engineering analysis and test information leading into poor synchronisation between requirements and design, making impossible to reuse requirements to make variants or updates to a system, and having potential quality problems during the integration process or when the system has been delivered.

In order to overcome the deficiencies a model based approach was released which INCOSE defines Model-Based Systems Engineering (MBSE) as the formalised application of modelling to support system requirements, design, analysis verification,
and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases[20].

In consequence, several organisations including OOSE (Object-Oriented Software Engineering), Booch, and OMT (Object Modelling Technique) decided to unify their work to develop the modelling language UML (Unified Modelling Language) which is widely used in software development.

Wymore introduced the idea of a model-based approach for systems engineering. Subsequently, INCOSE and OMG (Object Management Group) decided to customise UML for systems engineering applications[10]. In addition, many organisations for academia, tool vendors, industry and government were involved in the development of modelling language for systems engineering and finally released SysML (System Modelling Language).

2.4. Systems Engineering education methodologies

Many approaches have been used to teach Systems Engineering and Model Based Systems Engineering. In this section, several works will be presented in order to identify the gaps that different approaches have.

To start, Ross, Fitzgerald and Rhodes, which are part of the Systems Engineering Advance Research Initiative of the Massachusetts Institute of Technology (MIT), in order to improve the learning experience of Systems Engineering, developed a computer game Name Space Tug Skirmish in which the students are meant to learnt 6 key concepts related to Systems Engineering while they play this game. The six key concepts that the students would learn are benefits, design, resources, uncertainties, and time-dependence and contingent value. This game aims to provide a systems engineering experience that would help them to understand the key concepts previously mentioned. The objective of the game is to be the first player to make one hundred American dollars while the players run a business of rental space tug services to move objects that orbit around Earth. There are two phases as part of this game, which are: the design and the operations phase, and each phase has its own set of cards. The design phase is for students to improve their tugs, and the operations phase is the one in which they make the money in order to win. The authors of this idea concluded that this game facilitates the understanding of systems engineering concepts which proves that the development of serious games is suitable to teach students concepts of a certain topic [21].

Lewis recognises the challenge of effectively teaching systems to students, addressing the four key areas such as, knowledge of product realisation processes, project resource planning (PRP), designing skills, and analysing and testing skills. The University at Buffalo developed a program that seeks bridging the gap between practice and education as well as the gap among courses. This program involves forming product development teams, which includes students from different engineering courses.
and from freshman to senior level, in order to design a virtual aircraft, which will be tested at the end of the semester in a Flight Research Simulator in the Calspan Flight Research centre. The integration of students of different engineering courses and different levels is useful to improve their communication and work group skills. Besides, it also provides the opportunity to learn from students with a different perspective according to their engineering background. As a conclusion to a survey carried out among students, it was stated that for engineering programs the use of textbook problems is not an effective way of learning[22].

Barbieri, Fantuzzi and Borsari proposed a model-based design methodology for the development of mechatronic systems, which highlight the benefits of the implementation of this methodology. The tools used for this methodology are Model-Based Design (MBD) approach, SysML syntax for the conceptual model, and hyperlinks to link the SysML model and domain-specific models. Instead of using the traditional Vee model, the W model, showed in Figure 5 was proposed by Natterman 2010 cited in [23], was chosen because it enhances the virtual integration of the sub-systems during the system design. This paper also outlines the phases of the designing process based on the W model and model-based design to show the advantages of this methodology. Nonetheless, it is applied to an already existing system which is a tetra pack filling machine, rather than designing something that is not already a product[23].

![Figure 5. W model with five phases[23]](image)

At the Vienna University of Technology, a Model-Based Engineering course is taught. This course consists of lectures and three sequential lab exercises. In this course programming and modelling languages including ATL (Atlas Transformation Language), UML (Unified Modelling Language), OCL (Object Constraint Language), and others concepts and methods are explained. The concepts necessary to solve the lab exercises are taught during lectures. Students learn how to employ industrial frameworks, which will allow them to build their own models besides learning about
Model Driven Architecture (MDA). Even though the practical exercises are focussed on software development, students have the opportunity to experiment while using model driven architecture[24].

2.5. Conclusions

The evolution of systems engineering demonstrates the need of a methodology that facilitates and improves the process of product design seeing them as whole system instead of individual parts that forms a certain product. Over the years systems have become more complex; thus, the use of Model Based Systems Engineering approach has become popular because it allows to develop systems with shorter lead times effectively, as well as improves communication among departments, facilitates traceability of element models among others compare to the traditional document based approach of systems engineering which does not provide the same advantages.

It has to be recognised that some of the attempts encourage students to learn this methodology in their own time; in addition, some of these projects address problems that are fundamental while designing systems even though they are not related to the technical aspect of engineering such as, the lack of ability to communicate with people with different engineering background. In addition, they demonstrate the integration and relationship between different engineering tools that are useful to engineer systems.

Furthermore, the authors presented in this paper agree that the best way to teach engineering students is to provide them with material that allows them to practice what they learn in lectures to ease the understanding of how to apply theoretical concepts in real life. There are many projects that attempt to improve the learning experience using different approaches; however, these approaches either provide rigid material in which students do not have the opportunity to think about all the aspects of designing systems, or sometimes they are focussed only on practical experience which involves building something, but lacking of a phase in which the students have to use a design methodology in their systems. On the other hand, there are projects that only focus on the general concepts of the methodology, and they do not provide a complete experience in which the students can apply all the concepts regarding systems engineering or model based systems engineering methodologies.

Model-Based Systems Engineering is difficult to understand if learners do not have the opportunity to experience the whole process of designing and implementing a system in which they have the freedom to think in more detail about the systems requirements, behaviour, structure, etc. leading to its implementation in a guided environment. Due to the complexity of the topic, it is difficult for learners to evaluate if they are designing a system well or wrong; however, completing the process using the methodology will give them a better understanding of how to apply it.
3. Model Based Systems Engineering Approach and Methodology

3.1. Approach

Since the MBSE training platform can be classified as a complex system, the Model Based approach was adopted because it has several advantages such as, organising the tasks to develop this project as well as the elements that comprises it, which also gives a clear picture of the project, facilitating the tracking of the progress of the project. The SysML language and diagrams to illustrate how this project was carried out.

Therefore, the MSc. project will be treated as a system that is being under development, so it will be translated to different diagrams to represent all the aspects comprising this project. Figure 6 shows the project use case diagram that represents how the actors, which are the author of this project and his supervisor, interact with the system. This diagram illustrates the actions that the actors have to perform in order to achieve a goal which lead to complete the project.

![MSc. Project use case diagram](image)

**Figure 6. MSc. Project use case diagram**

A system requirement represents a condition that needs to be satisfied in order to determine the level of completeness of the system; therefore, the requirements diagram
is suitable to represent what this project intends to achieve as described by its aim and objectives established in section 1.3 and 1.4 respectively. Figure 7 illustrates the aim and objectives of this project translated into a requirements diagram. The aim is the main purpose of this project, and as part of it, there are three objectives contained. Additionally, it shows that objective Obj2.1 is derived from the objective Obj2 that is to develop the MBSE training platform.

![Diagram](image.png)

**Figure 7. MSc Project objectives as system requirements**

This project is composed of several elements, which are depicted in Figure 8. The elements that compose this project are the MBSE training platform which is the software that will aid the students in order to reinforce the learning process of MBSE methodology, the Case Study which is a system proposed to be developed as part of the learning process of this methodology and the written report which is the document containing all the information related to this project.
3.2. Methodology

The Model Based Systems Engineering methodology is adopted to facilitate the development of this project. The steps followed to carry out this project are shown in Figure 9 in an activity diagram. This diagram depicts the sequence flow of activities; additionally, some activities have flow ports with arrows indicating the objects flow. There are two types of arrows connecting the activities. The solid line arrows specify that a flow of objects exists whereas the dashed line arrows indicates the next step of the process.

First, academic papers and books are used to carry out a literature review that contains how Systems Engineering was started, the different contributions by the different authors, improvements in the process methodology, and an examination to the evolution of how traditional document based Systems Engineering evolved into Model Based Systems Engineering to understand the benefits that the application of this methodology brings. Additionally, as part of this literature review, some work related to Systems Engineering and Model Based Systems Engineering in education were reviewed in order to know what other authors have done and identify the difficulties and gaps that the application of different approaches and methodologies applied to either teach or learn this topic brings.

Second, once the literature review was carried out, the difficulties and gaps have to be identified with the purpose of addressing them to attempt finding a way of improving
the learning experience of Model Based Systems Engineering and facilitate its learning. Sequentially, this activity leads to the activities of development of case study and design of the training platform. The output, which is the identified difficulties, goes to the activity of completing this report.

Third, the activities of designing the training platform and the developing the case study were carried out concurrently. The object flow indicates that the difficulties identified in the previous activity are not fed directly into these two activities; however, these two activities seek for easing the learning of model-based systems engineering. The information developed for the case study is the result of this activity, which is also an input of the activity to design the MBSE training platform. The result obtained from the design of the MBSE training platform is an architectural framework that establishes the main elements that comprises the structure of the software. This will allow easing any modification that has to be performed in the future and for further development to the author and any other interested developer who wants to carry on this project.

Fourth, based on the design developed on the previous activity, the MBSE training platform is implemented. The implementation of the MBSE training platform consists in programming the software, which will be the tool that will support the learning process of the MBSE methodology.

Afterwards, as fifth step, the MBSE training platform has to be evaluated, for which a questionnaire containing multiple choice questions would be used to ask several tester users about the complexity of the concepts and information presented, and if the exercises contained facilitate the learning of the MBSE methodology. This data will be quantified in order to be analysed in the next step.

Sixth, the results obtained from the survey carried out in the previous step will be analysed in order to know which elements implemented on the training platform were successful and which areas need further improvements.

Finally, the activity that refers to the completion of the written report has three inputs that are: the data obtained from the design and implementation of the MBSE training platform and even the case study developed as part of it, the difficulties identified and the analysis made to the questionnaire results. This information is valuable to complete the written report, measure the level of completeness of the project and to perform further improvements to the MBSE training platform in the future.
3.3. Planning

The development process of this process was divided in 5 different tasks that includes carrying out a literature review, identifying difficulties, developing the training platform, developing the case study, and implementing the training system in a virtual environment.

Three milestones with the corresponding deliverables were established in this project. The first milestone corresponds to the difficulties that MBSE learners have while studying this methodology.

On the second milestone, an architectural framework, and the case study should be obtained as a result of the tasks between milestone 1 and milestone 2.
The last milestone has the derivable of implementing the MBSE training platform based on its design. This also includes the integration of the case study information into the MBSE training platform.
Figure 10. Project Planning
3.4. Data Collection

In order to collect data to evaluate the MBSE training platform, a questionnaire was developed in order to consult the testers of the platform to find out what they thought. A sample of 25 mechatronics graduates from De Montfort University and Universidad Tecnologica Equinoccial was selected to test the training platform.

The questions have five multiple-choice answers. It was designed in that way to obtain quantifiable data and to avoid ambiguity in the answers from the testers.

The questionnaire is comprised of five questions that will be used to measure the performance, interface and clarity of content.

Table 2 shows the questions with their corresponding possible answers.

**Questionnaire**

<table>
<thead>
<tr>
<th>Question</th>
<th>Possible Answers</th>
</tr>
</thead>
</table>
| 1. How would you assess the systems performance in terms of functionality and speed? | – Extremely good  
– Very good  
– Moderately good  
– Slightly good  
– Not good at all |  
| 2. How user-friendly is our software’s interface?                      | – Extremely user-friendly  
– Very user-friendly  
– Moderately user-friendly  
– Slightly user-friendly  
– Not at all user-friendly |  
| 3. How would you assess the clarity of how concepts are presented?      | – Extremely clear  
– Very clear  
– Moderately clear  
– Slightly clear  
– Not clear at all |  
| 4. How clear is the description of the case study?                     | – Extremely clear  
– Very clear  
– Moderately clear  
– Slightly clear  
– Not clear at all |  
| 5. How useful were the help buttons to solve any uncertainty?          | – Extremely useful  
– Quite useful  
– Moderately useful  
– Slightly useful  
– Not useful at all |

Table 2. Evaluation questionnaire
4. Model Based Systems Engineering Training Platform

4.1. Overview

The development of the Model Based Systems Engineering training platform is divided in two phases:

The first development phase is the design phase which consists of establishing the training platform architectural framework, developing the content for the training platform including key concepts that need to be clear to reinforce them as part of learning Model Based Systems Engineering, developing a case study, which could be modified according to the learners field of study, that will be used to add a personality to the training platform, and it is the system that will be used to perform the MBSE methodology.

The second development phase is the implementation of the MBSE training platform design which describes the tools used to program the training platform, the elements that were implemented and how they work, the system adopted to reinforce the learning experience, the development of the case study, and the system’s evaluation results.

4.2. Design of Model Based Systems Engineering Training Platform

4.2.1. Overall Design

The Model Based Systems Engineering training platform architectural framework is illustrated in Figure 11, which also shows the different modules that comprise the training platform.

Moreover, it also shows one of the advantages of using Model Based Systems Engineering to design systems because this way of representation facilitates the access to different modules in order to apply any kind of modification. The following six modules form the training platform: tracking progress, assessment, MBSE generic concepts, help, customised case study and resources. It can be seen that the Case Study block is outside the training platform framework. The reason for this is that the case study is not part of the training platform itself, but it is used to add personality to the customised case study module.
Figure 11. MBSE training platform architectural framework

Figure 12 depicts the MBSE training platform use case diagram, which describes how the actors, which are the developer, the learner and even the case study interact with the platform.

The developer is able to add, edit and delete content as well as customising the case study block using the information the case study actor provides; also, the developer is in charge to test that the training platform is working properly.

The learner is able to keep track of his/her progress using the MBSE training platform. The keep track progress use case has an extension point related to the learners’ registration, which is the condition to extend the functionality of this use case. If it is the first time that the learner is using the platform, the use case sign up will extend the track progress use case allowing learners to register with a username and password to use the software. If the students are already registered, the track progress use case will always include the functionality of the use case login with the username and password used in their registration.
4.2.2. Progress tracking module

To facilitate the continuity of learning MBSE methodology, it is imperative that the training platform contains a module that allows the learners to keep track of their progress.

This training platform requires first time learners to sign up by using a username and password, which will be used subsequently as their login details. Once they have logged into the training platform, the learners will be able to view their progress history regarding the content they have studied, the answers to the exercises they have completed, compare answers with other learners, and check on their performance.

4.2.3. MBSE generic concepts module

Even though the development of this training platform is not meant to deliver the concepts regarding Model Based Systems Engineering, it provides an overview of some important concepts, so learners can review them in case they need to refer to them to solve small doubts.

Regarding the content of this module, the main general terms that are defined in this module are system, model, Model-Based Systems Engineering, and SysML.
Furthermore, this module should illustrate the different diagrams that comprise SysML by using a concrete example, which will facilitate showing the existing relationship between different models and model elements in the same model. The models and their elements that are going to be explained in this module are: requirements diagram, use case diagram, sequence diagram, state machine diagram, block definition diagram, and internal block diagram. In the current design, this module only contains an example describing one system.

4.2.4. Customised case study module

Since it is not possible to develop a universal case study that is suitable to all the fields of engineering, and with the purpose of adding personality to the training platform, a module that can be customised with different case studies is needed.

The idea of this customised case study module is that it can be modified with different topics according to the audience learning Model Based Systems Engineering.

The case study is meant to provide part of the hands-on experience material for the learners on which they will perform the designing process in order to reinforce the concepts of Model Based Systems Engineering as well as giving them the opportunity to explore how to apply them.

Figure 13 illustrates the internal block diagram of the customised case study module and the case study information used to describe it to the students; subsequently, an abstraction was performed to present this information in a model to describe the case study functions. It also shows that from this abstraction the learners have to perform the requirements analysis of the case study.

Figure 13. Customised case study internal block diagram
4.2.5. Assessment module

Since there is not a guide that tells how to assess a design process, it is not possible to implement a module that assesses this qualitative process; however, the use of the language and the understanding of the concepts can be assessed with questions containing multiple-choice answers.

Therefore, this module is in charge of providing short quizzes that will evaluate the learners’ knowledge and let them know which areas need to be reviewed. It shall evaluate not only the concepts presented in the MBSE Generic concepts module, but also part of the process while working in the development of the case study system wherever possible.

4.2.6. Help module

The pop-up help content is there to assist the learners, by providing additional necessary information in order to clarify the terms and concepts used. The functionality of this module is necessary to increase the learners’ interactivity with the training platform, and to facilitate the learning experience by presenting this information dynamically, which avoids presenting all the information at once.

The help module will be used to add additional content in the other modules where necessary.

4.2.7. Resources module

In case the MBSE generic concepts contained in the training platform do not solve the doubts that may arise while using it, the learners can refer to the resources listed in the platform, so they can further understand the topics they need to review.

The resources modules contain resources that go from books to video lessons, tutorials, and links of interest.

4.3. Implementation of Model Based Systems Engineering Training Platform

Once the architectural framework of the training platform was defined, and the content to be included in its different modules was decided, the training platform was implemented according to its design.

Unfortunately, time was the biggest constraint affecting this project; consequently, it was not possible to implement all the modules contained in the design of the training platform completely.
The implementation of the training platform was focused on the functionality of the different modules, but regarding the hands-on material about the process of model based systems engineering, only the requirements analysis of systems was implemented.

4.3.1. Overview

In order to implement the training platform, it was necessary to use an IDE (integrated development environment) that allows the development of software that can be freely distributed among students. Consequently, the IDE chosen to develop the Model Based Systems Engineering training platform was Processing 2.2.1, which is an open source software based on the computer programming language JAVA and is capable of generating stand-alone applications with embedded JAVA, so the applications can be executed in environments that do not have Java Development kit (JDK) installed [25].

The execution environments of the training platform are from Windows XP to Windows 8 with either 32 or 64 bits architecture processor, regardless of whether Java development kit is installed. Furthermore, the application can be generated to be executed in Mac OS X and Linux operating systems.

4.3.2. Current implementation

Due to time constraints, not all the modules of the training platform were implemented completely.

Figure 14 and Figure 15 show the implementation of the track progress module outlined in the design of the training platform. The username, password, the content that has been reviewed, and the answers to exercises are stored in text files. The training platform accesses these text files every time it needs to retrieve information from them.

Figure 14 shows the start screen of the MBSE training platform in which it can be seen that it requests a username and password.
Figure 14. MBSE training platform start screen

Figure 15 displays the MBSE generic concepts menu, in which it can be observed that the buttons with the label “Model” and “Model Based Systems Engineering” have a different colour indicating that the user: tester has already reviewed these two concepts. Additionally,

Figure 15 shows the generic concepts that can be found in the training platform.
Figure 16 exhibits the resources that are provided to the learners of the training platform. Currently, it has some books, a link to the YouTube channel of IBM Rational User Education, in which several lessons regarding Model Based Systems Engineering and SysML language are presented, and a link to the SysML OMG specification, which contains all the reference of SysML language. All the concepts implemented in the training platform can be found in Appendix C.
Figure 16. MBSE Resources

Figure 17 shows how the case study system is presented to the learners in an abstract representation, which is the system that the learners have to design as part of the reinforcement process. It can be observed that it also shows that the cursor is over one of the help buttons in order to show additional information on the screen. This figure shows the implementation of the case study and the help module part of this design.
As part of the assessment module only part of the requirement analysis can be performed. The assessment module contains the answers to exercises that will help the learners to reinforce what they have learnt.

Figure 18 shows one of the exercises in which the learners can practice classifying the types of requirements as functional or non-functional.
Figure 18. Requirement analysis exercise

Figure 19 displays the exercise in which students have to define requirements for the system. In this exercise is not possible to assess the learners answers; therefore, the defined requirements are stored in a text file, so the learners can compare their answers between them and ask the instructor for feedback.
4.3.3. Self – Reinforcement of Knowledge System

Felder and Silverman recognised the importance of experimental learning noting that people learn in different ways and teaching methods vary: “How much a given student learns in a class is governed in part by that student’s native ability and prior preparation but also by the compatibility of his or her learning style and the instructor’s teaching style”[26].

It was also recognised that engineering students tend to be active learners. This type of learner does not learn as well in a passive situation such as the traditional lecturing style. Rather, they learn better in circumstances in which they can experiment and learn in groups[26].

Figure 19. Define Requirements exercise
Enhancing the learning process by providing learners with a hands-on training platform supports the traditional theoretical learning while also giving them the opportunity to learn via discovery.

In general, MBSE learners study this methodology to design systems without seeing the results of their design materialised in a real product. Therefore, the training platform enables the students to become active learners; thus, reinforcing the knowledge gained in lectures while reviewing and practicing independently.

4.3.4. Case Study

For this project, a case study that simulates part of a manufacturing process was deemed necessary, due to its relationship with several elements of different fields of engineering. These include electronics, mechanics, computer programming, and even machine vision.

The purpose of having a case study is to feed its information into the training platform. The training platform will present the customer’s vision and an abstract representation for the system required by the customer. The case study provides the opportunity to the learners to apply the Model Based Systems Engineering methodology to design and build a system based on the case study information.

As mentioned in section 4.2.5, it is not possible to assess a design explicitly in terms of good or bad; nevertheless, once the design of the system has been implemented the learners should be able to do a self-evaluation of their design by checking the percentage of completeness of the requirements and whether the requirements are met or not.

The case study developed for this project is described as follows: A manufacturing company that produces square and circle pieces wants to automate its process of classifying the pieces. Currently, the manufactured pieces go through a conveyor belt and an employee has to classify them manually according to their shape and place them in their corresponding basket at the end of the conveyor belt.

4.3.4.1. Case study presented to learners

Figure 20 and Figure 21 show what is presented to the learners besides the textual description of the case study, and based on this information they have to perform the MBSE methodology to design the case study system.

Figure 20 shows an abstraction of the process that the system has to follow in order to achieve its goal, which is to identify and route the pieces correctly. This abstraction is based on the case study description and it is presented to the learners using models to make the content clearer instead of just presenting textual information.
The process includes four top tasks, which are described as follows:

**Transport**: refers to the way the pieces are transported by the system. In this case, a conveyor belt is used to perform this task.

**Sense**: once the piece reaches the sensor position, the sensor has to extract the information from the piece, which is then passed to the control subsystem.

**Identify**: the control subsystem performs the algorithm identification to determine if the piece is either a circle or a square.

**Route**: the systems possess two arms that will route the piece to the right hand side of the conveyor belt if it is a square and to the left hand side of the conveyor belt if it is a circle.

![Diagram](image_url)

**Figure 20. Case study system process**

Figure 21 depicts a model of the parts that contain the case study system, which learners would have to design as part of the learning reinforcement.
Figure 21. Case study system physical abstract representation

4.3.4.2. Case study design

Part of this project was also the design and implementation of the case study, which could serve as a guide for future developers. However, this does not mean that the design of the case study has to be exactly as the one presented in this paper. The idea of this case study is to let learners think freely on how to design and implement the system described in the way they think it would be best, proposing their own ideas and once implemented check if they met the requirements established in their own designs.

Unfortunately, this is also one of the parts affected in this project by the time constraints, so not all the design process is illustrated in this work.

The use case diagram and requirements diagram are the first two diagrams developed concurrently since they are fundamental to subsequent design phases.

Figure 22 illustrates the interaction between the operator and the system that shows the commands that the operator gives to the system such as start and stop the conveyor belt, and identify pieces, as well as the actions that the operator can perform including initialising the system and performing maintenance to it.
Figure 23 shows part of the requirements established as part of the design process of the classification and routing system, which refers to the identification criteria used in the system. It also illustrates how requirements can be derived from other requirements as in the case of choosing the identification sensor. Appendix A shows the complete requirements established in this project.

Requirements can be used to assess the learners design. For example, it can be seen that Req05.1 indicates that the system should change the piece route once it has been identified, but it does not indicate to which side the pieces should be routed which gives a little freedom to the result. As long as the requirement is fulfilled in the implemented version of the system, it can be assess as a positive result.
Based on the requirements diagram the physical structure of the system can be defined since these components have to satisfy what is established in the requirements to successfully implement the system.

Regarding the system physical structure Figure 24 illustrates its block definition diagram with a top-level view with its main three blocks that compose it. Each assembly block contains its own internal components illustrated in Appendix B.

This is one of the design phases in which the learners have the opportunity to use different tools to support their design, like CAD (Computer Aid Drawing) modelling tools.

**Figure 23. Requirements: identification criteria**

Based on the requirements diagram the physical structure of the system can be defined since these components have to satisfy what is established in the requirements to successfully implement the system.

Regarding the system physical structure Figure 24 illustrates its block definition diagram with a top-level view with its main three blocks that compose it. Each assembly block contains its own internal components illustrated in Appendix B.

This is one of the design phases in which the learners have the opportunity to use different tools to support their design, like CAD (Computer Aid Drawing) modelling tools.
Appendix D illustrates the first attempt to design its structure. It includes strut aluminium profiles, which comprise the main structure and other elements of the system. Appendix E illustrates the final design used in the implementation of the system, which differs from the first attempt on how the strut aluminium profiles were assembled using gussets angle brackets to join them, the design of the servo arms and the elements that support the rollers are also in charge of holding the system on the ground. Appendix E, Appendix F, Appendix G, Appendix H, Appendix I show all the drawings of the definite design used in this work.

![Diagram of Classification and Routing System block definition](image)

**Figure 24. Classification and Routing System block definition diagram**

Figure 25 illustrates the internal block diagram corresponding to the metallic structure, which is the main base of the system that is part of the mount assembly.

It can be observed that the strut profiles using the slots in their corresponding faces are attached to other strut profiles using gussets connectors.
Figure 25. Metallic Structure internal block diagram (ibd)

Once defined the structure and physical components of the system, it is possible to develop sequence diagrams, which represent different scenarios contained in the use cases.
Figure 26 depicts a sequence diagram to represent one of the scenarios of the use case initialise system. This diagram represents the process that the operator has to follow to initialise the system, which can also be used to evaluate the functionality of the system. A pre-requisite of this scenario is that the computer has to be switched on first.
4.3.4.3. Case study implementation

Concerning the percentage of completeness of the system construction, it can be said that the system was 95% completed. The only aspect that was not taken into account was the actuator in charge of the motion of the conveyor belt.

This section describes the element used in the construction of the physical structure of the system.

To build the main base, strut aluminium profiles were selected because their shape facilitates assembly and disassembly of the structure in order to make adjustments. Five strut profiles were needed in different sizes; therefore, they were cut according to the drawing shown in Appendix F. The connectors used in this case to attach the different strut profiles were gusset connectors.
Appendix G illustrates the design of the arms that would change the route of the pieces during the process. The part of these arms that is directly attached to the servo was bought from a retail store because it was easy to attach to the servo motor and it was long enough to attach the part that was built. Figure 27 shows the assembled arm.

Figure 27. Assembled arm

The servomotor selected to power the arms was the servo hitec-422, which has a torque of 4.1 kg-cm that was enough to move the arms. Figure 28 shows the servo selected, and Table 3 indicates the specifications of the servo.

Figure 28. Servo HS-422

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque</td>
<td>3.3 kg-cm to 4.1 kg-cm</td>
</tr>
<tr>
<td>Speed</td>
<td>0.16 sec/60°</td>
</tr>
<tr>
<td>Weight</td>
<td>45.5 g</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Length: 40.4 mm</td>
</tr>
<tr>
<td></td>
<td>Width: 19.6 mm</td>
</tr>
<tr>
<td></td>
<td>Height: 36.6 mm</td>
</tr>
<tr>
<td>Rotation range</td>
<td>180°</td>
</tr>
</tbody>
</table>

Table 3. Servo hs422 specifications[27]

Regarding the camera, a webcam of 5 megapixels is capable of collecting enough detailed information from the pieces in order to perform the identification.

Since this is a custom design, the rollers for the conveyor belt have dimensions that suited particularly this system, so it was not possible to get them from a retail store; consequently, acetal plastic rods were selected due to ease of machining[28] in order to
build the rollers in the mechanical lab according to the drawing in Appendix H. Figure 29 shows one of the built rollers.

![Figure 29. Roller](image)

Appendix I shows the design for the brackets to support the servomotors. Nevertheless, due to the lack of bending material in De Montfort University’s mechanical lab, these brackets had to be obtained from a retail store. Figure 30 shows the servo brackets used in the project.

![Figure 30. Servo Bracket type J](image)

Figure 31 illustrates the system assembled.

![Figure 31. System assembled](image)
4.3.5. Results

The results obtained from the questionnaire used to evaluate the training platform are the following. To obtain these results the tool Survey Monkey was used because it allows generating questionnaires and sharing them over the internet effectively.

Appendix J contains the results presented in tables and Appendix K contains the raw data.

Question one results shown in Figure 32 indicate that more than 50% of the testers think that the training platform performance was moderately good. Additionally, more than 25% of the testers think that the platform performance was very good and more than 10% think it was extremely good. Therefore, the overall platform performance is efficient.

![How would you assess the systems performance in terms of functionality and speed?](chart)

**Figure 32. Question 1 results**

Figure 33 shows the results from question two. It shows that the user interface is generally friendly to the user meaning that the training platform is easy to use and the testers did not have a difficult time working on it.
Figure 33. Question 2 results

Figure 34 and Figure 35 refers to questions three and four respectively. These questions ask about the clarity of the content presented. More than 10% think that the concepts presented are slightly clear while more than 50% answered that the concepts are moderately clear. This 10% should be reduced to at least less than 5% since this concept should be presented clearly to the learners. Figure 35 indicates that more than the 50% of the users think that the description of the case study is clear and less than the 10% think that it was slightly clear which can be considered a success.

Figure 34. Question 3 results
Finally, Figure 36 indicates how useful the help buttons are while using the training platform. Unfortunately, it can be observed that more than the 40% percent of the users answered that the help buttons were slightly useful, which indicates that these buttons are not fulfilling their purpose successfully.

Figure 35. Question 4 results

Figure 36. Question 5 results
5. Discussions

In the literature review, it was shown that different organisations from industry, government and academia are interested in professionals that can manage the design of complex systems; also, how systems engineering has evolved from the traditional document based systems engineering to the model based systems engineering methodology because over the years, systems have become more complex. Additionally, different approaches have been adopted by different authors to enhance the learning experience of Systems Engineering approach and Model Based Systems Engineering; however, in any of these approaches adopted, the MBSE learners have the opportunity to experience working on the whole systems-life-cycle.

The adoption of MBSE approach and methodology facilitated the development of the project, since it made it easier to define the elements that compose the MBSE training platform and their relationship, to establish its architectural framework, and to track the progress of the project.

The purpose of this project was to develop a MBSE training platform that reinforces/enhances the learning experience of MBSE, which included the development of a software that provides MBSE generic contents, and a case study that learners have to design and implement by using the MBSE methodology as main material to fulfil the purpose of the project.

Unfortunately, this project was overambitious to be completed in the time period provided, so not all the modules comprising the training platform were completely implemented and neither the case study was completely designed and built. However, an architectural framework was defined which could be used for further development and part of the system described in the case study was partially design and implemented.

Besides the further implementation that needs to be performed on the MBSE training platform, to have a complete picture of its success, the results from the evaluation of the system showed that there are some areas that need improvement in order to fulfil their purpose appropriately. For example, the case of the help module and the clarity of the concepts presented on it.

Even though the MBSE platform can improve the learning experience of this methodology, the main limitation is assessing their work. Only the understanding of the concepts and SysML language can be assessed by the training platform; nevertheless, the training platform cannot evaluate the process of design. Currently, it can assess part of the requirement analysis of the system presented in the case study, but it cannot give appropriate feedback about the definition of the requirements of the system. That is the main reason why the training platform cannot replace any instructor, who is teaching this methodology. It is only meant to be a supporting material to what is reviewed in
lectures. However, the learners should be able to reinforce the content that they have reviewed in their own time, and discuss with their classmates.

In addition, the training platform is meant to facilitate the understanding of the content reviewed in lectures and to perform the designing process of the system described in the case study. The critical doubts that may arise by using this platform regarding the MBSE methodology should be discussed with the instructor.
6. Conclusion and Future Work

6.1. Conclusions

- The difficulties identified for Model Based Systems Engineering learners are:
  - It is not possible to assess whether a design is right or wrong. Being a qualitative process, it is not possible to determine if a design is right or wrong just by looking at it. The way to know if a design is right or wrong is by implementing it, and comparing if it fulfils its purpose effectively.
  - Usually, several resources contain many examples in which MBSE methodology has been used to design systems. Nevertheless, they do not provide a detailed systematic guide for learners.
- The training platform architectural framework was designed and partially implemented due to the time constraint. This architectural framework established the base for further development.
- A customised case study was developed in order to reinforce MBSE concepts and requirements analysis assessment module. Due to the time constraint, it was not possible to implement all the phases comprising the MBSE methodology.
- This project is overambitious for the timeframe, since it consists of developing the training platform, its content, the case study and implementing its design. Due to the time constraint, therefore the physical construction of the case study had to be abandoned.

6.2. Future Work

- Since the requirements analysis was the only part of the process that can be assessed, the rest of the design process has to be implemented in order to provide a complete experience to learners.
- Currently, the system only allows saving the requirements analysis in a text file. For the future, a subsystem that allows the learners to submit their work online will be developed, so they can receive direct feedback from the instructor.
- According to the learners’ audience, more case studies should be further developed to cover topics of their field of interest.
References


Appendix A. Case Study Requirement Analysis

- **Load**
  ID = Req07
  Pieces are loaded by the user.

- **Load method**
  ID = Req07.1
  Pieces shall be loaded one by one.

- **System Performance**
  ID = Req01
  The system shall classify two pieces per minute.

- **Identification Criteria**
  ID = Req05
  The system shall identify between circles, squares.

- **Routing**
  ID = Req05.1
  The system shall change the piece route once it has been classified.

- **Identification Sensor**
  ID = Req05.2
  The system shall use a camera to get information from the piece to be classified.

- **Arms**
  ID = Req05.1.1
  To change the route the system shall control two arms.

- **Structure**
  ID = Req03
  - length < 60 cm
  - width < 30 cm
  - height < 30 cm
Appendix B. Case Study Block Definition Diagram
Appendix C. Concepts implemented in MBSE training platform
System

is a

set

of

interacting

elements

and

sub-systems

to

achieve

a

goal
Model Based Systems Engineering is a Multidisciplinary Approach to develop Systems Solutions by Using Models to Define Requirements, Define Functions, Define Components, and Validate Design.
Max Acceleration
- id: Req1.4.8
  - The automobile shall accelerate from 0 to 60 mph in less than 8 secs

Rain sensing wipers
- id: Req5.20
  - Wipers shall go on when moisture is detected on the windshield

Moisture sensor
- id: Req5.20.1
  - The automobile shall use sensor RS4001

Test case
- Moisture detection test
Appendix D. Case Study System design first attempt

INSTITUTION: De Montfort University

DRAWER: Guillermo Mosquera

DRAWING: 1st attempt

All dimensions are in mm

SCALE: 1:5
Appendix E. Case Study physical final design
Appendix F. Metallic Structure design

Bosch Rexroth Strut
Profile Angle Bracket, 8 mm

INSTITUTION: De Montfort University
DRAWER: Guillermo Mosquera
DRAWING: Metallic Structure

All dimensions are in mm
SCALE: 1:2

A4
Appendix G. Arm assembled design
Appendix H. Roller design
Appendix I. Servo Bracket design
### Appendix J. Questionnaire results

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<thead>
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<th>Percentage</th>
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<tr>
<td>Extremely good</td>
<td>16%</td>
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<tr>
<td>Very good</td>
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<td>Moderately good</td>
<td>52%</td>
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<tr>
<td>Slightly good</td>
<td>4%</td>
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<td>Not good at all</td>
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Table 4. Question 1 results

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Table 5. Question 2 results

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Table 6. Question 3 results

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<td>Very clear</td>
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<td>Moderately clear</td>
<td>60%</td>
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<tr>
<td>Slightly clear</td>
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<td>Not clear at all</td>
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Table 7. Question 4 results

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<td>Quite useful</td>
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<td>Moderately useful</td>
<td>40%</td>
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<tr>
<td>Slightly useful</td>
<td>45%</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----</td>
</tr>
<tr>
<td>Not useful at all</td>
<td>0%</td>
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Table 8. Question 5 results
### Appendix K. Raw data

#### Tester 1

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</tr>
<tr>
<td>Q2: How user-friendly is our software’s interface?</td>
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<td>Q3: How would you assess the clarity of how concepts are presented?</td>
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<td>Q4: How clear is the description of the use case study?</td>
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<td>Q5: How useful were the help buttons to solve any uncertainty?</td>
<td>Moderately useful</td>
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#### Tester 2

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<tbody>
<tr>
<td>Q1: How would you assess the system’s performance in terms of functionality and speed?</td>
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</table>
### Tester 3

| Q1: How would you assess the systems performance in terms of functionality and speed? | Extremely good |
| Q2: How user-friendly is our software’s interface? | Very user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Very clear |
| Q4: How clear is the description of the use case study? | Moderately clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Moderately useful |

### Tester 4

| Q1: How would you assess the systems performance in terms of functionality and speed? | Extremely good |
| Q2: How user-friendly is our software’s interface? | Extremely user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Moderately clear |
| Q4: How clear is the description of the use case study? | Very clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Quite useful |
### Tester 5

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Tester 9

| Q1: How would you assess the system's performance in terms of functionality and speed? | Moderately good |
| Q2: How user-friendly is our software's interface? | Very user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Moderately clear |
| Q4: How clear is the description of the use case study? | Moderately clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Moderately useful |

Tester 10

| Q1: How would you assess the system's performance in terms of functionality and speed? | Moderately good |
| Q2: How user-friendly is our software's interface? | Moderately user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Slightly clear |
| Q4: How clear is the description of the use case study? | Moderately clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Slightly useful |
### Tester 11

| Q1: How would you assess the system’s performance in terms of functionality and speed? | Moderately good |
| Q2: How user-friendly is our software’s interface? | Moderately user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Very clear |
| Q4: How clear is the description of the use case study? | Moderately clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Quite useful |

### Tester 12

| Q1: How would you assess the system’s performance in terms of functionality and speed? | Very good |
| Q2: How user-friendly is our software’s interface? | Moderately user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Moderately clear |
| Q4: How clear is the description of the use case study? | Moderately clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Slightly useful |
Tester 13

| Q1: How would you assess the systems performance in terms of functionality and speed? | Moderately good |
| Q2: How user-friendly is our software's interface? | Moderately user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Slightly clear |
| Q4: How clear is the description of the use case study? | Slightly clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Moderately useful |

Tester 14

| Q1: How would you assess the systems performance in terms of functionality and speed? | Moderately good |
| Q2: How user-friendly is our software's interface? | Slightly user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Moderately clear |
| Q4: How clear is the description of the use case study? | Moderately clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Slightly useful |
### Tester 15

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**Tester 21**

| Q1: How would you assess the system's performance in terms of functionality and speed? | Moderately good |
| Q2: How user-friendly is our software’s interface? | Moderately user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Very clear |
| Q4: How clear is the description of the use case study? | Very clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Quite useful |

**Tester 22**

| Q1: How would you assess the system’s performance in terms of functionality and speed? | Very good |
| Q2: How user-friendly is our software’s interface? | Extremely user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Moderately clear |
| Q4: How clear is the description of the use case study? | Very clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Quite useful |
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<th>Q1: How would you assess the system's performance in terms of functionality and speed?</th>
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<td>Moderately useful</td>
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Tester 25

| Q1: How would you assess the system's performance in terms of functionality and speed? | Moderately good |
| Q2: How user-friendly is our software's interface? | Moderately user-friendly |
| Q3: How would you assess the clarity of how concepts are presented? | Slightly clear |
| Q4: How clear is the description of the use case study? | Moderately clear |
| Q5: How useful were the help buttons to solve any uncertainty? | Slightly useful |