From Course to Online Learning Paths

Improving the Teacher's Experience of an Existing Online Node-link Course Tool

by

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Abstract

The online website Skill Circuits is a tool developed by teachers at the Delft University of Technology. Skill Circuits is an online learning tool that presents students with a node-link (i.e. a tree) structure where each node represents a skill, containing tasks that aim to teach the skill. The website aims to benefit teachers, by letting them think how all the 'skills' in their course relate and whether or not they have sufficient material to teach these skills. At the same time, the website aims to benefit students by giving them a learning path to follow, where each step is a small task, and each skill is visually connected to previous skills, showing how the learning material is connected.
This thesis aimed to help new teachers understand the concept of these node-link structures — called skill circuits — and also expand the website with features to help them evaluate their skill circuits, both before and during the course.
A documentation help page was developed, which explained the concept and intended usage of the website and was accompanied by a proof-of-concept skill circuit explaining the same topics. Tools to help evaluate a skill circuit were also developed, which included tools that could be used before the course was held, and tools that used analytics generated by students. One noteworthy tool took inspiration from the Constructive Alignment principle, where a teacher can label parts of their skill circuit with learning objectives to see if there is alignment with their course material.
All of these features were evaluated with a small focus group consisting of teachers, which showed enthusiasm toward the proposed features.

Acknowledgements

I wish to take this opportunity to thank my friends and parents for their continuous love and support, which kept me motivated and allowed me to complete this thesis.

This also would not have been possible without the help of my supervisors Gosia, Marcus and Manuel. I am very thankful for your continued support and guidance throughout this thesis.

Lastly, I would like to thank Stefan Hugtenburg and Ivo van Kreveld, whose use of Gamification in their courses inspired me to start this thesis.

Contents

1 Introduction

1.1. Educational technology

Information and communication technology has become an important aspect within all layers of education (Bond, Zawacki-Richter, & Nichols, 2019). Educational technology such as digital classrooms, learning management systems (LMS), instructional design, learning analytics and mobile collaborative learning are some examples of this. It is clear that technology is moving fast with concerns that teachers might not be able to keep up (Fernández-Batanero, Román-Graván, Reyes-Rebollo, & Montenegro-Rueda, 2021; Stošić, 2015). Teachers may also find it difficult to cater to individual learners when technology such as LMSs often allows only a single learning path (Joseph & Abraham, 2017). Not every learner will learn the same way due to their differences from other learners, meaning that a single learning path might not cater to all learners. Different levels of expertise or different ways of preferred learning are part of the reason why a single-path approach does not work.

1.2. Learning Paths and instructional design

The term "learning path" has various definitions depending on the context of its usage. With regard to LMS and e-learning, it refers to an ordered sequence of concepts or learning objects which must be taught in order for the learner to understand target learning objectives. This sequence provides a road map to the learner (De Smet, Schellens, De Wever, Brandt-Pomares, & Valcke, 2016; Capuano et al., 2009). Within instructional design, one could find a similar concept when looking at learning hierarchies, as first described by Gagné (2009). A learning hierarchy is a hierarchy of skills, skills lower in the hierarchy are seen as prerequisites for higher-order skills. A learning hierarchy does not represent the most efficient learning route but instead, it represents "the most probable expectation of greatest positive transfer for an entire sample of learners concerning whom we know nothing more than what specifically relevant skills they start with." (Gagné, 2009, p 3). The methods proposed by Gagné (2009) are still relevant for instructional design, they are still used for developing curricula (Kerr, 2000) and are a foundation for beneficial models such as Task (Hierarchy) Analysis (Shipley, Stephen, & Tawfik, 2018), which have a positive effect on learners (Omotayo & Osuala, 2022).
Instructors that take these learning paths into account can expect better learning outcomes for their students. The path that a student follows is also important when using an LMS for a course. In fact, one of the perceived strengths of LMSs is being able to organise course content (Fadde & Vu, 2014). This organisational benefit can ease the process of instructional design for teachers. Be it for constructing learning paths or using other instructional design techniques,

such as Constructive alignment.

1.3. Main focus: Learning path website "Skill Circuits"

The main focus of this thesis, the platform "Skill Circuits", is an online website that has the potential to remedy some of the shortcomings of LMSs with regard to learning paths. The core idea of the website is to give the learners a suggested non-linear learning path from which they are allowed to deviate, thus allowing them to choose the path that they feel would fit them best. This learning path is structured similarly to Gagné's learning hierarchies. Different levels of expertise are handled by suggesting multiple degrees of difficulty for the proposed path, where specific course material is either hidden or shown depending on the choice of expertise. A full overview of the Skill Circuits platform is given in Section 3.1. When using Skill Circuits, students benefit from being given a clear learning path to follow, with connections between topics which add context and meaning to each topic. For teachers, the benefit lies in helping them think about the learning path that they want students to follow. It makes teachers aware of what learning activities their course has and how these connect with assessment, and when constructing a learning path on the website they can spot gaps in the material that they have. This falls neatly in line with Constructive alignment, which is generally used for all courses within the Delft University of Technology and is further explained in Section 3.2.

1.4. Objective: Improving Skill Circuits for new teachers

The earlier mentioned difficulty from teachers in adapting technology was also observed with the Skill Circuits website. Its creators had a clear view of how the website should be utilised, but this was not immediately clear to other teachers. The creators originally pitched the idea for this thesis to look into improving the onboarding of teachers. For this thesis, it was chosen to improve the onboarding while also determining if there is literature that can support the creators' intended usage of the website. For this objective, the following research questions were defined:

RQ1 How should a teacher map their existing course, which follows the constructive alignment principle, to a set of skills in order to construct a hierarchy for use in a skill circuit?

RQ2 To what extent can we support teachers in the creation of a skill circuit through analysis tools, such that it gives valuable insight into the quality of their circuit design?

RQ3 What learning analytics, obtained from students using a skill circuit, are most insightful to teachers? Are there analytics that can help improve the skill circuit?

1.5. Thesis outline

The thesis is structured as follows. Chapter 2 discusses other solutions for creating learning paths and solutions from other LMSs. Other similar learning path visualisations — also called "Node-link qualitative visualisation" — are discussed, specifically those used for educational purposes. Chapter 3 gives the necessary background required to understand the rest of this thesis document, the Skill Circuits website will be discussed in-depth along with Constructive alignment, an instructional design technique which this thesis focuses upon. Chapter 4 explains what was implemented alongside this thesis, how the requirements for this implementation were set and what designs followed from these requirements. Chapter 5 then discusses the method of evaluation for the implementation, this includes how and what aspects were evaluated

along with the results of this evaluation. Finally, Chapter 6 concludes the thesis by discussing conclusions drawn from the evaluation, conclusions of the research questions, shortcomings, and recommendations for future work.

2

Related work

This chapter discusses existing literature and systems, highlighting perceived gaps in these works that require solutions. The chapter starts by looking at some node-link qualitative visualisation techniques in education. This look includes the existing methods for the construction of these structures, along with their shortcomings. Finally, this chapter looks at existing technology such as Learning Management Systems (LMS) and Learning Analytics (LA), focusing on the tools and guidance given to educators that help them measure the quality of their course and its adaptation within these systems.

2.1. Node-link qualitative visualisation within education

Within education, there exist many qualitative visualisation techniques aimed to represent knowledge, each with its own function, application, graphical representation, and rules. The primary interest of this thesis lies in methods that visualise their knowledge through node-link methods. There exist many such methods used both in- and outside of education. This section discusses the methods used in education which exhibit a node-link structure, focusing on their value toward instructional design and the methods required to validate the structure.

2.1.1. Learning hierarchies

One of the first examples of such a method within education is learning hierarchies as described by Gagné (2009). Learning hierarchies' primary function is to provide a clear hierarchy of skills, each link symbolising a connection between skills where skills high in the hierarchy were seen as prerequisites for skills further down (Gagné, 2009). The application of these learning hierarchies is mostly within instructional design. Their purpose lies less in visualising skills and more in providing a method to uncover an ideal route of presenting skills to students. The route provides the greatest statistical chance of positive knowledge transfer to learners from which we know what skills they start with. There are several methods to obtain a learning hierarchy. The process usually breaks down into creating an initial guess and then evaluating and improving this initial guess. This evaluation process requires the resulting learning activity to be analysed with participants. This is not something that would be ideal for the purpose of this thesis. This thesis focuses on creating a good initial guess for a skill circuit. Outside of general guidelines, Gagné does not discuss other methods of gauging the quality of a learning hierarchy outside of the evaluation methods.
The method to construct learning hierarchies provide good ideas for answering RQ1. Given that a teacher knows the skills they will cover, they could construct an initial learning hierarchy

which serves as a decent initial skill circuit. It would still lack answers on how skills should be gathered and defined, and how a teacher could analyse the validity of their design before using it in practice.

2.1.2. Concept maps

A technique that is more focused on its aid through visualisation, compared to the previously discussed learning hierarchies, are concept maps and their derivatives, originally developed by Novak (1980). It is important to note that the term concept map might bear resemblance to similar visualisations such as topic maps and mind maps. In short, a concept map links together ideas and information where each link is labelled to describe the type of connection. Concept maps can also have slightly different variations according to their use case, especially since their use also spans various subjects, which also impacts their function. The suggested use case of a concept map as first proposed by Novak is for it to be a support tool for students created by the teacher to visualise key topics or more abstract concepts within a course. Its validity is not usually measured or evaluated and apart from some core design rules, there is no strict method for creating a concept map. There does exist a similar method going by the same name which does employ a more structured methodology, but this method does not see much use for instructional design (Trochim & McLinden, 2017).

2.2. Learning management systems

Learning Management Systems (LMS) are web-based systems which connect learning content to learners in a standardised manner. It can manage various aspects useful for e-learning, such as learning materials, learning events, student participation and administrative tasks, such as communication with students (Sejzi & Aris, 2013).

While Skill Circuits is not a fully standalone LMS, it does resemble one. More importantly, some of the challenges of creating such a system — such as teacher guidance — are also present in Skill Circuits.

I would like to discuss how other LMSs visualise learning paths and if they give any guidance or recommendations to teachers for constructing these learning paths.

Most LMSs provide students with a linear path to follow with the option of being able to skip ahead — unless this is disabled by the teacher. This learning path is usually represented by grouping content into folders or segments which categorise learning material. Examples of this are Moodle's "topics", Canvas's "modules", d2l's "modules" and many more. This method of representing a learning path is currently the default approach most LMSs take. This method does not allow for visualising a non-linear learning path for students.

In terms of teacher guidance and recommendations, there is a lot of material available both on- and outside the LMSs. Many LMSs — such as Moodle, Canvas, and Blackboard Learn — have documentation explaining every feature along with guides on how to get started as a teacher, instructional designer, admin or even as a student. Moodle even has multiple courses hosted through Moodle, in order to help educators become familiar with Moodle or even help them become better at instructional design. Moodle and Canvas also host a forum where educators can come together, ask questions and discuss.

3 Background

This chapter will provide the necessary background information to understand the rest of this thesis. Most importantly the Skill Circuits platform is explained along with its various components.

3.1. Skill Circuits

This section will explain the website Skill Circuits. Its intended purpose, along with all of its components and how the platform was used before the additions of this thesis will be discussed. Skill Circuits is an open-source[1] and ongoing project with a live version being hosted by the TU Delft[2]. It is subject to continuous changes. The below description with accompanying figures is from July 2023 and might be out of date.

3.1.1. Basic principle

The basic idea of a skill circuit is to give the students a clear overview of the course. Topics that are handled in the course are shown in a tree-like structure, each connection in the tree resembles a connection between topics. A topic within Skill Circuits is called a "skill", but will be named a "skill-block" in this document to avoid confusion. Each skill-block will have various tasks that a student should complete in order to master the skill. These tasks are marked as complete by the students themselves and is not done automatically.
Each skill-block is part of a single sub-module and each sub-module is part of a single module. Each module is then a separate tree made up of sub-modules. A simplified example of this hierarchy can be seen in Figure 3.1.

It is important to see Skill Circuits as an optional tool for the student to guide their learning. All exercises and assessments are done off-site so students do not feel pressured to use Skill Circuits if they do not want to. It is therefore standard practice and encouraged to use other platforms in tandem with Skill Circuits to host all learning material.

3.1.2. Current usage

The Skill Circuits website is currently in use by three teachers from the TU Delft, spanning five different subjects from the computer science & engineering bachelor programme. These five courses are:

[1] Public GitHub can be found at https://github.com/eip-ewi/Skill-Circuits
[2] Latest deployed version of Skill Circuits can be found at https://skills.ewi.tudelft.nl/

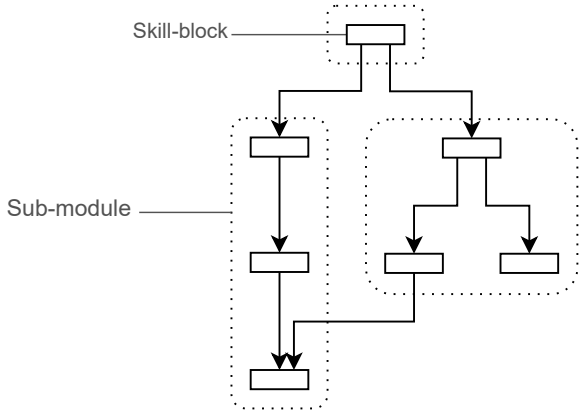


Figure 3.1: A simplified view showing the hierarchy of a module. Each block represents a skill-block which is connected to one or multiple skill-blocks. Each skill-block is in exactly one sub-module and all sub-modules together form the module.

1. Reasoning & Logic
2. Algorithms & Data Structures
3. Algorithm Design
4. Automata, Computability and Complexity
5. Concepts of Programming Languages

Two of the three teachers are also the main contributors towards furthering the development of Skill Circuits and are also seeking to onboard new teachers through workshops and other means.
Skill Circuits does not see many users currently. It is mostly seen as an additional tool that a teacher is free to use however they want. There are no strict guidelines or rules. If a teacher requires assistance in the creation of their skill circuit they are advised to contact the two leading teachers.

The current workflow by the aforementioned three teachers for creating a skill circuit can be described as analysing course material in combination with "what feels right?". Much thought goes into creating a skill circuit for their course but their methods are what works for them and are not necessarily reproducible by others.

3.1.3. Skill-blocks

Basics

The smallest building block within a skill circuit is a skill-block. A skill-block encompasses a small topic within a course. It contains the resources necessary to understand the topic that is discussed.

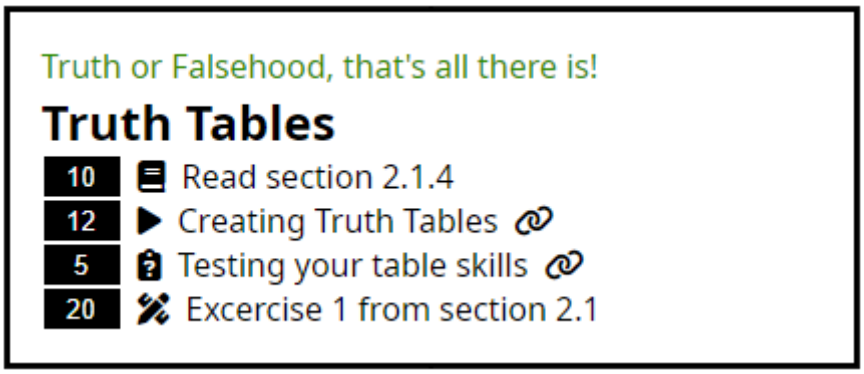


Figure 3.2: An example of a basic skill represented by a skill-block. This basic skill covers "Truth Tables" under the "Truth or Falsehood, that's all there is!" sub-module and contains 4 tasks that are yet to be completed.

Skill-block content

A skill is made up of one or multiple tasks that students can mark as 'complete'.
Each task has 4 elements:

1. A button with a time estimate. Clicking the button marks the task as complete.
2. An icon indicating the type of the task. As seen in Table 3.1.
3. Text detailing the task.
4. (Optional) a link to the task's resources with an icon indicating this.

Icon	Description
	reading task
	video task
	quiz task
	implementation task
	exercise task
	collaboration task
	experiment task

Table 3.1: The various types of tasks and their icons.

Connections

Skill-blocks can be connected to other skill-blocks to represent knowledge dependencies. A connection signifies that it is recommended to first complete the prerequisite skill-block(s) before continuing. This is not enforced, which allows students to skip ahead.
Connections allow large topics to be cut up into smaller pieces, allowing students to take it step by step.

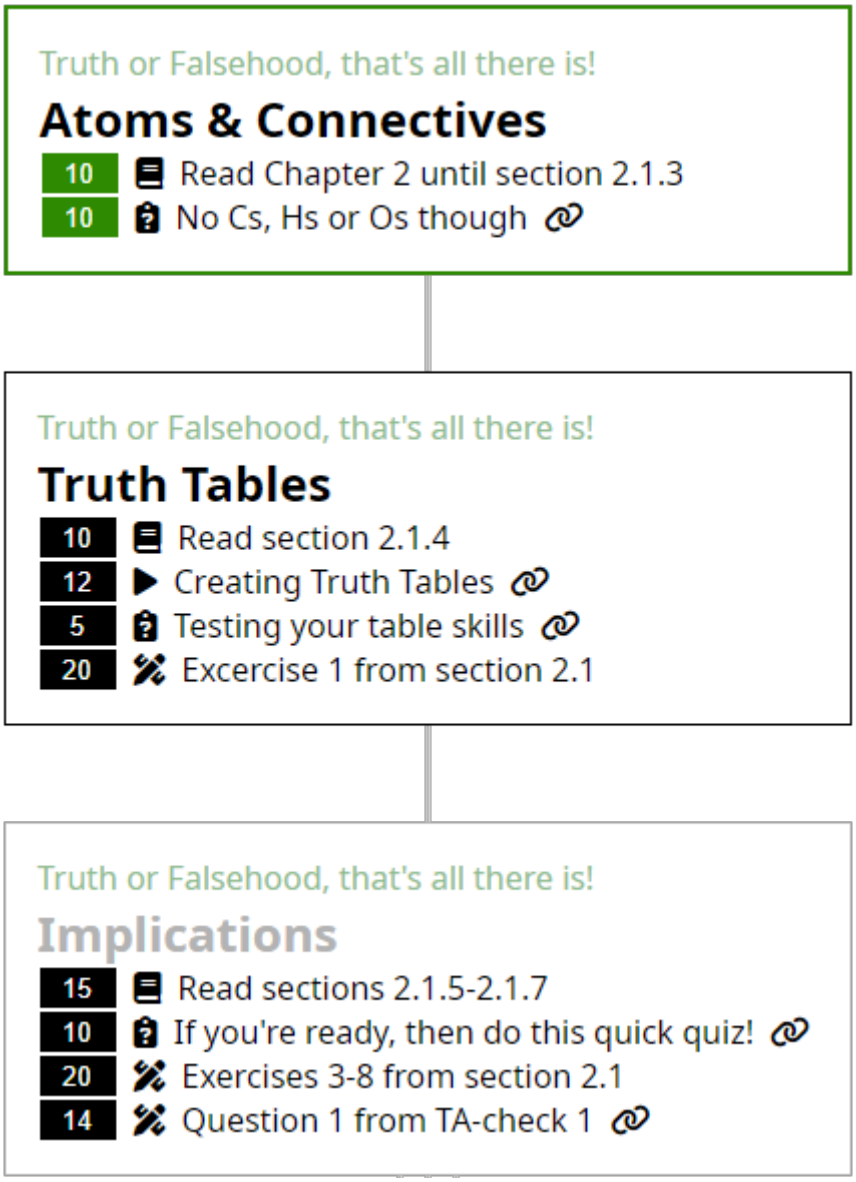


Figure 3.3: Three connected skill-blocks representing three different skills under the same sub-module. The first skill "Atoms & Connectives" has been labelled as complete, unlocking the next skill "Truth Tables".

Optional skills

Skill-blocks can also be marked as optional. This is usually done for topics that will not be relevant to the assessment. Instead, this can be extra information to give students additional context as to why they are learning this topic or how this topic is represented in the real world. They could even be used to remind students to post questions or fill in surveys.

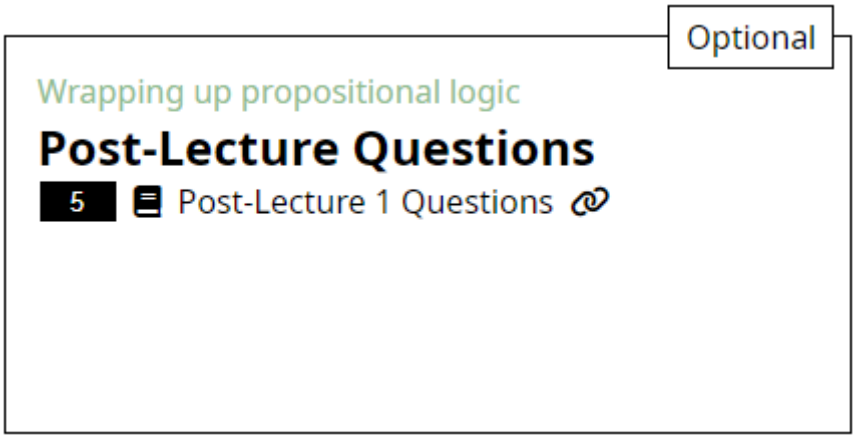


Figure 3.4: An example of a skill that is labelled as optional.

External skills

External skills allows teachers to link back to a skill-block from a previous module. This way the teacher can show connections to material that was covered in earlier parts of the course. This is especially helpful when students need to refresh their memory on these skills. If they need to practice these skills again they can simply click the external skill to be sent back.

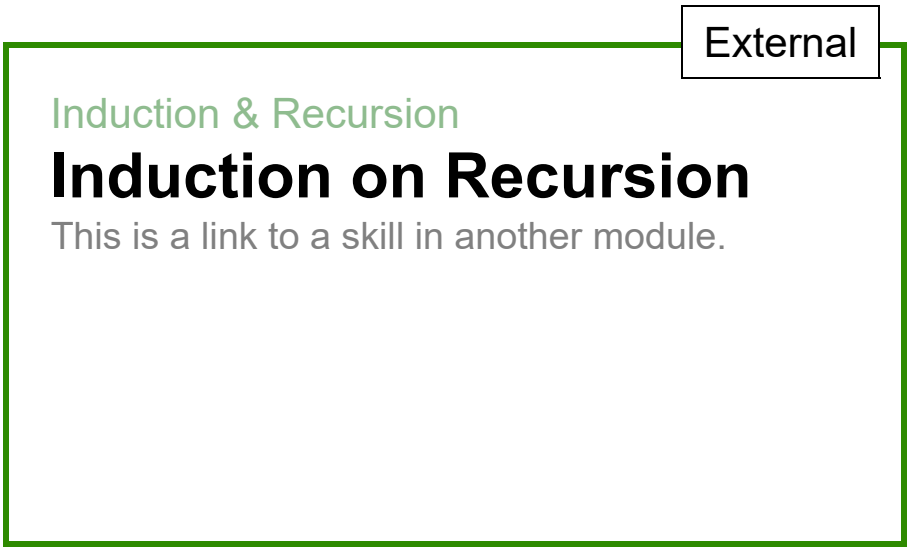


Figure 3.5: An example of a skill that is labelled as external.

3.1.4. Sub-modules

Basics

Sub-modules represent slightly larger topics which various skill-blocks fall under. On the website, they are presented in two ways to the student:

1. At the top of every skill-block, signifying which sub-module the skill-block belongs to.
2. As a separate "sub-module circuit" each sub-module is shown as a block and is connected to other sub-modules from the same module to signify their connection. An example of this is shown in Figure 3.6.

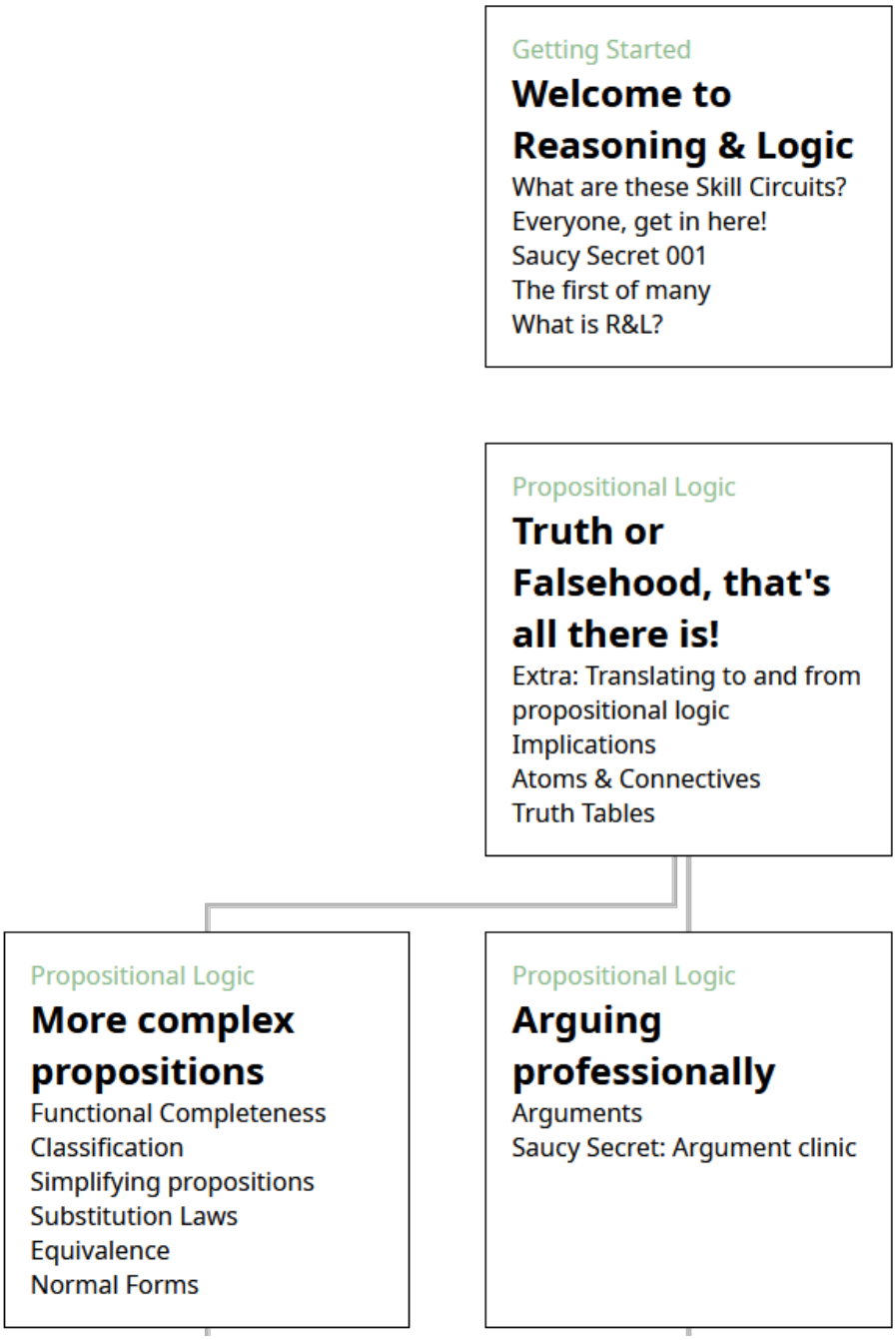


Figure 3.6: Four sub-modules from two modules represented through blocks. Each block shows the module name, sub-module name and the skills belonging to the sub-module. The last three sub-modules are from the same module and are connected.

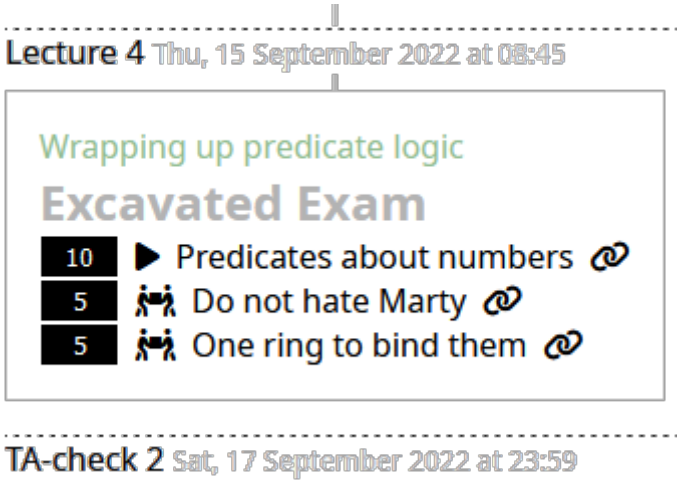


Figure 3.7: Two checkpoints with the names "Lecture 4" and "TA-check 2" indicating a checkpoint for a lecture and one for an assignment due date.

3.1.5. Modules

Basics

Modules represent the larger building blocks within a skill circuit. A module encompasses a large topic within a course. A module is made up of various sub-modules in order to guide students through the module.

Checkpoints

Checkpoints are simple time indicators which can be added to a module. A checkpoint consists of a name and a timestamp which together can give context to the surrounding skill-blocks as can be seen in Figure 3.7. There are a couple of approaches one can take with utilising these checkpoints. For example, a teacher can choose to add every lecture as a checkpoint to the skill circuit, indicating that skill-blocks prior to this checkpoint are required or will be covered in the lecture. Checkpoints can provide a similar purpose for assignment deadlines or other arbitrary milestones.
It is currently required to have at least one checkpoint per module.

3.1.6. Paths

One final aspect of Skill Circuits, which allows students to customise their learning experience, are Paths. A path can be created by the teacher by giving it a descriptive name, after which a teacher can add tasks from the skill-blocks to these paths. This adds the ability to limit tasks to specific paths which can be utilised for a couple of uses. For example, a teacher can choose to add a path for each type of student they think will follow their course. One path could be for students that wish to simply pass the course, only requiring them to complete essential tasks. A second path could be for students who wish to learn additional information about the subject, allowing them to see tasks like extra reading material or other resources. A third path could be for students who wish to have extra practice material for relevant parts of the course. These three paths could serve quite a number of students and might provide them with valuable relevance. A teacher is free to create as many paths for as many purposes as they might desire.

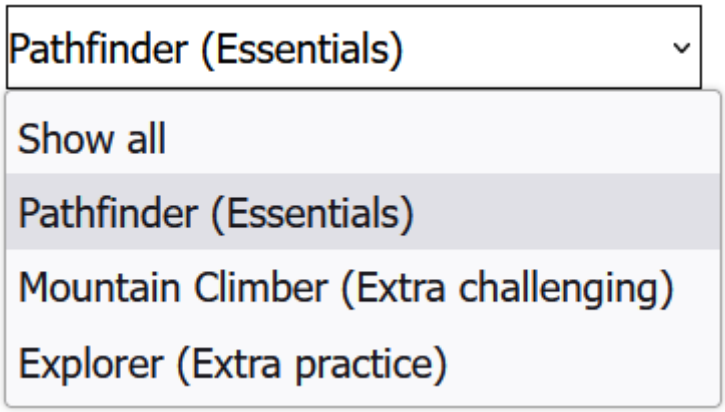


Figure 3.8: The path selector that is made available to students. This skill circuit provides three path options.

3.1.7. Putting it all together

When you combine all the elements that were discussed in this section you end up with a skill circuit like the one in Figure 3.9.

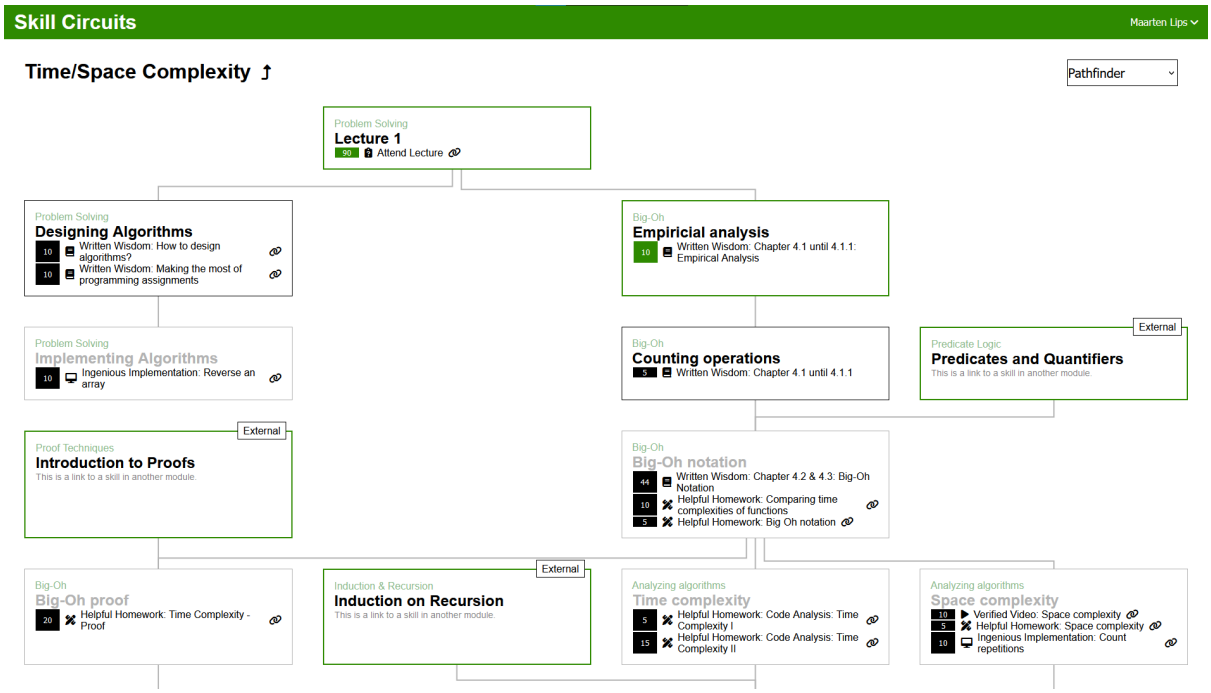


Figure 3.9: A view of the Skill Circuits website displaying a module from a skill circuit of the course Algorithms & Data Structures.

3.2. Constructive alignment

Construct alignment, as first described by Biggs (1996), is a principle that can be used during the design of a course. It comes from constructivism — a family of theories where adding meaning to a learner's activities is a central idea — and an emphasis on alignment between learning objectives and target assessment from instructional designers. The idea is to utilise constructivism as a decision-making guide for stages in instructional design. These stages are: deriving learning objectives, deciding on learning activities and assessment. These three stages are typically visualised as seen in Figure 3.10. The principle dictates that when all three stages

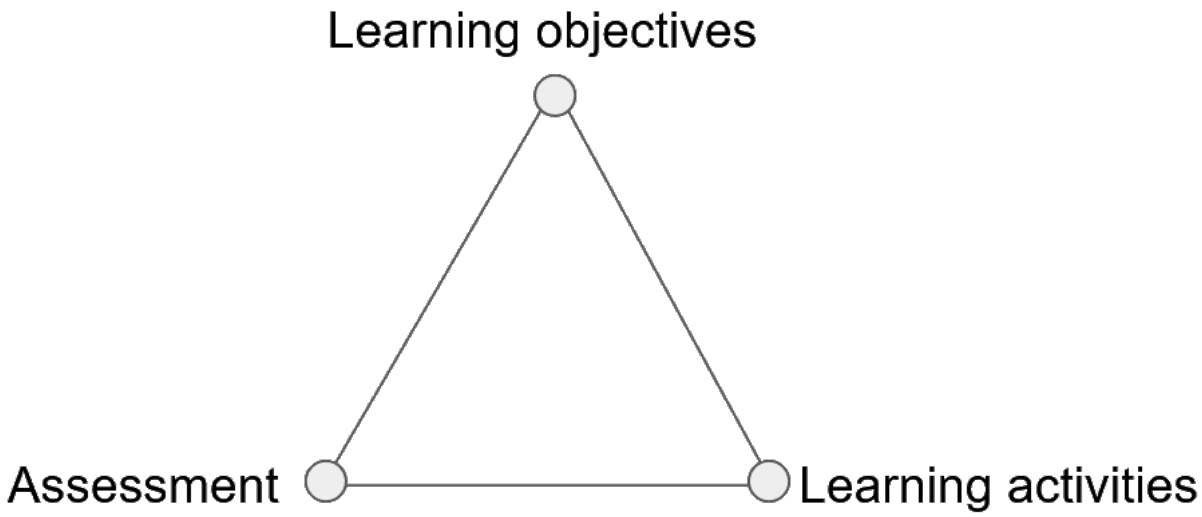


Figure 3.10: The three stages of constructive alignment. The connections symbolise that each stage must be aligned so that students will be taught the intended learning objectives.

are aligned, the course is properly teaching its students the intended learning objectives.
As I understand it, this is an instructional design principle that all teachers at the Delft University of Technology (TU Delft) must be aware of since it is part of the University Teaching Qualification, which is why it is relevant to this thesis (*Development of Teaching and Active Learning*, n.d.). For example, if a teacher is already familiar with constructive alignment or has already used it for their course, then I could use the aspects of constructive alignment in providing a translation layer to a skill circuit.
Each course at the TU Delft has its learning objectives presented to the students in the study guide. Many teachers will communicate these 'course-wide' learning objectives to the students along with some more focused learning objectives, i.e. learning objectives for a single lecture or a set of lectures.

4

Implementation

This chapter goes over the software components that were implemented together with this Thesis. The software that was developed was written on top of an existing codebase which utilised Spring Boot and Thymeleaf to render a website. First, the requirements obtained from the perceived gap in research along with stakeholder interviews are analysed in Section 4.1. The resulting design and the reasoning behind it are given in Section 4.2. Finally, the actual implementation of the design together with relevant technical details are given in Section 4.3.

4.1. Requirements

4.1.1. How requirements were obtained

Initial requirements were obtained through semi-structured interviews with the target audience. The target audience was comprised of teachers that were interested in using the Skill Circuits website, primarily those that had no prior experience in using the website, but knew what it was. On top of that, teachers that had used the website before were also interviewed. This resulted in a total of three participants, of which two had used the website before to create skill circuits for their courses. It is important to note that these two participants were also creators of the website.

This thesis started with a slightly different objective than the one proposed in this document. The focus was more on improving the user experience of the website through changes in the user interface. The motivation for this change in the objective is further explained in Subsection 4.1.1.

Initial requirements interview

Of the three participants, only one had not used the website before. This teacher showed interest in using the website and had heard about it from other teachers. The teacher was interested in using the website in the near future for some of their courses but had not done so yet. It was the intention to work together with this teacher to set up requirements and evaluate the engineering component at various stages. An interview was set up with various questions prepared beforehand. The interview itself did not follow a concrete structure. Below is a summary of this interview.

A. The interviewee views the main purpose of Skill Circuits as:

1. A learning path to follow for students which guides their study.
2. A way for a teacher to think about the concepts/skills in their course and to reveal what parts lack material (reading & exercises).

B. The difficult part in creating a skill circuit is:

- Figuring out the scope of a concept within the structure of a skill circuit. Is a concept from the course best represented as a skill-block, a task or perhaps an entire module?
- Knowing how to represent links between concepts with choices such as creating a connection between skill-blocks or instead grouping the tasks in a single skill-block.

C. The interviewee views the benefit of creating circuits for their courses as follows:

- Course 1 will have significant parts of its material changed. This means that the new material also lacks exercises, literature and other material. Skill Circuits might help during the development process of the course to highlight what might be missing.
- Course 2 will have almost no changes making it a key candidate for testing any new design changes.

D. The interviewee lists the following features as ones that would improve the design experience of a skill circuit online:

- Adding a guide or "how-to" section to the website and leaving the design process mostly offline.
- Being able to move large groups of skill-blocks around to other modules, including their connections, would prove useful when changes to the design are necessary.
- An "analysis tab" that would highlight any common shortcomings of a skill circuit. The interviewee expressed the need for this component to be a separate tab in order to reduce clutter and unwanted warnings during normal development.

E. Tools the interviewee would use to start designing a circuit are:

- Whiteboard or any other physical tool. Design tools on the computer never work as well.

F. Online tools that serve a similar purpose that the interviewee has used before are:

- Draw.io[1], but only to create neater versions of something that was designed on a physical medium.
- Digibord as a digital whiteboard during lectures with the ability to save drawings.

Obtained requirements

Question D from the initial requirements interview would prove useful for setting the initial requirements for this project. The first requirement that was set following the interview was the idea of creating a guide or "how-to" section on the website with the purpose of improving the onboarding of new teachers. Previously, teachers would have to learn how Skill Circuits functioned through word of mouth or by attending a workshop. It would make more sense that the website itself could teach them how to create a skill circuit for their own course. The bare minimum for this requirement would be to create documentation explaining the intended use of Skill Circuits. More novel ideas that could make reading this documentation more fun and intuitive were also considered such as creating a skill circuit specifically for the purpose of

[1]Draw.io is a website that functions as a virtual canvas, primarily used to create diagrams.

onboarding. This would form the basic requirement for the initial onboarding of new teachers. This requirement is further discussed in Subsection 4.1.2.
The second requirement that was set, and became a primary objective of the thesis, was the idea of an "analysis tab" or better yet "design analysis tools". These design analysis tools would consist of various analysis tools that looked at the current state of a skill circuit. Each tool would then give the teacher valuable information about their skill circuit. Some could present simple statistics and others could warn the teacher of any common shortcomings in a skill circuit. These design analysis tools would be a counterpart to the usage analysis tools. Together they would allow analysis during the design stages of a skill circuit and during the usage of the skill circuit by students. This requirement is further discussed in Subsection 4.1.3.
The final requirement was set to complement the first two requirements. In the previous requirements, we first introduce a teacher to Skill Circuits, and then help them to create and analyse their skill circuit prior to its use in class. To help reinforce and 'complete' the cycle, the requirement for creating "usage analysis tools" was set. This requirement aimed to give teachers information on how their skill circuit is being used by students. The usage analysis tools would present a teacher with relevant information that would allow them to analyse a skill circuit's completeness, usefulness and actual usage by students. Participants of the requirement interviews also expressed their interest in adding such analysis to Skill Circuits. It is much akin to "Learning analytics", but the requirement focuses mostly on data taken from a group of students, not individuals. This requirement is further discussed in Subsection 4.1.4.

Motivation for change in objective
From initial interviews, it was gathered that most users did not utilise the website for designing their skill circuit. Meanwhile, there was a clear desire for tools to be added to the website that could help with design, primarily for those that were new to the website. With this in mind, it was perceived that before any such tools could be developed, the usability of the website must improve first such that teachers would actually use the website during the development of their circuit. The objective of these user interface changes was to convince teachers to use the website exclusively instead of relying on other media to design their skill circuit. Successfully evaluating user interface changes meant that multiple different designs needed to be created to facilitate an evaluation like A/B-testing (Kohavi & Longbotham, 2017). This was deemed too large for the scope of this thesis. Since the primary reason for these user interface changes was to eventually serve teachers with useful design tools, it was chosen to instead focus on creating these tools to persuade teachers to use the website during the development of their skill circuit. This is why the "user interface improvement" part of the objective eventually turned into creating the design analysis tools. Before this change in objective, it was still required to obtain some reference for the requirements that needed to be set. With a focus on user interface improvements.

4.1.2. Documentation & The meta skill circuit
For the documentation, the following requirements were set:

- The documentation must be easily extensible, this means that the actual documents should not be created through code. Instead, the documents should be viewable outside of the website and ideally be imported for display on the website.
- Initial documentation should be created but does not have to be complete. These can be improved later on and outside of this thesis.
- The documentation should be presented in a clear and understandable way. Ideally an approach similar to other LMSs or websites.

Together with the documentation it was also decided to develop an accompanying skill circuit. The documentation and skill circuit would together provide a course that introduces and explains Skill Circuits. This skill circuit was dubbed the "meta skill circuit" (meta SC), since it is a skill circuit, explaining Skill Circuits. The following requirements were set for the meta SC:

- The meta SC should contain and utilise all components available on the Skill Circuits website. I.e. paths, optional skills, different task types, etc.
- The documentation should function as the main reading material for the meta SC. Reading tasks within the meta SC should link to the documentation.

4.1.3. The design analysis tools

The main purpose of the design analysis tools can be summarised as follows:

1. Giving a teacher tools to determine whether their designed circuit reflects their course well.
2. Giving a teacher tools to spot errors or common shortcomings in their designed circuit.

The latter could be accomplished by providing simple indicators for things like:

- Amount of skill-blocks per module.
- Amount of tasks by type.

This could be further expanded with 'checks' for common mistakes such as:

- Are there any disconnected skill-blocks?
- Are there any skill-blocks without tasks?

These statistics and checks are pretty trivial to implement and think of. The question becomes which of these can provide meaningful insight or can best prevent common shortcomings. I feel it is important to give as many tools to the teacher as possible, without it becoming overwhelming.

Focusing instead on the other purpose of the tools mentioned above, it is necessary to figure out what "a circuit that reflects a course" means exactly. This is not a trivial question to answer and is also something out of the realm of possibility for this thesis. For this reason, it was instead chosen to utilise Constructive Alignment as an acceptable indicator for this purpose. For example, by taking the existing learning objectives of a course and seeing how well these are reflected within a skill circuit, one might be able to determine the alignment of the circuit to the course. This idea could be easily implemented through software and seemed promising in delivering an added benefit to the existing website. For this reason, it was chosen to further develop this feature.

Three elements would need to be implemented for this feature to be deemed complete:

1. A way to add learning objectives to a skill circuit.
2. A way to attach learning objectives to relevant parts of the circuit.
3. A useful tool that shows how well each learning objective is covered in the skill circuit.

For the first element, it was chosen to represent a learning objective through a short descriptor (name, title or another identifier) and its accompanying Bloom's taxonomy category. For example, the learning objective "Understand the usage of Skill Circuits" could be described by "Skill Circuits usage" together with the 'comprehension' category of Bloom's taxonomy. A teacher should be free to choose how to format these short descriptors and can pick a single category per objective from a list. In addition, attaching a category to the learning objective gives the possibility to develop tools which analyse the coverage of each category as well.
For the second element, it was important to determine which parts of a skill circuit should be labelled with learning objectives. Natural candidates for this include the skill-blocks and the tasks within skill-blocks. It was decided that tasks provide a better fit for this feature since each task within a skill-block could technically cover a different learning objective. For example, a reading task might cover knowledge or comprehension while an exercise task might cover application or analysis.
For the final — and perhaps most important — element it was important to provide a tool which was useful in both an insightful and functional way. For example, giving a teacher a table containing the number of tasks per learning objective (insight), while also presenting them a full list of each task, linking back to its position in the circuit when context or changes are necessary (functional).

4.1.4. The usage analysis tools

The usage analysis tools hold a similar function as the design analysis tools but with different data and visualisations.
The key idea is to give a teacher insight into how their skill circuit is being used by students. The existing website does not store a lot of data from the students' usage of the website. The only data that is stored is a list of tasks that a student has completed. This makes sense implementation-wise since all other information can be inferred from this list such as skill-blocks completed, modules completed, path chosen and etc. This data alone can provide a lot of useful statistics for the teacher. However, an additional requirement was set for recording the time at which a task was marked as completed by a student. With a time completion date, a lot more statistics could be inferred, such as completion order, completion time relative to the due date, completion date outliers and more. More importantly, this completion time data did not come with a cost of ease of use to the student. This is important since one of the primary strengths of Skill Circuits was its simple usage for students. Asking them how long a task took — for example — would take away from this strength. Additionally, while it is possible to track and store more data from the students, it was not deemed necessary for this thesis. Especially since the added benefit would be minor and the statistics from task completion and completion time alone would prove plentiful.

4.2. Design

In this section, the design for the proposed components is explained. Requirements that were gathered are taken into account. Figures are used to help explain design choices.

4.2.1. Onboarding

Two components were developed that together would serve as a guide for new teachers.

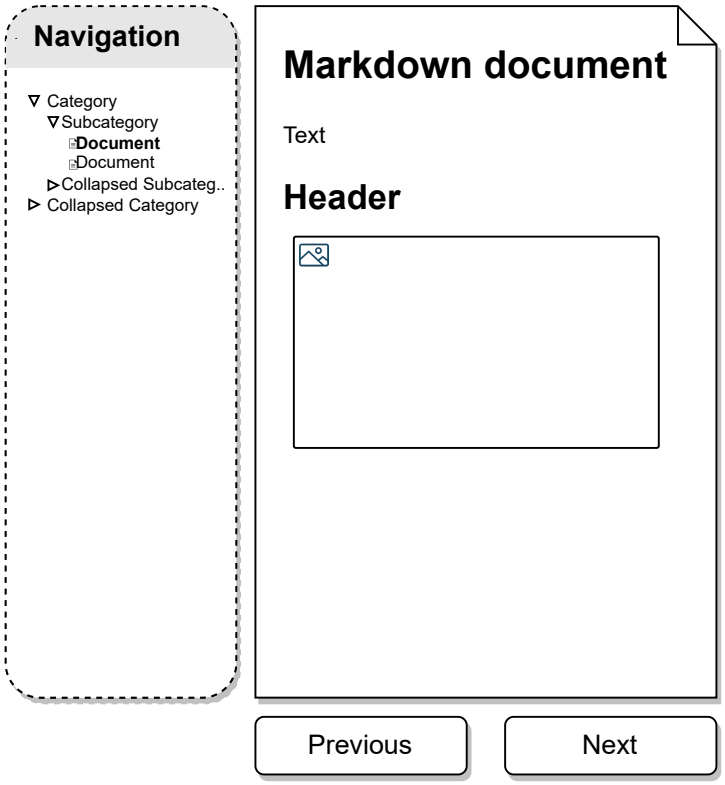


Figure 4.1: Design for the documentation. Each category, subcategory and document has its own viewable page and document.

Component	Purpose	Implementation
Documentation	Separate pages that would serve as a book. Each page explains an aspect or component of Skill Circuits.	A method to render Markdown documents as HTML was implemented on the website, this would allow easy extension of the documentation without much coding work.
A 'meta' skill circuit course	Showing teachers how a student would use the platform by giving them the experience of following a skill circuit as a student themselves. Simultaneously, this skill circuit teaches them what the Skill Circuits platform is and how they could use it.	Code was rewritten to allow for special types of skill circuits that can be created by Skill Circuit admins and can only be viewed by teachers. The proof-of-concept 'meta' course was drafted for this feature, its design can be viewed in Appendix A.

Table 4.1: Table showing a brief overview of the two components that were developed to facilitate the onboarding of new teachers to the Skill Circuits platform.

Documentation

The design for the documentation takes inspiration from many of the standard approaches other tools and systems take to design their documentation. The documentation consists of various Markdown files. Users can navigate between the various files using a navigation pane. The design can be viewed in Figure 4.1.

Meta skill circuit
The meta skill circuit is a skill circuit created together with this thesis. Its full design can be viewed in Appendix A. This section will provide reasoning for its design.
The meta skill circuit aims to educate on three important aspects which are reflected in its three modules as seen in Table 4.2.

Module name	Learning goal
What is Skill Circuits?	Explain the usage of a skill circuit together with its strengths and its various components.
How to design a skill circuit.	Give ideas and tips on how to start designing a skill circuit for an existing course and how to utilise the design analysis tools to validate this design.
Using & analysing your circuit during your course.	Explain how to utilise the usage analysis tools to verify whether the previously designed skill circuit is having the desired effect.

Table 4.2: Table showing the three aspects of the meta skill circuit and the resulting modules.

Module one and part of module two can be directly linked to the requirement of a guide as gathered from the interview discussed in How requirements were obtained. Module three and the rest of module two cover the aspects that were implemented with this thesis.
It is important to see this meta skill circuit as a proof of concept, which can be iterated upon further if it is deemed valuable during the evaluation. For this first version, it was deemed necessary to at least include one of each element of a skill circuit and to have a reading task for each skill-block. This meant that each skill-block required reading material which did not yet exist. This reading material is part of the documentation, which would be hosted on the website itself and be separately available as a makeshift book.

During module two the teacher is taught two design methods together with tips for organising the design process. The two design methods are examples of how one could start the design process. These methods are the two methods taught during Skill Circuit workshops and were coincidentally developed during this thesis independently from these workshops. They are merely taught to give an idea of where to start. The two methods have been dubbed "filling modules" and "grouping skills". The "filling modules" method is most suitable when it is clear to a teacher what the major topics are in a course, these usually represent the modules of a skill circuit. "Grouping skills" is quite the opposite, this method is most suitable when a course has a well-defined grouping of course material which can easily represent skill-blocks, which can then be grouped to create (sub)modules.

4.2.2. Design analysis tools
Design analysis tools aim to help teachers analyse their skill circuit while they are designing it. It provides analysis tools and statistics, which aim to give insight into the current quality of the skill circuit.
These analysis tools can be viewed on a separate page only by the teacher(s) of a course. It was important that these tools were separated from the skill circuit page since this was a specific requirement that was gathered.

All analysis tools will be discussed in this section and can be split into two categories: Analysis tools that gather statistics from the skill circuit and tools that gather statistics from the manual labelling of learning objectives done by the teacher. This labelling will be discussed first.

Learning objective analysis tools

The main idea behind "learning objective analysis tools" is to allow teachers to attach learning objectives to parts of their skill circuit. These learning objectives are part of Constructive alignment, as explained in Section 3.2. Teachers within the TU Delft often write down their learning objectives in a "constructive alignment table", which includes the learning objective, bloom level, learning activities, formative assessment and summative assessment (*Align activities and assessment with constructive alignment*, n.d.). For the analysis tools, it was chosen to attach learning objectives with its bloom's level to the learning activities in the skill circuit.
By labelling which parts of the skill circuit handle which learning objective, it is possible to generate statistics that can give insight into how well each learning objective is taught.

Learning objectives should be represented by a descriptive title along with a category of Bloom's taxonomy. Teachers must be allowed to add as many learning objectives as they want to a skill circuit. Once they have created a few learning objectives they can attach these learning objectives to parts of the skill circuit. The created learning objectives can be attached to tasks in the skill circuit. This choice was made since a single task might relate to different learning objectives than other tasks within the same skill. Each task is allowed to have multiple learning objectives with no limit. A simplified diagram to conceptualise this design can be seen in Figure 4.2.

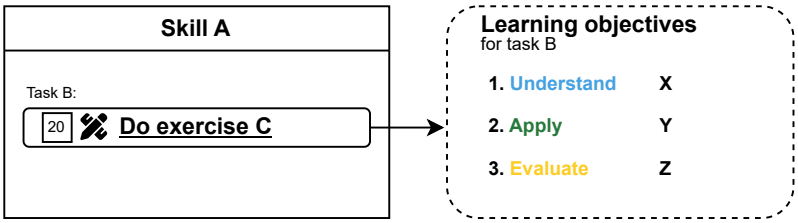


Figure 4.2: A diagram which shows that an SC task can have various learning objectives attached to it. Each task within a skill can have different learning objectives.

After the tasks have been labelled, the website can automatically generate charts such as those seen in Figure 4.3. Teachers can see if their learning objectives are covered by an equal amount of tasks with charts as seen in Figure 4.3a. They can also see which modules contain the most or least tasks for each learning objective with the chart in Figure 4.3b. Finally, they can see the distribution of the learning objectives per module from the chart in Figure 4.3c.

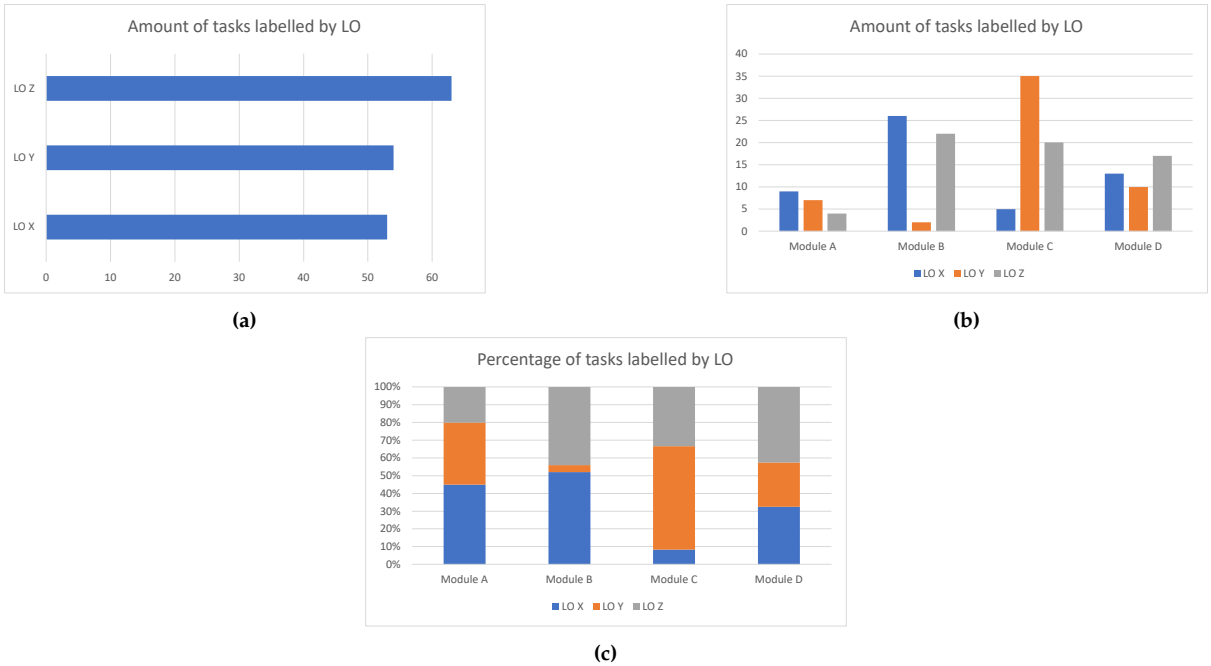


Figure 4.3: Examples of charts that could be generated from labelling data.

These were the charts that I felt were both helpful and achievable to develop during the course of the thesis. On top of these charts, the analysis tools should include a table, like the one in Figure 4.4, listing all tasks grouped by each learning objective along with links to that task. This table would aim to give a useful overview of the learning material attached to each learning objective. With the idea that teachers can verify if all tasks are labelled correctly and analyse the types of tasks used for each learning objective.
Finally, it is important that the actual implementation allows further extension and development of more charts in the future.

Tasks labelled by learning objective						
Learning objective	Create	Evaluate	Analyze	Apply	Understand	Remember
U		2				
V	1					
W					1	
X					1	
Y				1		
Z		1				
Total	1	3		1	1	

(a)

Tasks labelled by learning objective						
Learning objective	Create	Evaluate	Analyze	Apply	Understand	Remember
U		Task A Task C				
V	Task B					
W					Task A	
X					Task C	
Y				Task B		
Z		Task D				
Total	1	3		1	1	

(b)

Figure 4.4: Two versions of the same table. Table 4.4a aims to show teachers how many tasks each learning objective covers, to help spot gaps. Table 4.4b aims to add functionality, for example, if the teacher spots any errors or would like to make changes, they can click the link to be sent to the corresponding task.

Skill circuit tools & statistics

These should be tools that use the current state of the skill circuit as their input. Each tool should provide unique information, providing insight into the quality of the skill circuit. The measurement of quality should sometimes be up to the teacher, in these cases the tool provides a different perspective on the contents of the skill circuit. For example, a tool that lists the number of modules a skill circuit has might not have a clear measure of quality.

A table of all tools that were conceptualised during the design process can be seen in Table 4.3.

Title	Data source	Description
Combined min/max time estimate	Task time estimates	Summing all time estimates for a skill/submodule/module shows how long students are expected to spend for various components. Different time estimates can also be given for each possible path, along with the minimum/maximum time needed to complete the components.
Checkpoint size	Checkpoints and skills before it	Displays the size of each checkpoint. Either by the amount of skills or tasks that come before it, or the sum of time estimates of those tasks
Amount of tasks by type	Task types	Displays the number of tasks for each type (see Table 3.1)
Module size statistics	Module contents	Displays the number of submodules, skills and tasks that each module contains
Dead link detection	Task links	Warns teachers on any dead links. Dead links could be links leading to a 404 or privated/deleted YouTube videos
Disconnected skill-blocks	Skill-blocks and their connections	Warns teachers if any skill-blocks do not have any connections to other skill-blocks

Table 4.3: A table containing the title, data source and description of every tool that was conceptualised during the design process.

4.2.3. Usage analysis tools

Usage analysis tools should give teachers information on how their skill circuit is used by students. The student data that is available gives information on when a task has been completed by what student. However, it is difficult to draw certain conclusions since it is unreliable because students choose themselves when they label a task as complete. This creates situations where a student might forget to complete a task or labels a task as complete in order to move on, even if they have not actually completed the task. This creates even more difficulties when trying to create measurements for skill completions. When has a skill been completed by the student? Only when they have labelled all tasks in that skill as complete? What about tasks that are part of a path that they are not following? What if they forgot to label a task as complete?
In the end, I settled on two ways to communicate student progress to the teacher:

1. Showing the number of tasks done by a student compared to the maximum of each path. This ends up giving a completion percentage for each student, which could then be aggregated to a single percentage reflecting average student progress.

2. Taking the task that is furthest in the skill circuit for every student, and assuming every task before that has been completed. This also gives a completion percentage for each student by looking at what tasks are still left for each path. This percentage can be aggregated to a single percentage reflecting average student progress.

For tools where this information is relevant, the teacher should be given the option to view both of these measurements. These measurements could be shown to the teacher per component, i.e. giving both measurements for only module 1. This information could be shown to the teacher through tables, charts or even a visualisation as seen in Figure 4.5.

Figure 4.5: Design for visualisation of student progress. Percentages could be calculated through one of the two measurements.

Other ideas

With the data that is available from the website a couple of other ideas emerged during the design process of this project. First of all, an order of tasks could be determined for each student which could be useful information to the teacher. The difficulty lies in aggregating this data and communicating this as an aggregated measurement to the teacher. A "most common task order" measurement would be the end goal.
The time between task completions could also be used to draw other conclusions, such as estimating the time it took for students to complete a task. However, these conclusions are relying on the assumption that students did not take any breaks between task completions, so these measurements are not that reliable.
A notable omission from these analysis tools is combining student data with the learning objectives that were labelled, this was sadly missed during the design process of this project but could be looked into for future work.

4.3. Implementation

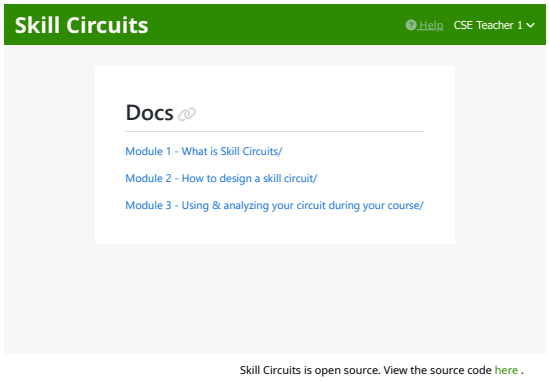
4.3.1. Onboarding

Documentation

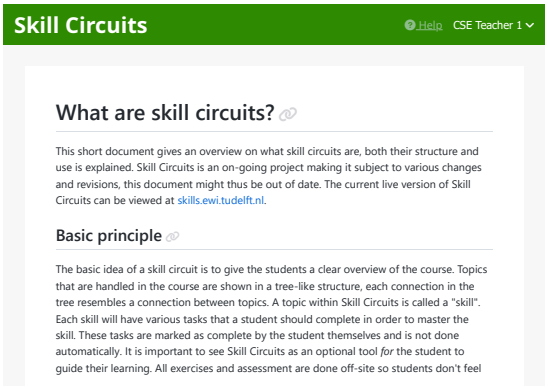
The actual implementation of the documentation created during this thesis deviates from the design as proposed in Subsection 4.2.1. The navigation pane along with the "previous" and "next" buttons have not been implemented, but are possible features to be added in the future.

In the current implementation, the website hosts the documentation under the /DOCS/ URL path. Only teachers or site admins are allowed to view this documentation and they can easily find it by pressing the "help" button at the top of every page.
When viewing the documentation, the users will be able to navigate through all the documents which are stored on the server under a /DOCS/ folder as can be seen in Figure 4.6. The structure of the folder is directly converted to the website, this allows anyone to write and add documentation without any need for coding. This conversion is done by using *flexmark-java*[2] to convert markdown files to HTML on the server and sending these to the client. However, future implementations might want to consider converting the markdown files on the client with the use of a javascript library since this reduces the load on the server. This might offer better parity and functionality as well since flexmark-java does not offer as many modern features as other markdown implementations.

[2]flexmark-java is a java implementation of CommonMark available on GitHub.



(a) Documentation landing page.

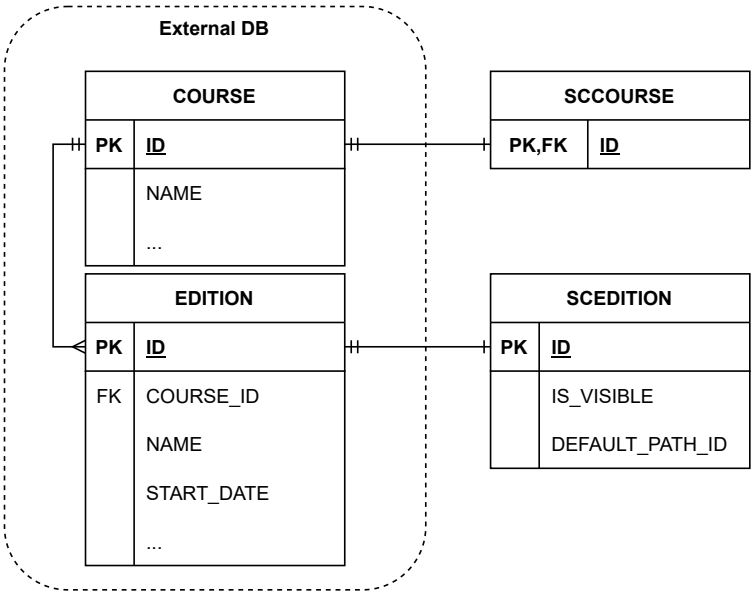


(b) A documentation document.

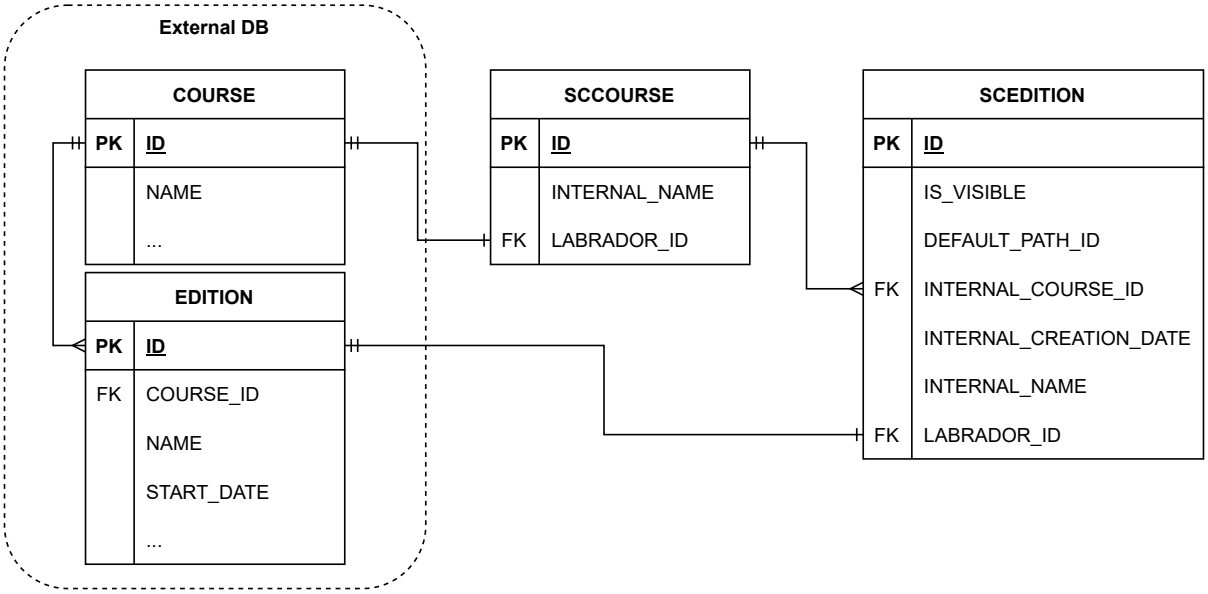
Figure 4.6: Actual view of the documentation. Folders will render as a list of links to sub folders and documents, documents are rendered as standard markdown.

Meta skill circuit

Previously, each skill circuit was directly tied to a specific edition of a course, which meant that each course could have several 'editions' of a skill circuit. This course and edition information was obtained from an official university database. The IDs saved in the Skill Circuits database matched the IDs of this external database, which meant that new skill circuits could not be created without creating official courses and editions. This, in turn, meant that the meta SC had to either be added as an official course at the university or that the system had to be rewritten to decouple the IDs of each database. It was chosen to do the latter since decoupling the IDs could be something that would be useful for future features. The change in database schema can be viewed in Figure 4.7, it was chosen to allow the creation of 'internal' courses and editions — which are not present in the external database.



(a) Old database design.



(b) New database design.

Figure 4.7: Changes made to the database design for implementing internal courses and editions, allowing the creation of the meta SC. The new design decouples IDs from the external database and stores extra information locally when a course is internal.

In the old design, the local database only kept the IDs of courses and editions for which a skill circuit existed. Other relevant information like *course name* and *edition start date* were retrieved from the external database on-demand. In the new design, functionality was added to allow internal courses and editions. When a course or edition is internal it has no external ID (LABRADOR_ID) and instead has relevant information stored locally (i.e. INTERNAL_NAME).

Additionally, since the meta SC would be a skill circuit where teachers are in reality the students, it was chosen to implement this for all internal courses and editions. The part of the code that handled user permissions was changed for internal courses and editions to facilitate the following:

- Students do not have access to internal courses and editions.
- Teachers are allowed to view and use internal courses and editions.
- Site admins are allowed to view and edit internal courses and editions.

4.3.2. Shared implementation for analysis

This section goes into depth on the technical aspects of the analysis tools that were implemented. The design analysis and usage analysis share a lot of similarities in their implementation on the server side. On the client side, the differences lie mostly in the tools and charts that were developed, which are discussed in the next two sections.

To reiterate, the Skill Circuits website uses Java Spring Boot for its back-end. To implement the analysis tools, it was required for the back-end to send the required data to the front-end. This could be done in two ways. Either the back-end sends all the raw data to the front-end, after which the front-end transforms the data into what it needs. Or the back-end transforms the data before sending it. The first option had the benefit of reducing the number of calculations on the server side, at the cost of increasing this on the client side. The downside of sending the raw data to the client was the concern of privacy since the usage analysis would use student data. This, on top of the fact that transforming the data on the client side was seen as less trivial to implement, gave the reason to implement the transformation step on the back-end.

It was desired to create code that would allow for easy extension with more tools, and thus more data transformations, in the future. For this reason, the implementation contains a number of layers of abstraction. A class diagram of the implementation of this transformation code can be seen in Figure 4.8.

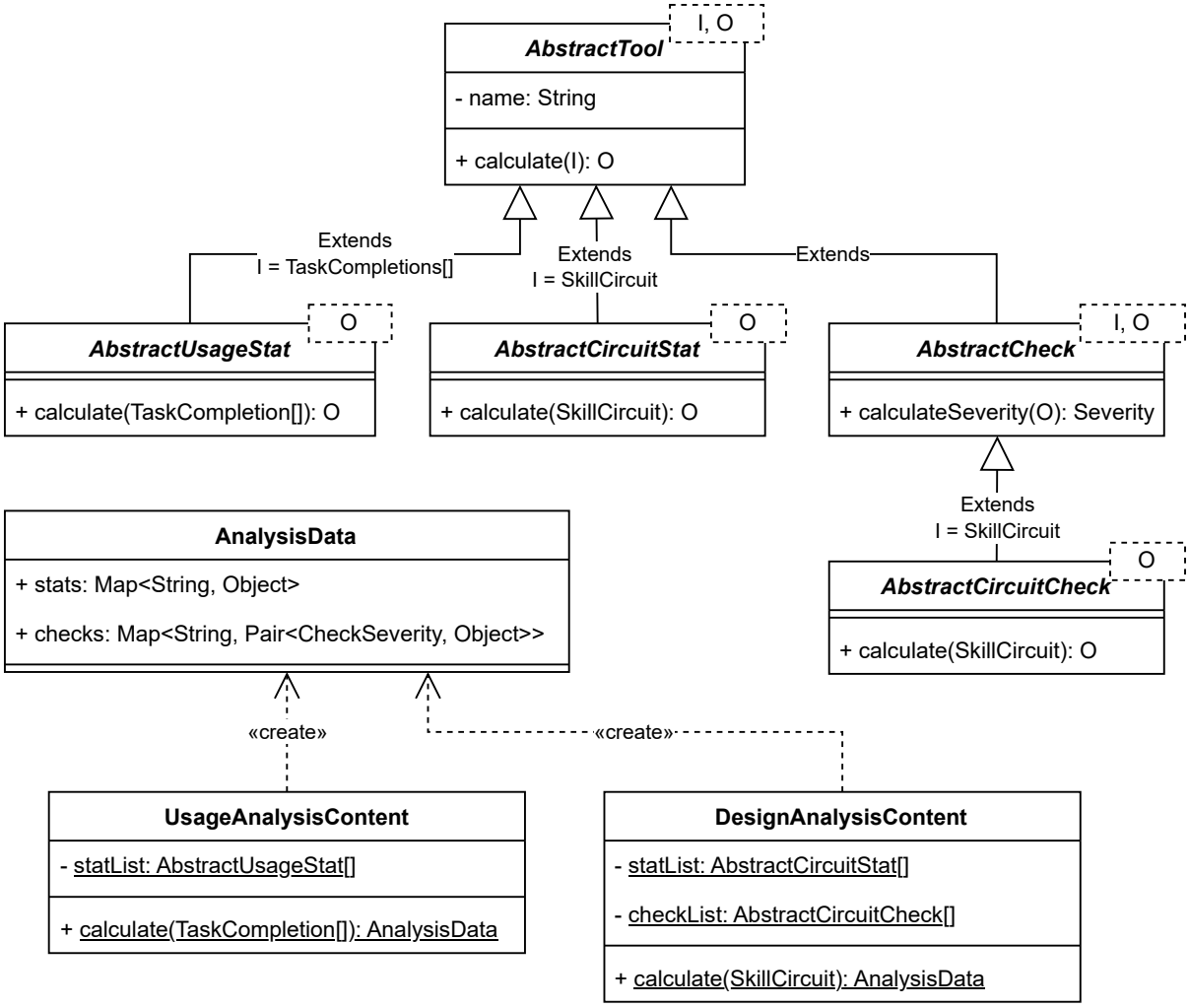


Figure 4.8: Class diagram of the transformation code. Data is sent to the front-end as an AnalysisData object. The client can then retrieve data for each tool from the stats or checks Map by using the unique name as the key. The TaskCompletion object represents a task completion by a student with a given timestamp, SkillCircuit represents the skill circuit in its entirety and Severity is an enum with various levels of severities.

4.3.3. Design analysis tools

This section covers the design analysis tools that were implemented. First the implementation of learning objectives and how a skill circuit is labelled, followed by the front-end tools that were created.

Learning objective analysis tools

The implementation for labelling learning objectives is very simple and leaves a lot of freedom to the teacher. First, a teacher must create learning objectives for their skill circuit; this is done on the website with a descriptive title and a level of the bloom's taxonomy, as can be seen in Figure 4.9.

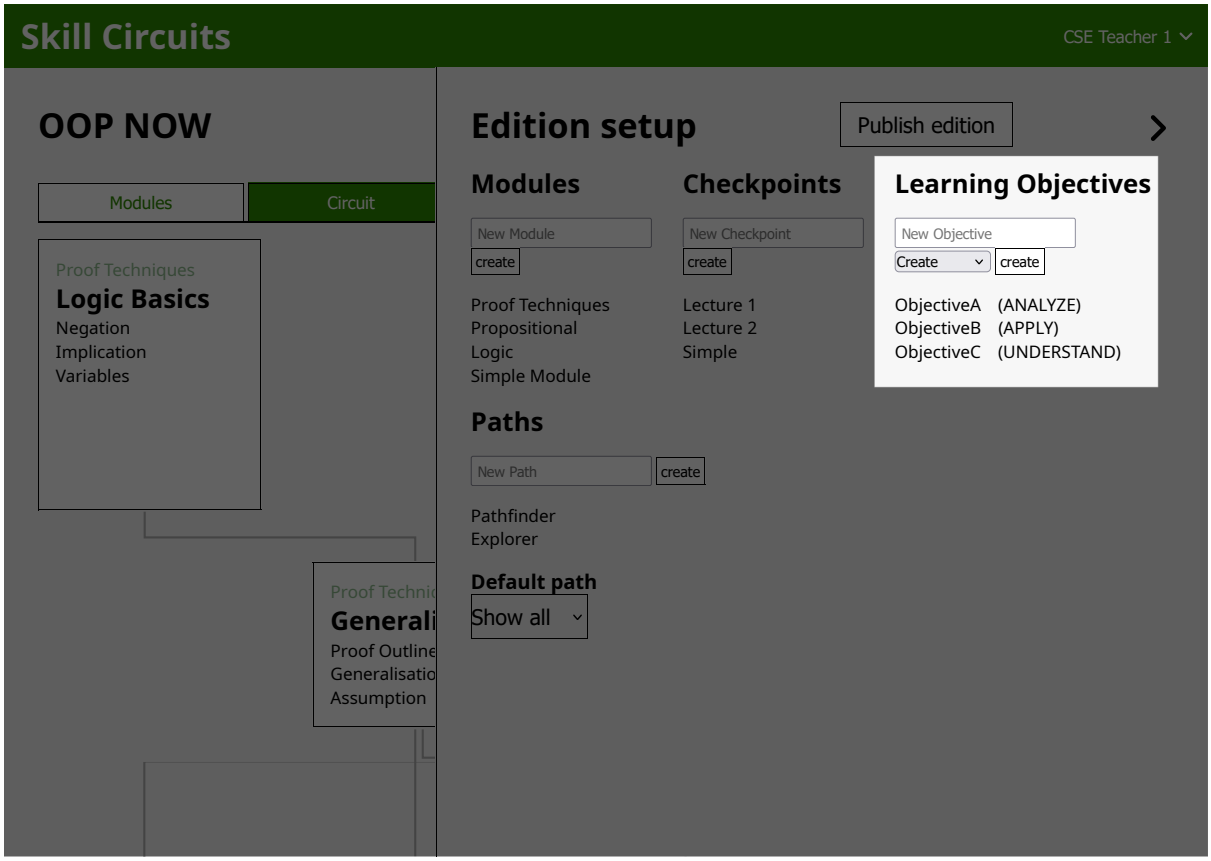


Figure 4.9: Full view of the Skill Circuits website. Focus is put on the form where teachers can create their learning objectives.

Once the skill circuit has been labelled with learning objectives, the teacher can start using the analysis tools. Teachers can quickly view what bloom categories are attached to a task as can be seen in Figure 4.10. The teacher is also free to edit the title and bloom category of each learning objective whenever they please. This is all stored in the database as a many-to-many relation, using two new tables as seen in Figure 4.11.

The tools that were implemented include the charts and learning objective table that were designed. The final layout of the table was simplified by reducing the number of columns used, which made the table smaller and more readable, the final table can be seen in Figure 4.12. For the creation of the charts, the Chart.js[3] Javascript library was used since the existing website already had this library included in its dependencies, though it was not used anywhere. The three charts that were designed were implemented, as can be seen in Figure 4.13.

[3]The Chart.js library can be found at https://www.chartjs.org/

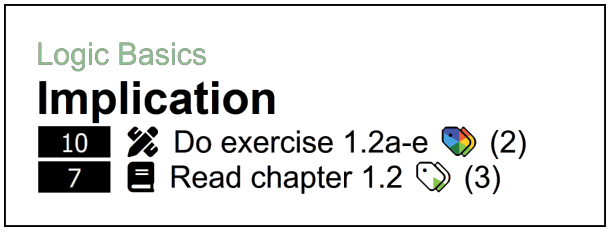


Figure 4.10: Teacher's view of a skill-block containing two tasks. Task one has multiple learning objectives, spanning all bloom categories. Task two only has a 'analyze' learning objective. Hovering over the tag icon will display the names of all attached learning objectives.

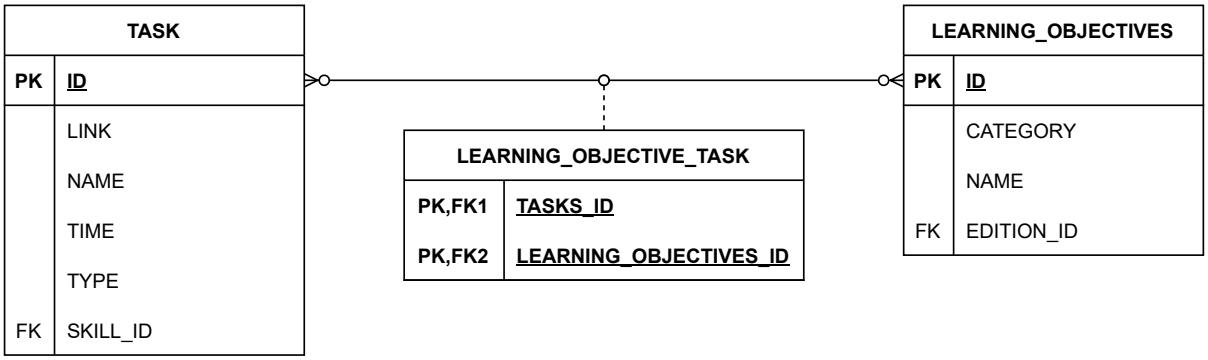
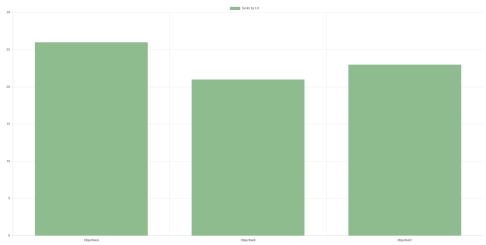


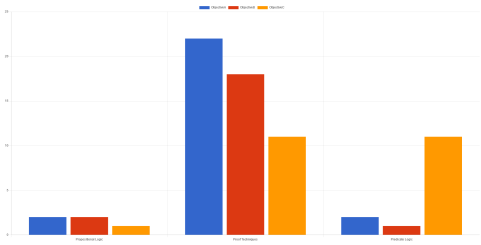
Figure 4.11: Database schema used for learning objectives. Task and learning objectives have a many-optional to many-optional relationship as defined by the LEARNING_OBJECTIVE_TASK table. No changes were made to the TASK table.

Learning Objectives	Tasks
Analyze	22
ObjectiveA	22 tasks: Read chapter 1.0 Read chapter 1.2 Read chapter 1.1 Read chapter 2.3 Do exercise 2.3a-d Watch video 1 Watch lecture 3 Read chapter 2.1 Read chapter 2.2 TA Check 1 Do exercise 2.0a-f Do exercise 1.0a Do exercise 1.2a-e Do exercise 1.1a-d Watch lecture 2 Read chapter 2.5 Read chapter 2.4 TA Check 2 Do exercise 2.1a-g Do exercise 2.2a-b Read chapter 2.0 Watch lecture 1
Understand	40
ObjectiveB	18 tasks: Watch lecture 2 Read chapter 2.5 Do exercise 2.5a Watch lecture 3 Watch lecture 4 Read Test yourself! Experiment with run time Do exercise 2.5a Do exercise 2.3a-d Watch video 1 Read chapter 2.4 TA Check 2 Do exercise 2.5b-d Project 1 Implement DFS Read chapter 2.5 Watch video 2: dominos
ObjectiveC	22 tasks: Do exercise 2.5a Do exercise 2.5b-d Project 1 Implement DFS Read chapter 2.5 Watch video 2: dominos Task 2 Task 8 Task 10 Task 4 Task 5 Watch lecture 4 Read Test yourself! Experiment with run time Do exercise 2.5a Task 1 Task 7 Task 9 Task 3 Task 11 Task 6

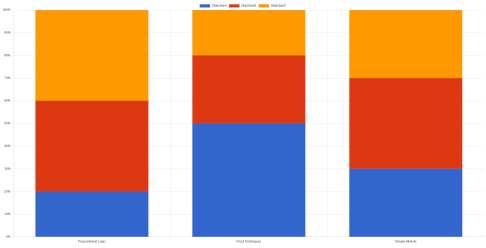
Figure 4.12: Table generated from a skill circuit that is labelled with three learning objectives. Links in the table will navigate the user to the relevant task.



(a) Amount of tasks per LO.



(b) Amount of tasks per LO in each module.



(c) Amount of tasks per LO in each module, shown as percentages.

Figure 4.13: The implemented charts, the designs of which could be seen in Figure 4.3. When multiple colours were not required, the colours would match the site's colour scheme.

Future improvements

In the current implementation, each task must be individually labelled with its corresponding learning objective(s). A more user-friendly approach, which was not implemented due to time constraints, would be to allow users to select a learning objective and select all tasks to which it should be attached.

Skill circuit tools & statistics

The basic design analysis tools used the skill circuit as their input data, after which the back-end would transform this in order to generate the tables such as the one shown in Figure 4.14. From the tools that were designed (shown in Table 4.3), the following were implemented:

- Combined min/max time estimate
- Amount of tasks by type
- Module size statistics
- Disconnected skill-blocks

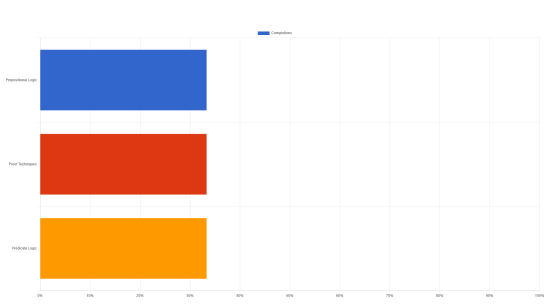
This means that the "Checkpoint size" and "Dead link detection tools" were not implemented.

Measurement	Time
Minimum time to complete circuit	7hrs
Maximum time to complete circuit	13hrs
Total time for optional skills only	3hrs
Pathfinder	10hrs
Explorer	13hrs

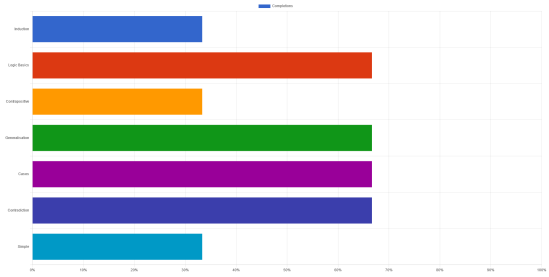
Figure 4.14: A table that presents the sums of all time estimates relevant to the skill circuit.

4.3.4. Usage analysis tools

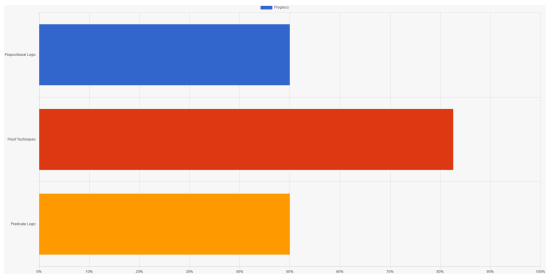
The final features that were to be implemented were the usage analysis tools. While there were a lot of designs for different tools, not many were implemented due to time constraints. Most notably, the tool that displayed information to the teacher in the form of a skill circuit, as seen in Figure 4.5, was not implemented since it turned out to be more work than anticipated. Instead, a number of charts were created using Chart.js, much like the charts for the design analysis. As explained in Subsection 4.3.2, the data for the charts used student data which was transformed into the relevant data used by each chart. The charts that were implemented for showing student progress are shown in Figure 4.15.
Finally, an additional chart was implemented that shows a timeline of student activity by showing the number of task completions for every day. This chart can be seen in Figure 4.16.



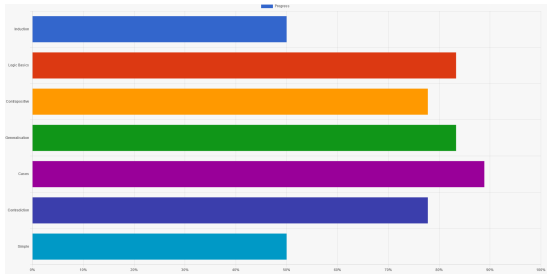
(a) Average task completions of all students for a module.



(b) Average task completions of all students for a submodule.



(c) Average progress of all students for a module.



(d) Average progress of all students for a submodule.

Figure 4.15: The implemented usage charts using the two measurements, as explained in Subsection 4.2.3, for showing student progress for modules and submodules. Average task completion looks at the number of tasks a student has completed, while average progress looks at the furthest task.

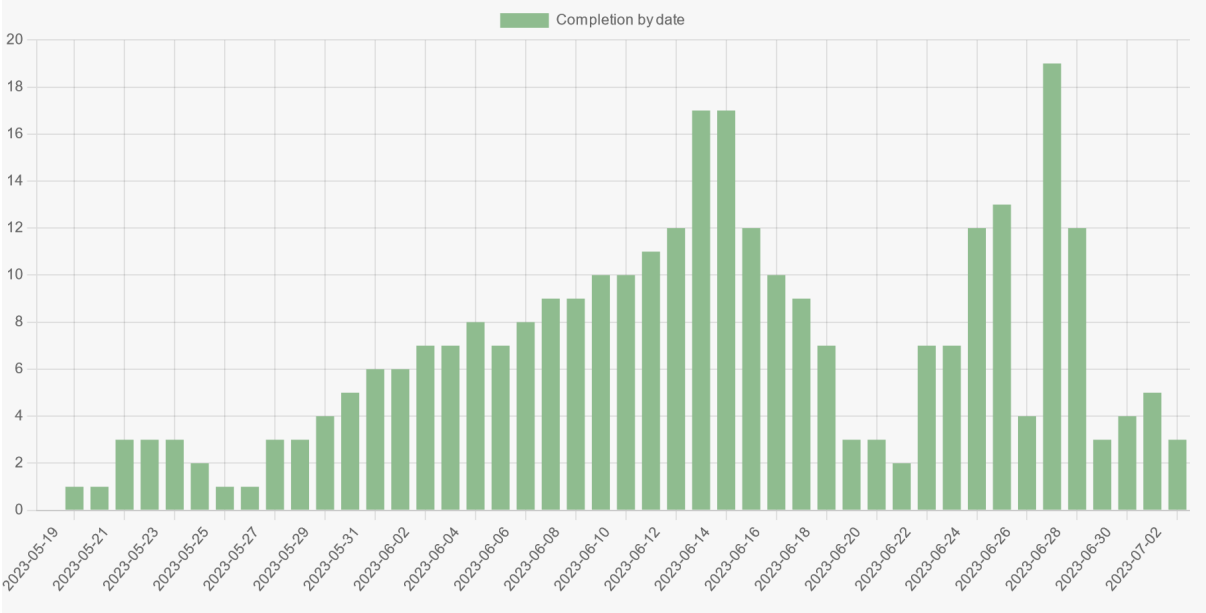


Figure 4.16: A chart that shows the number of tasks that were completed by all students on each day.

Future improvements

There is still a lot of room for future work to look into the development of more tools. The ideas as discussed in Subsection 4.2.3 were not implemented but are still worth a look. Primarily the idea of combining student data with the learning objectives that were labelled.

5 Method

This chapter discusses how the implemented software was evaluated. The aim of the evaluation along with the method used will be discussed. Finally, the results of this evaluation will be given.

5.1. Evaluation procedure of engineering component

This section discusses the evaluation of the engineering component. Why it was chosen to utilise a focus group along with the exact purpose of the evaluation.

5.1.1. Evaluation Method

To evaluate the engineering component a couple of limiting factors had to be taken into account. Namely a limitation in time and resources, but more importantly a limited amount of possible participants for the evaluation. To best evaluate the engineering component it would be required to find teachers that have used Skill Circuits before, but as discussed earlier with how requirements were obtained, this is currently a small number of teachers.

Instead, it was chosen to assemble a focus group consisting of members of the teaching team of which some have previously heard of Skill Circuits. A focus group was both deemed achievable and suitable for the purpose of the evaluation. Work from Krueger (2014) and Kontio, Bragge, and Lehtola (2008) was used to help create the focus group plans.

Other methods that were considered

A couple of evaluation methods were considered for this thesis, most notably using the Technology-acceptance model (TAM) or the thinking aloud protocol (Davis, 1989; Boren & Ramey, 2000). TAM was originally considered due to the objective of improving the user interface of the website which is now no longer the case. This, along with TAM not being suitable for a small size of participants, lead to TAM not being suitable for this thesis.
For the thinking aloud protocol there were instead two ideas: First, it was intended to evaluate different iterations of the engineering component and ask participants to talk aloud to uncover what they liked in terms of improvements made to the website along with further improvements they would like to see. Second, since the previous plan was not possible due to time limitations it was instead chosen to evaluate the website as a whole by asking participants to solve a scenario while talking aloud. In this scenario they were tasked to update an existing skill circuit by analysing its performance (usage analysis tools), and by adding new segments to the skill circuit.

Participants would be given everything they might require to succeed in the task, such as the meta skill circuit, new learning objectives and new course material for the new segments. This evaluation plan was also deemed too ambitious and perhaps too error-prone to be suitable for this thesis.

5.1.2. Purpose

The primary purpose of the focus group was to help answer the research questions while also gathering opinions on the changes that were made to the Skill Circuits website.

Answering the research questions

RQ1: "How should a teacher map their existing course, which follows the constructive alignment principle, to a set of skills in order to construct a hierarchy for use in a skill circuit?"

Fully answering this question might prove impossible, but throughout this thesis, I have realised that the creation of a skill circuit from a course can vary due to numerous circumstances. The ideal approach can change according to the structure of the course; a project-based course will have a different skill circuit compared to a more generic course with exams and assignments. The sheer number of differences in courses, along with personal preferences on how to design a skill circuit, makes it hard to give a single answer to this question.

However, during this thesis, I have developed a selection of features that I hope can help teachers find their own answers to this question. A solution that fits their course and preference on how to utilise Skill Circuits with their course. I hypothesise that Design analysis tools and Usage analysis tools will aid teachers in answering this question and hopefully alleviate the problem of new teachers not knowing whether their skill circuit is 'good'.

With the focus group, I wish to ask participants if they agree that design tools — such as learning objective labelling — help with the initial mapping from course to skill circuit and that the usage analysis tools help solidify this mapping.

RQ2: "To what extent can we support teachers in the creation of a skill circuit through analysis tools, such that it gives valuable insight into the quality of their circuit design?"

Over the course of this thesis, I have developed various ideas for tools that I feel could help during the creation of a skill circuit. For answering this research question I would want the participants' opinions on each of these ideas. However, I do not wish to overwhelm the participants, so I will ask them to highlight which tools pique their interest the most and which tools they feel do not add any value. Additionally, I want to leave room for discussion on tools that I did not think of or potential improvements on tools that I show.

RQ3: "What learning analytics, obtained from students using a skill circuit, are most insightful to teachers? Are there analytics that can help improve the skill circuit?"

For this question, I wish to ask the participants' opinions on what usage analytics they wish to see. I think answering this is best done by asking participants which analytics are most important to them, and which analytics provide little benefit, similar to how I hope to answer RQ2.

5.1.3. Participants

A total of six participants were invited for the focus group. These participants were all teachers of the same teaching team and were presumed to have heard of Skill Circuits before. Two teachers were unable to attend, meaning a total of four participants attended the meeting. Of these four, three participants had used Skill Circuits for their course before.

5.1.4. Focus group meeting outline

The following questioning route was made to help answer the research questions:

Questioning route

1. **Opening/Introduction question:** What are your experiences with Skill Circuits?
2. Question two would depend on the answer to question 1:
   (a) **Transition question:** What are the main benefits in making a Skill Circuit? Is it useful for the teacher or for the student?
   (b) **Transition question:** What do you think are the main challenges in creating a Skill Circuit?
3. **Key question:** What is your opinion on using the documentation for introducing new teachers?
4. **Key question:** What do you think of using a Skill Circuit to introduce teachers to the platform?
5. **Key question:** What sort of insight do you think these learning objectives can give?
6. **Key question:** Do you think that attaching learning objectives to an entire circuit is worth the insight?
7. **Key question:** What graph or tool do you feel is helpful to you when creating a skill circuit?
8. **Key question:** What visualisation or tool, showing student usage of your skill circuit, would you find helpful?
9. **Ending question:** What features are missing that you feel could help new teachers understand and use Skill Circuits?
10. **Ending question:** What did I miss? Do you have anything that we didn't talk about but should have?

Meeting story

The questions were grouped together into phases a new teacher would go through when using Skill Circuits. This was done to provide a cohesive story during the focus group meeting, with the goal of walking the participants through the entire process of making a skill circuit.
The three phases are as follows:

1. **Introduction phase: questions 3-4.**
   In this phase, the teacher will need to learn the concept of Skill Circuits and how to use the website.
2. **Design phase: questions 5-7.**
   In this phase, the teacher will start with designing their skill circuit for use in their course.

3. **Final phase: question 8.**
   In this phase, the teacher has made a skill circuit and is now using it with their course.

Linking key questions to research questions

The key questions can be linked to the research questions as can be seen in Table 5.1, each link is further explained in the following paragraphs.

Question 3

What is your opinion on using the documentation for introducing new teachers?

The documentation itself can be linked to RQ1; it is part of the process of "how" a teacher should map their course since the documentation is supposed to communicate this "how".
I wish to ask the focus group if this is the correct way of communicating this information to new teachers, or if they feel there are other — more suitable — methods.

Question 4

What do you think of using a Skill Circuit to introduce teachers to the platform?

Using a skill circuit to introduce teachers can be linked to RQ1, similar to question 3. Moreover, the meta skill circuit has the added benefit of providing teachers with an extra perspective. They get to experience how a student would view a skill circuit, and hopefully experience for themselves what kind of benefit it could provide.
I wish to ask the focus group whether the idea in itself is good and whether they agree that it gives this extra perspective.

Question 5

What sort of insight do you think these learning objectives can give?

The learning objectives feature relates to both RQ1 and RQ2. RQ2 because it is one of the analysis tools that I hope gives a teacher insight into their circuit design. But also RQ1, because I feel it is one of the analysis tools that can really help a teacher figure out if their skill circuit reflects their course well.
I wish to ask the focus group whether they agree that attaching learning objectives helps teachers spot gaps in their skill circuit and that it eventually leads to a skill circuit that reflects their course.

Question 6

Do you think that attaching learning objectives to an entire circuit is worth the insight?

This question relates purely to RQ2. I wish to ask the focus group if they think the process of labelling learning objectives is actually worth the effort; if the analysis tools that I presented are worth this effort.

Question 7

What graph or tool do you feel is helpful to you when creating a skill circuit?

The graphs and tools in this question refer to those presented as design analysis tools, so this question relates to RQ2.
I wish to ask the focus group which tools stand out to them, which tools would have a large benefit to them, and if any tools need some changes.

Question 8

What visualisation or tool, showing student usage of your skill circuit, would you find helpful?

This question relates to RQ3 since the tools in question visualise analytics obtained from students using a skill circuit.
Similar to question 7, I wish to ask the focus group which tools stand out to them.

Research question	Relevant key question
RQ1	3, 4 & 5
RQ2	5, 6 & 7
RQ3	8

Table 5.1: Table showing which key questions relate to which research questions.

Meeting outline
The questioning route was accompanied by a presentation, where each key question was preceded by presenting the relevant features. Table 5.2 shows the planned outline of the meeting.

Time	Subject
0:00-02:00	Introduction
2:00-5:00	Q1
5:00-9:00	Explain thesis objective
9:00-10:00	Brief definition of a Skill Circuit
10:00-13:00	Q2
13:00-15:00	Present Documentation feature
15:00-20:00	Q3
20:00-21:00	Present Meta skill circuit feature
21:00-26:00	Q4
26:00-28:00	Present Learning objectives labelling & tools
28:00-34:00	Q5
34:00-39:00	Q6
39:00-41:30	Present other Design tools
41:30-46:30	Q7
46:30-50:00	Present Usage analysis tools
50:00-55:00	Q8
55:00-1:00:00	Q9
1:00:00-1:05:00	Q10 (If there is time left)

Table 5.2: Meeting outline with time estimates that was prepared for the focus group meeting.

5.2. Results
This section details the results of the focus group meeting and summarises all the relevant points that were discussed. A transcript of the meeting is available in Appendix B.

5.2.1. Introduction
The four participants were all people I was familiar with, for this reason, I knew what their answer to question one would be. For this reason, I opted to skip this question during the meeting and move on to more relevant matters.

Q2: "What are for you the main benefits of making a Skill Circuit? Is it useful for the teacher or for the student?"
One participant (participant *B*) answered that for them the main benefit is for the teacher. It helped them identify what things they expected from students and whether they actually have practice material for these things. *B* stated that "... these are areas where we should work on because we see that a lot of students are struggling with this skill, but we have nothing for them to practice with or that fits different learning styles."
Participant *A* agreed that they see a large benefit for the teacher when using Skill Circuits. They were also able to query among their students if they liked using Skill Circuits compared to Brightspace (the LMS that is widely used at the TU Delft). *A* mentions that the students that used Skill Circuits indicated that they liked the idea of completing tasks, stating that it felt satisfying, especially when working towards completing the entire skill circuit.
B was not entirely convinced of the benefits to the student. They mention that having to group relevant tasks together in a single skill meant that they had to present tasks to the student out of order, which caused some confusion among students. Additionally, *B* mentioned that students had different interpretations of how to use the skill circuit. *B* said that some students were very strict in completing every task before the relevant lecture, which was not the intention of *B*. After some discussion with the other participants, it was clear that the structure of *B*'s course, as well as *B*'s approach to using Skill Circuits, was different to theirs.
B later stated that they think the ability for students to choose different paths is very useful to students.
Finally, participant *D*, who had not used Skill Circuits before, felt that the connections between skills could be useful to students struggling with a specific topic. With the connections between skills, they could go back to previous skills and more easily figure out what they were missing.

5.2.2. Documentation

Q3: "So what is your opinion on actually using documentation for introducing new teachers?"
The participants all agree that the inclusion of a documentation or help page would be very welcome. In their opinion, these should focus on explaining the concepts related to Skill Circuits and not so much on technical details. Participants *A* and *B* specifically mention that they normally wouldn't start by checking a website's documentation and would instead first look around until they get stuck. *A* suggested that in this use-case the "help" button should take the user to a relevant documentation page, based on the page they were viewing, instead of the documentation 'homepage'. This could be something future work can look into.

5.2.3. Meta skill circuit

Q4: "What do you think of using a skill circuit itself to introduce teachers to the platform?"
Participants were all very enthusiastic about the idea of the Meta skill circuit. *A* even proposed that its availability should not be limited to teachers only, but also to students and teaching assistants. *A* feels that the Meta skill circuit could provide some nice insight to students that are interested in how the skill circuit they are using during the course was designed.

While not discussed during the meeting, I feel that the Meta skill circuit also complements the expected use of the documentation that *A* and *B* mention. They state they would only use documentation when they get stuck, which means they wouldn't read anything on the concepts used in Skill Circuits. The Meta skill circuit handles these same topics, but could instead be

seen as a fun demo of the Skill Circuits to new teachers.

5.2.4. Learning objective labelling

Q5 & Q6: Discussion on labelling a skill circuit with learning objectives

After I presented my ideas on using learning objectives in Skill Circuits a discussion arose. While I did not explicitly ask my prepared question, this discussion did answer it for the most part.
The discussion started with the participants wondering what kind of learning objectives to use in tandem with Skill Circuits. *B* mentions that for their course they have specific learning objectives for every lecture, but also 'course-wide' learning objectives. *B* feels that they would use the proposed feature with the lecture-level learning objectives, while I originally envisioned this feature to be used with course-wide learning objectives.
C is most interested in using the seven bloom levels within each topic that their course discusses, instead of looking at the course's learning objectives.
Overall it seemed that the participants agreed that the addition of learning objectives could help identify gaps in the skill circuit. However, each of them did feel they would use it differently. Luckily, the current system for using these learning objectives is quite flexible, but I still feel that it needs some further attention. For example, figuring out what the recommended use of the learning objectives should be for new teachers and figuring out what graphs or visualisations to include on the website that fit these different approaches.

5.2.5. Design tools

Q7: Discussion on design tools

Like question 6, I was not able to ask my prepared question 7. Instead, *A* commented on one of the tools I showed during the presentation, after which a discussion followed.
The tool in question is the one seen in Figure 5.1. *A* explicitly said that they really needed this tool on the website. *B* also liked the overall idea stating that "I think it is good to show these sorts of statistics". Where *A* added "It gives us some indication of how much material we've got".
After this interruption, I continued showing the rest of the tools that I had developed. I wanted to also highlight that these tools could go beyond showing statistics to the teacher and could include tools which checked for common mistakes. *B* seemed to like this and stated that warnings (like a module being too big) would be nice. The participants did not state that any of the tools that were shown should be excluded. There were positive comments on every tool with some additional ideas for improvement. I think it is fair to conclude that all tools were deemed helpful additions.

5.2.6. Analysis tools

Q8: Discussion on usage analysis tools

Again, while I was presenting all the tools I had developed, one of the participants commented on what they saw and a discussion followed.
From the discussion, I gathered that insight into what students are doing was lacking on the original website. Participants showed interest in what I had shown but expressed the desire for more filtering on additional metrics. This desire came from the fact that tracking students on the Skill Circuits website can be unreliable. More specifically, it is difficult to accurately measure how much each student has completed on the Skill Circuits website. For example,

Measurement	Time
Minimum time to complete circuit	7hrs
Maximum time to complete circuit	13hrs
Total time for optional skills only	3hrs
Pathfinder	10hrs
Explorer	13hrs

Figure 5.1: A table that presents the sums of all time estimates relevant to the skill circuit.

a student might choose to skip ahead and leave some tasks unfinished, how should this be measured when looking at the student's progress? While some teachers might be interested in seeing how many tasks a student has completed, other teachers might want to know how far a student has progressed in the skill circuit, even if this student has skipped some tasks. These different ways of measuring student progress should be given as a choice to teachers. Additionally, participants mentioned that they are mostly interested in the aggregated data from all students in the course, not data from individual students.

Another example was when I showed the chart seen in Figure 5.2, participants felt that along with the number of completions, the sum of task time estimates would be nice to see as well.

Finally, the participants focused on the design as can be seen in Figure 5.3, stating that they "want to have such a view" but with the ability to zoom in on each skill to get more detailed data on the individual tasks. Again, participants stated that it would be nice to have a choice in what metric to use for the percentages.

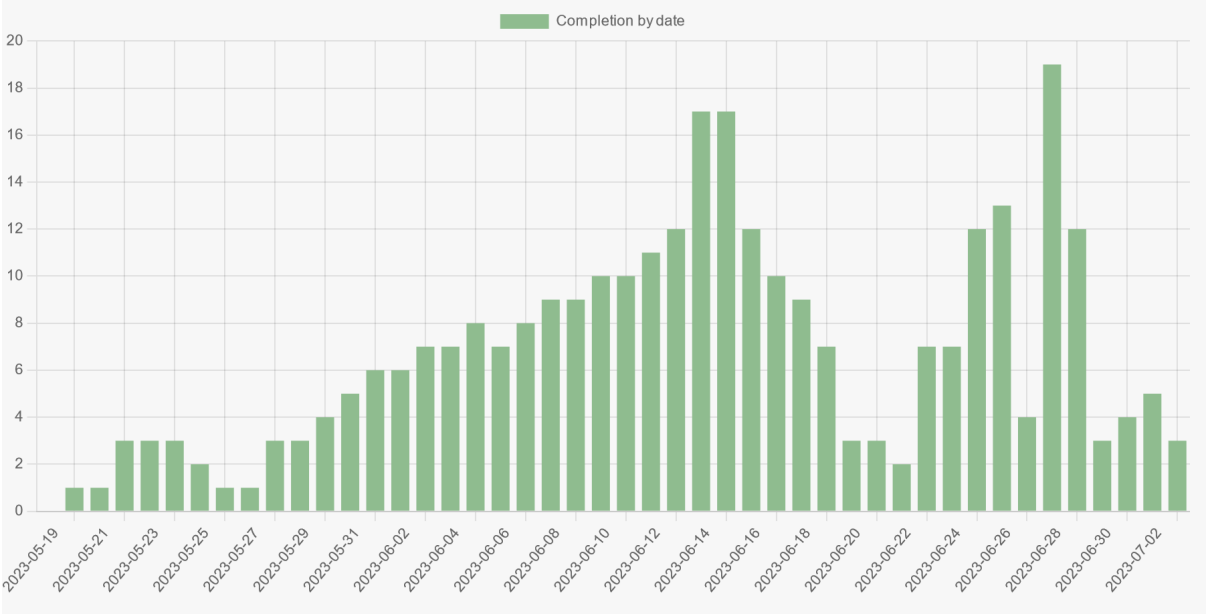


Figure 5.2: A chart that was shown during the presentation which sparked some discussion. The chart shows the number of tasks that were completed by all students on each day (in short: an activity chart).

Figure 5.3: Design for visualisation of student progress which was shown during the focus group meeting.

6

Conclusion

This thesis aimed to answer the research questions as repeated here:

RQ1 How should a teacher map their existing course, which follows the constructive alignment principle, to a set of skills in order to construct a hierarchy for use in a skill circuit?

RQ2 To what extent can we support teachers in the creation of a skill circuit through analysis tools, such that it gives valuable insight to the quality of their circuit design?

RQ3 What learning analytics, obtained from students using a skill circuit, are most insightful to teachers? Are there analytics that can help improve the skill circuit?

To answer these research questions, a number of features were developed for the existing Skill Circuits website as discussed in Chapter 4. A focus group meeting was held to evaluate these features as discussed in Chapter 5, which in turn would help answer the research questions.

These research questions were created with the objective of improving the experience of using Skill Circuits for teachers. Primarily new teachers, who might have difficulties understanding the concept of a skill circuit.
For RQ1 the focus on constructive alignment was chosen because it is a principle that all teachers at the TU Delft are suggested to utilise. The existing literature did not contain a direct answer. Constructive alignment inspired the idea of labelling parts of a skill circuit with learning objectives, to generate coverage of each learning objective through various tools that aim to spot gaps. This idea was developed as a solution to the problem that RQ1 poses and is one of the main contributions of this thesis. The focus group participants felt that this solution would benefit them in using Skill Circuits. The participants all had different ideas on how they would use such a feature, so it remains to be seen how teachers would actually utilise it once it is added to the website. While the solution shows promise, there is currently not enough evidence to show that it answers RQ1. On top of this, a documentation help page was developed, accompanied by a proof-of-concept skill circuit, which both aimed to explain the concept of Skill Circuits and how to use the website. This aimed to communicate methods of mapping a course to a skill circuit, with the hope that this helped the teacher reach their own answer to RQ1.

For RQ2, various tools were developed that helped to aid teachers in their skill circuit design. From the focus group, it can be concluded that all developed tools were deemed helpful additions. Tools like Combined min/max time estimate were helpful as they would save time on operations that the teachers already performed. Other tools like the Amount of tasks by type

and Module size statistics were helpful as they gave additional perspective on the contents of the skill circuit.
The aim of these tools was to give teachers different perspectives of their skill circuit from which they could draw conclusions on the quality of their design. This also provides a stepping stone to finding standards for a skill circuit, which could later be developed into guidelines and automatic detection systems. For example, participants of the focus group stated that it would be nice if the website would warn the user if one of their modules contains too many skills compared to the recommended amount. This thesis provides the teachers with tools to gather this information themselves, but no 'recommended' amount is known at this time since the number of courses using skill circuits is limited and too small of a sample size.

RQ3 needs further evaluation with actual course data. While the participants of the focus group were enthusiastic about the design I had shown, they were not entirely sure what analytics they would really want to see. There currently exists no analytics on the Skill Circuits website, making it hard to decide on which analytics to use, since it is not known how students use it in reality.

6.1. Shortcomings

The main shortcoming of this thesis is the lacking evaluation, which made it hard to draw any real conclusions. I think that this can be attributed to my lack of experience with evaluating software for research purposes and the difficulty in finding participants that matched the target audience.
On top of this, I think that RQ1 is somewhat hard to answer in its current formulation. At the start of this thesis, I hoped to find an answer in literature. However, I soon realised that the answer to this question became less of a simple answer and more of an "it depends". The answer depends on the course, the course material and the teacher's preferences.
For RQ3 I realise now that it would have been beneficial to request student data that is currently stored on the Skill Circuits website. With this, I could have gained some basic understanding of how students use the platform, from which I could make more well-informed decisions on the type of analytics to develop. This is of course something that future work could look into.

6.2. Future work

There is a lot of room for future work within the Skill Circuits platform which I was not able to work on. First of all, the documentation and meta skill circuit could both be further developed. The meta skill circuit could for example follow a more thought-out course.
More research could go into the impact that attaching learning objectives to a skill circuit can have. Since the focus group had differing opinions on how to use this feature, it would be beneficial to figure out which approach works best or if the current approach of leaving the decision up to the teacher is better.
There were also many other ideas for further improvements of the Skill Circuits website that came up during this thesis. Features like a context-aware help button, or student feedback possibilities for tasks through the use of emoji reactions, to name a few.
Finally, there is room for future work to look into evaluating the contributions of this thesis to see if they answer the research questions and if these contributions can really help teachers.

References

Align activities and assessment with constructive alignment. (n.d.). Retrieved 2023-07-26, from https://www.tudelft.nl/en/teaching-support/didactics/design

-develop/align-activities-and-assessment-with-constructive-alignment
Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher Education*, *32*(3), 347–364. doi: 10.1007/BF00138871
Bond, M., Zawacki-Richter, O., & Nichols, M. (2019, January). Revisiting five decades of educational technology research: A content and authorship analysis of the British Journal of Educational Technology. *British Journal of Educational Technology*, *50*(1), 12–63. Retrieved 2023-05-19, from https://bera-journals.onlinelibrary.wiley.com/doi/full/10.1111/bjet.12730 doi: 10.1111/bjet.12730
Boren, T., & Ramey, J. (2000, October). Thinking aloud: Reconciling theory and practice. *Professional Communication, IEEE Transactions on*, *43*, 261–278. doi: 10.1109/47.867942
Capuano, N., Gaeta, M., Marengo, A., Miranda, S., Orciuoli, F., & Ritrovato, P. (2009, September). LIA: an intelligent advisor for e-learning. *Interactive Learning Environments*, *17*(3), 221–239. Retrieved 2023-05-21, from https://www.tandfonline.com/doi/10.1080/10494820902924912 doi: 10.1080/10494820902924912
Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319–340. Retrieved 2022-11-25, from https://www.jstor.org/stable/249008 doi: 10.2307/249008
De Smet, C., Schellens, T., De Wever, B., Brandt-Pomares, P., & Valcke, M. (2016, August). The design and implementation of learning paths in a learning management system. *Interactive Learning Environments*, *24*(6), 1076–1096. Retrieved 2023-05-21, from https://doi.org/10.1080/10494820.2014.951059 doi: 10.1080/10494820.2014.951059
Development of Teaching and Active Learning. (n.d.). Retrieved 2023-07-20, from https://ocw.tudelft.nl/courses/development-teaching-active-learning/
Fadde, P., & Vu, P. (2014, January). Blended online learning: Misconceptions, benefits, and challenges. , 33–48.
Fernández-Batanero, J.-M., Román-Graván, P., Reyes-Rebollo, M.-M., & Montenegro-Rueda, M. (2021, January). Impact of Educational Technology on Teacher Stress and Anxiety: A Literature Review. *International Journal of Environmental Research and Public Health*, *18*(2), 548. Retrieved 2023-05-19, from https://www.mdpi.com/1660-4601/18/2/548 doi: 10.3390/ijerph18020548
Gagné, R. M. (2009, October). Presidential address of division 15 learning hierarchies. *Educational Psychologist*. Retrieved 2022-09-22, from https://www.tandfonline.com/doi/abs/10.1080/00461526809528968 doi: 10.1080/00461526809528968
Joseph, L., & Abraham, S. (2017, July). Instructional design for learning path identification in an e-learning environment using felder-silverman learning styles model. In *2017 International Conference on Networks & Advances in Computational Technologies (NetACT)* (pp. 215–220). doi: 10.1109/NETACT.2017.8076769
Kerr, R. A. (2000, October). Applications of Instructional Design Mapping Strategies in the Development of Complex Integrated Courses. *Journal of Pharmacy Practice*, *13*(5), 338–346. Retrieved 2022-09-22, from https://doi.org/10.1106/NDFT-1W6P-YB7B-KE28 doi: 10.1106/NDFT-1W6P-YB7B-KE28
Kohavi, R., & Longbotham, R. (2017). Online Controlled Experiments and A/B Testing. In C. Sammut & G. I. Webb (Eds.), *Encyclopedia of Machine Learning and Data Mining* (pp. 922–929). Boston, MA: Springer US. Retrieved 2023-03-29, from https://doi.org/10.1007/978-1-4899-7687-1_891 doi: 10.1007/978-1-4899-7687-1_891
Kontio, J., Bragge, J., & Lehtola, L. (2008). The Focus Group Method as an Empirical Tool in Software Engineering. In F. Shull, J. Singer, & D. I. K. Sjøberg (Eds.), *Guide to Advanced Empirical Software Engineering* (pp. 93–116). London: Springer. Retrieved 2023-07-30, from https://doi.org/10.1007/978-1-84800-044-5_4 doi: 10.1007/978-1-84800-044-5_4

Krueger, R. A. (2014). *Focus Groups: A Practical Guide for Applied Research*. SAGE Publications. (Google-Books-ID: 8wASBAAAQBAJ)

Novak, J. D. (1980). Learning Theory Applied to the Biology Classroom. *The American Biology Teacher*, *42*(5), 280–285. Retrieved 2023-04-20, from https://www.jstor.org/stable/4446939 doi: 10.2307/4446939

Omotayo, K. A., & Osuala, O. R. (2022). Effect of the Task Hierarchy Analysis Model of Instruction on the Biology Students' Performance and Attitudes in Osun State. *Ilorin Journal of Education*, *42*(2), 9–17. Retrieved 2023-05-22, from https://ije.unilorinedu.sch.ng/

Sejzi, A. A., & Aris, B. (2013). Learning Management System (LMS) and Learning Content Management System (LCMS) at virtual university.. Retrieved 2023-05-25, from https://www.semanticscholar.org/paper/Learning-Management-System-(LMS)-and-Learning-at-Sejzi-Aris/07d8054cd10d689e8236699464eecb277fc8d9c4

Shipley, S. L., Stephen, J. S., & Tawfik, A. A. (2018, July). Revisiting the Historical Roots of Task Analysis in Instructional Design. *TechTrends*, *62*(4), 319–320. Retrieved 2023-05-22, from https://doi.org/10.1007/s11528-018-0303-8 doi: 10.1007/s11528-018-0303-8

Stošić, L. (2015). The Importance of Educational Technology in Teaching. *International Journal of Cognitive Research in Science, Engineering and Education*, *3*(1), 111–114. Retrieved 2023-05-19, from https://www.proquest.com/docview/2258270969/abstract/4293BC99B0914D6BPQ/1

Trochim, W. M., & McLinden, D. (2017, February). Introduction to a special issue on concept mapping. *Evaluation and Program Planning*, *60*, 166–175. Retrieved 2023-04-20, from https://www.sciencedirect.com/science/article/pii/S0149718916301471 doi: 10.1016/j.evalprogplan.2016.10.006

A

Meta SC design

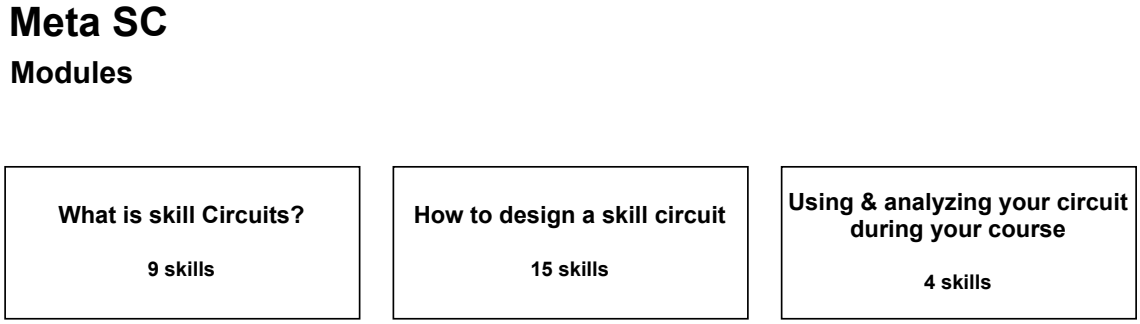


Figure A.1: The three modules that are covered in the Meta Skill Circuit

Module 1: What is Skill Circuits?

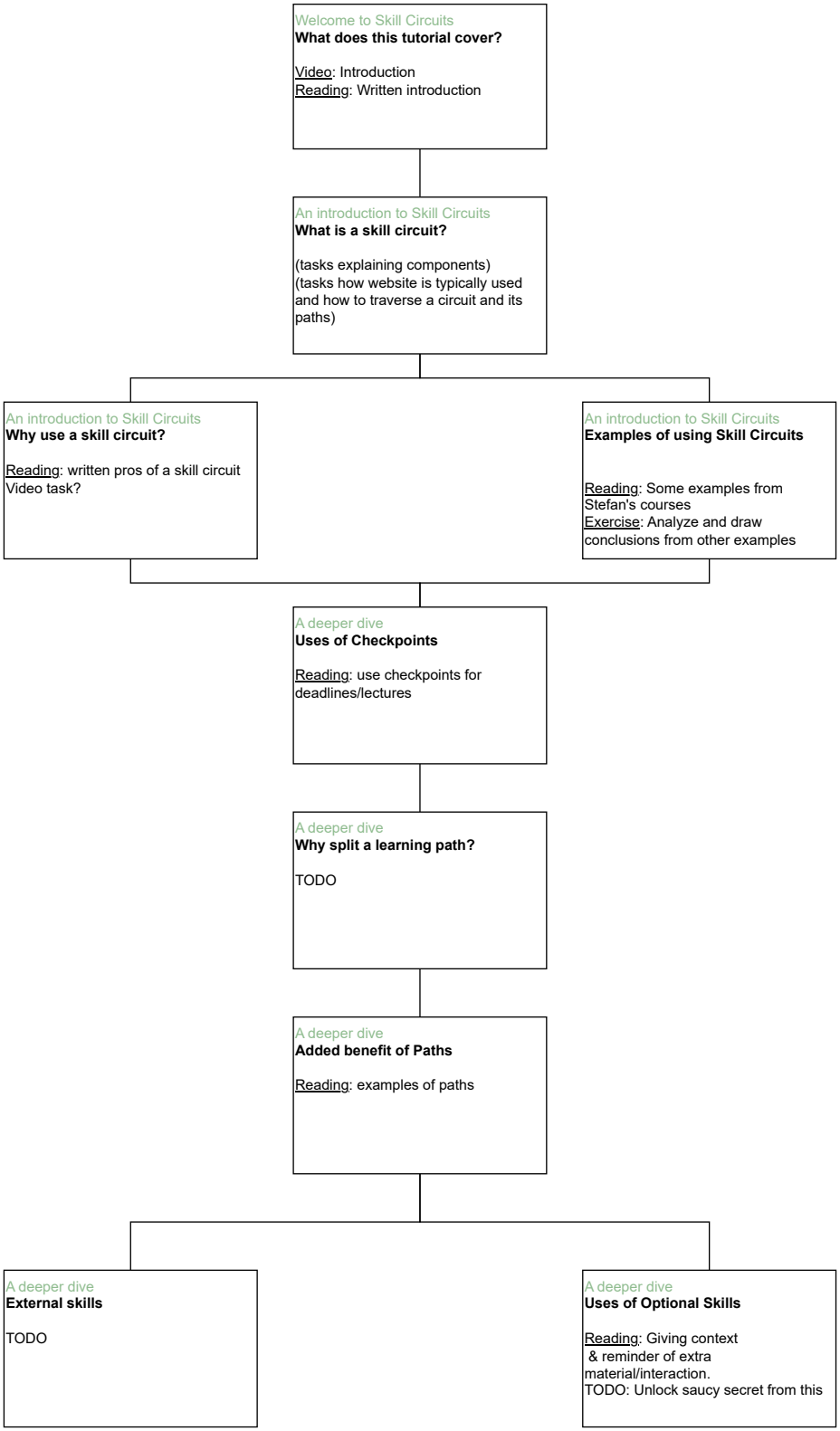


Figure A.2: Module 1 of the skill circuit. Each block is a skill, green titles represent the submodules.

Module 2: How to design a skill circuit for your course

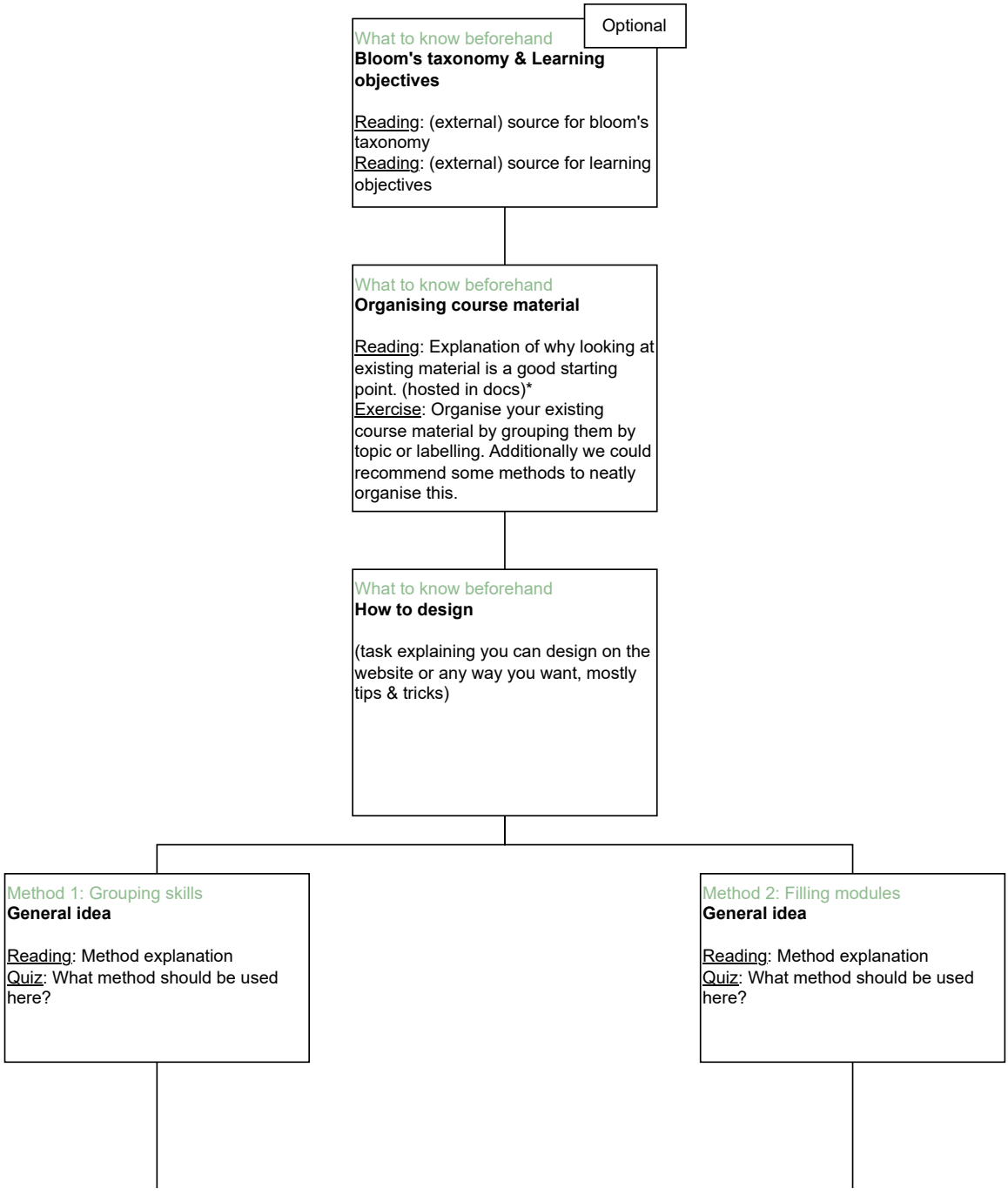


Figure A.3: Part 1 of Module 2 of the skill circuit. Each block is a skill, green titles represent the submodules.

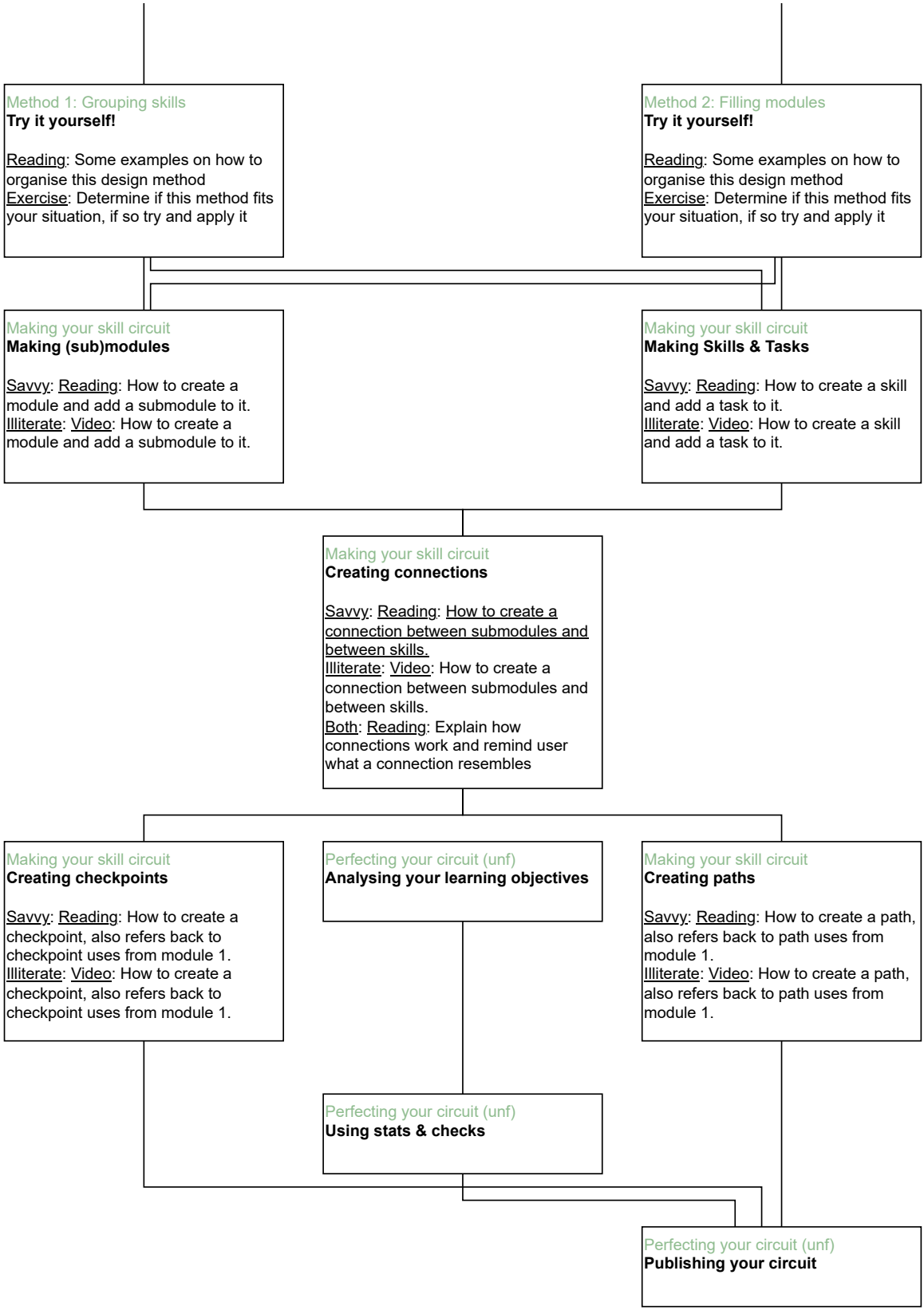


Figure A.4: Part 2 of Module 2 of the skill circuit. Each block is a skill, green titles represent the submodules.

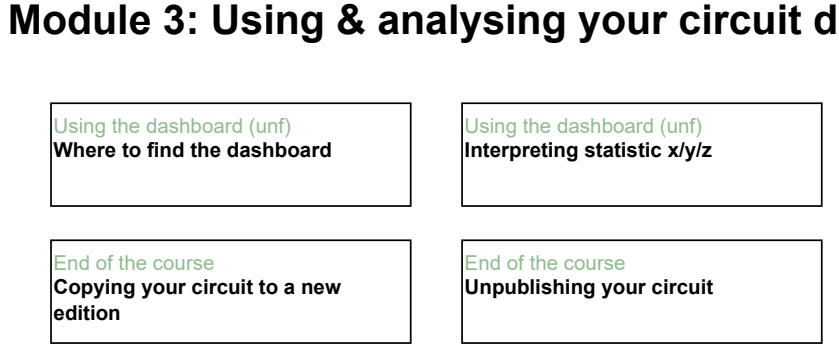


Figure A.5: Module 3 of the skill circuit. Each block is a skill, green titles represent the submodules. This module will be expanded upon together with the development of the dashboard

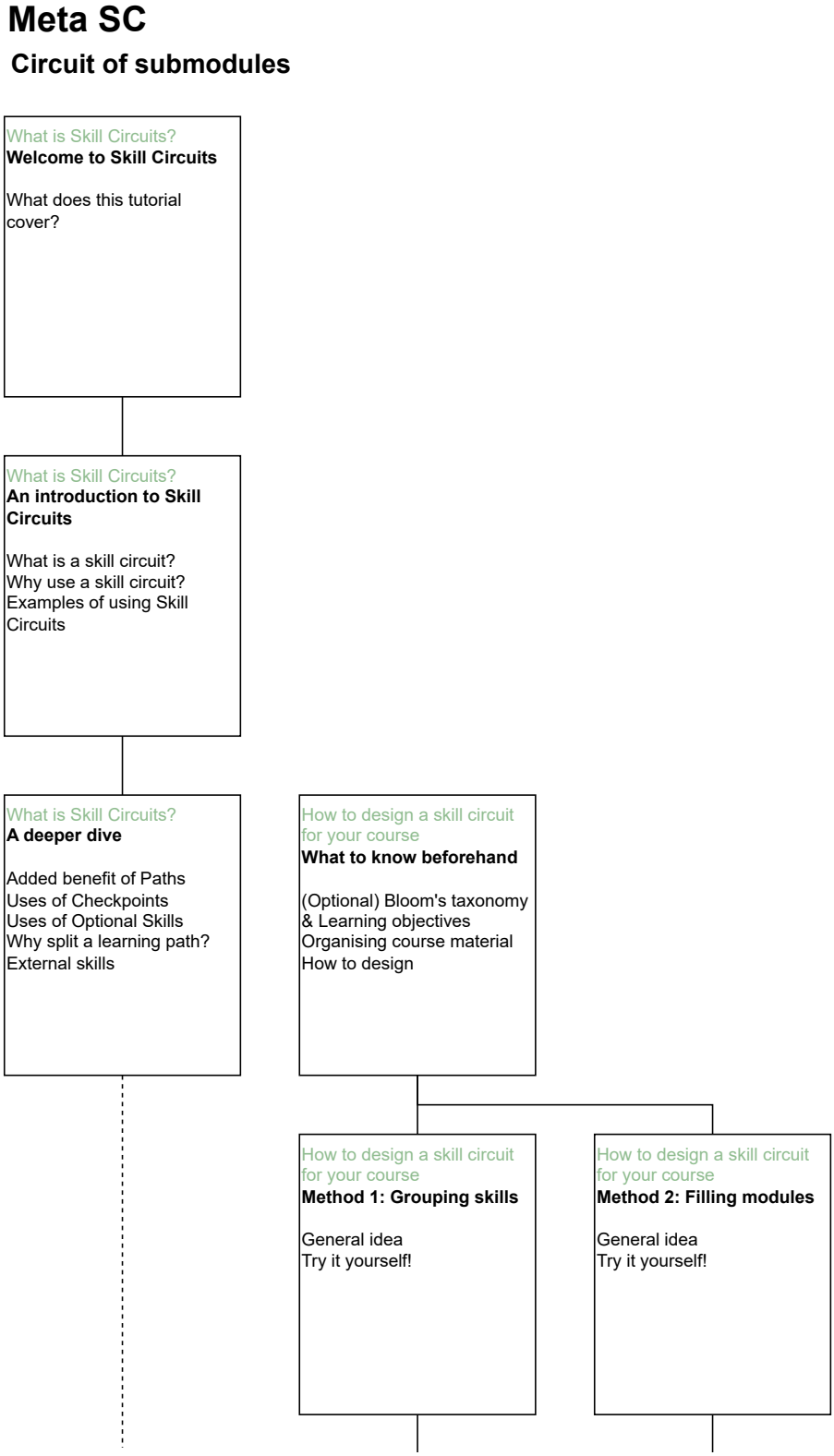


Figure A.6: Part 1 of the submodule circuit. Each block represents a submodule with its accompanying skills. Green titles represent the modules.

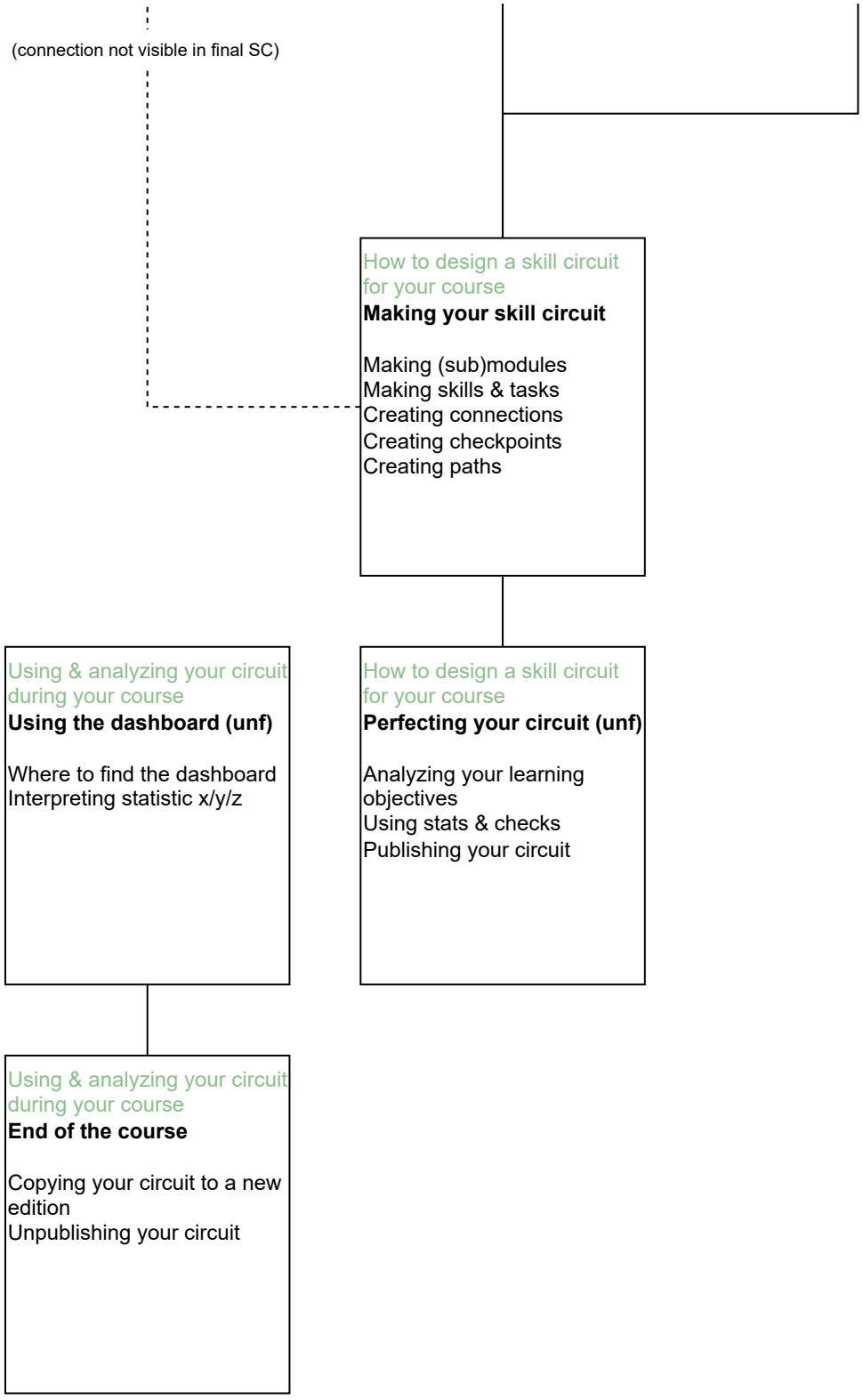


Figure A.7: Part 2 of the submodule circuit. Each block represents a submodule with its accompanying skills. Green titles represent the modules.

B

Focus group transcript

B.1. Q1

The first question that I asked: *"What are for you the main benefits in making a Skill Circuit? Is it useful for the teacher or for the student?"*
A: "I'd love for someone other than me or C to start"
B: I think it was really nice. I now use Skill circuits in CPL, with some good parts and some parts that I'm not quite happy with. But I think it was really good to also identify as a teacher in your course the sort of things you expect from students and whether you actually have practice material for each of those things. Because we found out for some things we need those, well we have some reading materials but no exercises or only exercises but no reading material. Those types of things. But I think it was very useful to sort of identify "Hey these are areas where we should work on because we see that a lot of students are struggling with this skill but we have nothing for them to practice with or that fits to different learning styles."
Me: "That comes maybe from the distinction in task types, you have the reading and the exercise things".
B: But at the same time this makes it really difficult to define a skill circuit. Because you don't want empty nodes in a skill circuit. So you have skills but they are sort of all dependent on each other and how to connect everything is not entirely clear. We did for some out of order but then students were confused. Now we end up grouping the wrong assignments together in order to conform to the linear order. I think it is useful for teachers but for students... Some are a bit more strict than others. Some say "Oh I did this all before the lecture but it was so difficult". "Oh yeah, you (the student) use it so everything before the lecture needs to be done, that wasn't necessarily our intention". Because it sort of logically it followed. It is one way to structure everything but I don't think we had already a bad structure. A lot of students said that weblab *(another website used by the TU Delft)*was already quite clear in what structure to do things, so in that sense, the skill circuit wasn't necessary for everyone.
A: And did the weblab also include the reading then?
B: No, but we have a very bad book.
B: Weblab is not as granular as our skill circuit. The skill circuit has shorter chunks but weblab has "now read chapters two and three".
Me: A & C, do you agree that it's more for the teacher or...?
A: Well I definitely see a large benefit for the teacher.
and I think for us we've even had discussions about what order to teach materials in based on what order we put them in the skill circuit I think. But at the same time, I find it hard to compare these things of course. Because 500 students have a small benefit, we have a larger one,

how do you compare? For one of my courses, for example, students can use either Brightspace or the skill circuits. I think there the main reason students use Brightspace is because the other courses use Brightspace. We queried this out I think years ago. For me, that is a sort of indication: if the main reason for using Brightspace is because others use it. Then I guess there's no inherent value in using Brightspace, it isn't more structured or better in some other way. But the people who use the Skill Circuit on the other hand, they indicated that they like this idea of the satisfying feel of ticking off the tasks and getting something that looks completed. Brightspace also had this thing that 'ticks down' but that also depends on how you configure Brightspace as a lecturer. And, this is a small group of students, but some also like the fact that there are some idiotic secrets hidden in the skill circuits.
B: maybe something to note but we didn't have time or the exercises to put that in this year. But the differentiation of level and the ability to choose paths, I think that is something very useful to students. Because we have a lot of students who are interested in more and "oh do you have like more stuff". And I would like to put that in the skill circuits. Well, we didn't have sufficient 'more stuff' to really define a separate path. But I think now that we have a new basis for everything maybe we have some time to work a bit more on the extra exercises. I think that's also a very useful benefit, for the interested students to motivate them more for the course.
D: I have a bit of a theoretical benefit, a naive one for the students, that it is easier to go back to the things that you don't know. If you're missing something then, sometimes in Brightspace - at least for my course- it's not really clear where you directly go back to if you don't understand something for a specific exercise. I think that might be easier here.
C: I don't know if many students use that, I haven't heard of it.
D: Which why I thought "theoretical and naive".
C: I do think it's useful, that the students can see how the learning material relates, but they probably don't realise this is useful to them.

B.2. Q2

So what is your opinion on actually using documentation (you know like kind of a simple documentation/help page), for introducing new teachers? What do you think of that? Do you think it's good or maybe there is something better?

A: I can start with how I use documentation of other tools. I hardly ever sit down to read something, from cover to cover to figure out how the new thing works, I just start clicking around. But the moment something doesn't do what I want it to do, then the documentation should be able to tell me within a minute, that is sort of how I use tooling. So, I think this idea of having help pages is good, but especially if somehow the system tries to infer what I am trying to do, and then when I click the help button I get sent to the right help page. Or the help page at least has an easy search thing. But for example, I can imagine now, when I'm designing the course view I get a different help page than when I'm designing a module. Something like this where the website tries to really support what I seem to be struggling with right now and then sends me to the right page based on that. I think that is how I normally use documentation on something like Brightspace or Osiris.

B.2.1. Extra Q2.1

Me: "Do you think that teachers would actually go to 'help' and actually start reading it or would an introduction page be a better thing."

C: I think skill circuits are more complicated though, than Brightspace
A & B: Nooo.
A: Conceptually yes but Brightspace has fifty-thousand more buttons so trying to get something done in Brightspace-
C: Well at least the concept of skill circuits then.
Everyone: Yes.
C: When you first see Skill Circuits you think "What is this?" and on Brightspace you think "Yeah it's a website, for content" and you still need to know where the buttons are, but that's kind of easier to look up. To immediately see "what is a skill circuit", I think it kind of makes sense to first read something about it before you use it. It is at least different than other tools.
A: That's fair, that's more about the conceptual model rather than the website.
C: So I guess that maybe the documentation should focus on that.
B: I'm not someone that looks at documentation very often in general, because technical documentation is something I don't really need because I can figure out how it works by myself. But I think the skill circuit is nice to read on how they're supposed to work but maybe also a lot more based on examples or maybe a feedback button on the bottom right corner that says "give me some feedback on my Skill Circuit". That might be too complicated to do something with.
C: I mean you have an empty skill circuit (that's what you start with on the website) so how do you even start? I think it kind of makes sense to...
A & C: read something about it.
C: I mean you can start putting boxes down but then realize "Oh this is weird what I'm doing".
B: Yeah but you only know what you want to do when you start doing it that you want to do it differently, in my experience.
A: Yeah but I think, so we told you a little bit about how modules, submodules, skills and tasks are all the things-
B: Well it is still confusing.
A: Yeah, fair enough.
B: But the submodule thing, this sort of hidden layer, that was very confusing to me for a very long time. But I'm not sure I would have looked that up in the documentation either.
B: So I think focusing maybe on the concept and lesser so on how to technically do things, or maybe quicker in those parts.
Me: More like getting started guides or conceptually explaining some examples.
A: Less focused on how the UI works, the UI should be good enough so that people can understand. It isn't yet, but at some point, it should be.

B.3. Q3

What do you think of using a skill circuit itself of introducing teachers to the platform?

B: I think a great idea.
A: I love this too, I would even cross out 'teachers' and instead put 'people'. For the students I would even recommend they do it, to figure out how we designed the course for them. And of course not all students, but for example the people that are somewhat interested in this and for example all my TAs I would tell them to go through this.
B: That's a good idea. I see the problems that you (A) have a certain style in your skill circuit and I didn't do the same and then students get confused about that. Because it is not inherent to the skill circuit it's more inherent to the way you have set up your course.
A: But I think that issue will become less if more people use it. Because it will be just like in Brightspace now more different people with more different styles rather than just me and C.

C: But that would mean that you would need a skill circuit for every course. Then a skill circuit to introduce students to the platform is not really useful. Because then teachers should make it themselves.
A: The tutorial can really be the basics. The conceptual model, this kind of stuff. We always have a short introduction, where we can mention specific things we do.

B.4. Feature #2.1 Learning objectives

B.4.1. Question from B

B: Maybe a problem is that at the course level, I have five learning objectives, every lecture I also have five learning objectives... those are split off from the larger learning objectives. I think that would be a problem for these overviews. *B would like to have both lecture learning objectives that then link to course-wide learning objectives*.
A: I recognise what you're describing. For example, the overall course objective is "learning arithmetic" but today we're learning to "add two numbers together". To me, this sort of boils down to skills, but I think skills are sometimes also just our fancy names for topics.
Me: ... I suppose in my view this is more about course-wide learning objectives. Do you think that would be too wide?
A: I wonder whether it makes sense to define learning objectives on a module level...?

C: I think per module doesn't only make sense
B: I wouldn't use course level. I think those are too generic to link, I would definitely go at least one level down in the learning objectives-
A: Really?
B: I would rather use the ones that I use on a weekly basis in my lectures, than the ones that are defined in the study guide.
C: No I don't think that at all, but I also wouldn't use the ones defined in the study guide, because those are "oh you need to know about sorting algorithms, you need to know about this". But I want just the other things that are not mentioned as the learning objectives, but the types of things you should do. For example in ACC "build a machine about this" and that could be about dfa's/nfa's... But, the distribution between different topics (for ACC, dfa's/nfa's/tms) that you already have because you're doing different topics, but you maybe also want a distribution between what you have to do with these things. Like designing these things, - (unintelligible)
A: I think you are almost arguing for "only have the seven bloom levels".
C: Yes.
A: That's it.
C: Yes. Or at least something similar.
B: The seven bloom levels within the topic.
C: The seven bloom levels overall and you use them in each topic.
B: Well but I mean my 'skill' currently contains multiple tasks of different levels and the task can contain again subtasks of multiple different levels.
C: Wait what do you mean?
B: So when you read through the book, the book halfway through the reading tells you "Here's an exercise go do it" and that requires a different bloom level within the same task.
C: Sure, so that should be a different task.
A & C: That's what we do.
C: Because we have "read book section this" and then "do this exercise in the book" Me: I do have it set so that you can add multiple of each to the task itself, so you can add as many as you want.

B: No no no no, that's not true.
A: No no, I'm exaggerating a little.
C: But if this is annoying then you should task where you can apply multiple learning objectives.
B: My tasks are usually a bit bigger than just one.
C: Then you should be able to apply multiple learning objectives to each task, oh this task has this learning objective and this learning objective. It has "understand" and "remember" or "apply" or "remember" and "apply"
Me: The way I have it currently set up is that you can define your own objectives, and I suppose at the end it is just up to the teacher of which graph to use if we give multiple so it could be possible that you are more interested in your course wide objectives. Or you have per module you have a couple of objectives so then you can just disregard this one *motions at graph*, it makes sense that *this* module C has way more of this learning objective because that is the only place I really talk about it.
A: I do wonder if a teacher would make them per module then there might be 7 modules, 5 learning objectives each. I wonder what the graphs look like when there are 35 learning objectives.
Me: Maybe some filtering would be nice.
A: Yeah.
B: But I mean that's sort of what I probably would do in an initial version because I already have those.
C: The learning objectives per module are just the submodules now
B: What's a submodule? The submodule is the hidden level? Because I have one or two submodules per module. But I have 6 learning objectives per lecture well okay per-
C: What learning objectives are you talking about?
B: let me open some slides.
C: if you're talking about topics then I don't think that's what you want from this.
Me: I'm also getting a bit confused at the moment.
D: well I think the idea is that you then have these learning objectives also that you have activities that cover all your learning objectives so that you don't have activities that are actually not related to your learning objectives but also that you don't miss activities for learning objectives of your course.
A: my course ADS math has 13 learning objectives for the course as a whole (which is too many).
C: I think these are topics not really type of learning objectives.
A: I tend to somewhat agree.
C: Analyze and implement, that's what it says. So I'd say the learning objectives that you want to see here are analyze and implement and not the separate learning objectives.
A: But for a single lecture I have these type of learning objectives, and then for the lab, we get to the implement part of some of them.
C: But, whether you have enough exercises for these learning objectives you can already see. Because you just go to the module and go to the skill that says "Here I need to count *(unintelligible)* of operations" and see if you have tasks there.
B: So for my circuit, it doesn't link so nicely.
B shows slides from their laptop
B: These are some learning objectives that we give in the lectures that say "After this lecture, you should be able to do these tasks" and then the last one does require the students to do some stuff on their own. That is not something you learn in the lecture.
So the lectures generally focus on a lot of lower bloom levels, let's say. Right? Because we sort of give knowledge. The actual learning objectives that they do with the exercises are more about the higher bloom level. Create, evaluate, those levels. But this is very different from the 6

learning objectives that I have for the course and this is again different from the topics that I have for my course.
Me: When you say "different" it also they are kind of part of one of them, you could place them in one of the boxes let's say?
B: I mean I can place each of these in one or multiple topics.
Me: But they could be separate a little bit? Sometimes?
D: But that's not bad right? You can have the same learning objectives in different places?
C: And that's what makes this useful I think.
B: Yeah I'm not saying it's not useful, but I'm just wondering about sort of the level where we define this. You could go as wide or as shallow as you want.
C: Yeah but I think if a learning objective appears in only one module, then it's not a learning objective that's useful to visualise here. Because then you can already go to that module and see if it-.
B *(slightly sarcastic)*: Well maybe I want a learning objective circuit? Not a Skill circuit?
C: Yeah but, I guess in a way it already is.
B: Yeah but I might like the link to be a bit clearer. Let's say "Congratulations you can now do this", rather than... So the skill doesn't convey the same text because it is sort of a must shorter word, it's not an actual sentence of "you can do this".
A: Well you can do this with achievements.
B: Hmm no no no.
C: I really think we are having learning objective circuits, not skill circuits. Each skill is a learning objective.
D: And this makes it more explicit *(talking about the feature)* when you really name it?
C: But I think these are other types of learning objectives.
A: You are only interested in the categorisation, I guess only the seven levels of bloom without any... so not "create an algorithm", but just "create" full stop. And you want to know for which tasks they need to do different types of this taxonomy.
C: Yes.
D: Yeah it makes sense.
C walks to the whiteboard
C: So how I would, for example, any algorithm course maybe like it's about greedy algorithms, divide and conquer, dynamic and network flow and then in these four topics you need to be able to.
Create an algorithm, analyze the algorithm, proof correctness, and implement it as well.
C has made a 4x4 table with 4 different algorithm types and 4 different 'bloom' levels
These are kind of 16 things you need to do.
B: So my course doesn't work like this.
C: So the columns are the modules and submodules and the rows are the things you are actually interested in, in this view..
some talk about B's course being out of the ordinary.

B.4.2. Additional question from me

Me: Maybe an additional question for me because I don't know if it was clear. Currently, this is only visible to the teacher. The student does not see any of the learning objectives, is that something that you would want to have instead? Like, for the student to see "you're learning now about this broader thing", or is that maybe a bit too much?

A: It should definitely not be there in their face all the time.

B: But maybe there could be a separate view that showcases it.
A: This is what I'm thinking. For the people that want to know they can find out.
B: I mean, I'm not intending to hide anything from them, and if I've already put it in then might as well also show it, but indeed not overflow them with too much information and stuff now, or too many different ways you go through the skill circuits because then it gets difficult.

B.5. Feature #2.2: Skill circuits stats

B.5.1. Interjection during the presentation from A

A: But I... I need... yeah, I'm really going to say need. I need that table on the right. Because now the only way for me to find out is by running some JavaScript that one of my TAs wrote for me that just takes all the numbers on the page and add them together and that sucks. So having this would be great.
B: We created lots of new exercises that we did not have time to make a proper time estimate for, so a lot of our skill circuits have actually "zero" time amount for tasks where we don't know because we didn't want to put in something and everyone be like "Oh yeah it took me like 4 times as long as you estimate it", and then everyone feels bad. Or they'll say "Oh it's two hours long, I wouldn't even start".
A: So I tell people if you spend the amount of time that we estimate on it and you're not done yet, stop and ask for help. Nobody does, but that's how I put in my estimates, so I tell them this implementation should take you no more than 40 minutes, and then some come to me and say "It took me 6 hours". Okay well, then you messed up because after 40 minutes or so you should have stopped and asked for help.
B: But I like the idea. I think it's good to show these sorts of statistics.
A: It gives us some indication of how much material we've got. (*talking about the table that shows components presumably*)

Me: I have one other thing as well that is a little more interactive
I show the disconnected skill metric and explain that more metrics can be added
some discussion about what a disconnected skill is and that sometimes you want it intentionally
A: I like this idea so long as I'm able to say "This next skill, yes it should be disconnected, don't warn me about it".
Me: And my purpose of showing this is more like more interactive things could be done, not just like very simple "oh, this is the data". But I couldn't really think of anything else at the moment.
B: Maybe an idea, if you go back once here, maybe you could also show indicators of "Hey we commonly see that a course consists of N modules or a course consists of so many skills" and say like "Hey, it seems that you have a lot of skills in your module" it doesn't need to mean that it's bad that you could sort of point out like "hmm, that's maybe not entirely how you should set up your course". So if we know what the right way is, then it might be nice to add some sort of "hey!".

B.6. Feature #3: Usage analysis

Showed the student activity chart B: I think the idea is good but I would also like to have the same view for a specific task or a specific skill or a specific module. So we can zoom out to different levels, to see where people are and what they are doing.
A: Yeah.
C: Yeah maybe count up the time for the task, instead of one task. Because one task can be very

short or long.
B: So I would say add some filters and do that as well, so you can say either amount or time on the axis as well.

I show more ideas

B.6.1. Question from me

Which visualization or tool, using student analytics, would you like to see?

A: Now as a teacher, we can see a number with every task and how many students have completed it. It's nice but... that's it. I think I would be most interested in... finding out. Ok so, I wonder a lot about.. what you did just now. I like this idea of "How many people did a skill" so the average completion thing. But what does it mean to complete a skill? Because depending on your path you will have a different completion requirement for some that is doing 1 task, for others that's doing 8. I mean that that can be a big difference, so that should be somehow taken into account then. So, someone who did the path where there's only one task once they complete it, they're 100%. Whereas people who go for their path with eight tasks, if they do only that one thing, they're only at 12%.
B: I would actually argue that as soon as you sort of move on to the next task, we have to consider the previous task, even if you did only parts of the exercises, as complete. And a lot of students actually, I see them do this, even if they have not done these tasks when they feel like they have mastered this skill, they will tick all of them because then it looks nicer. Sort of an "I completed it but I didn't do these things".
A: We're working on this too, in the future they can select which task they wish to do and the ones they don't want to do they move them out of their path. So there's a pre-defined set of tasks based on their path and they can easily add tasks or remove tasks from their path.
B: So I quite like the view (*the skill circuit completion overview*), I want to have such a view.
A: Yeah.
B: But what does it mean to have a "certain amount of completed"? Maybe we can choose between different metrics.
A: Yeah, for me maybe even "started by". So at least one task is completed.
B: I mean I could see that if we have this overview and I click on the task that sort of expands into the subtasks of how each of those is completed. If you do that, then I can already just investigate say, hey, 10% is quite low and they see, oh, they did one out of the 10. (*so the overview would show 10% completed, but when clicking on the skill it shows that 1 out of the 10 tasks was completed by all*)

B.6.2. Additional question from me

Would you like to zoom in on individual students or is that a bit too much?

B: In general I think Brightspace does this a bit too much. I don't really care about individual students. I have too many, so I have the luxury to look at aggregates. And if an individual student wants to talk about it then maybe they show us their circuit.

B.7. End of session, what did I miss?

The question started with a discussion of general issues with skill circuits, not relevant to this thesis
B: Maybe to get back to your question. A way to give feedback, I think it would be a really sort

of simple thing to, on the exercise, where you say complete to also add a happy smiley, sad smiley, neutral smiley or something on the task and then maybe the text box opens up and they can either type something or not. To get sort of an indication of Was this task good or not that you did? Were you happy that you now spent half an hour on this task, or did you say this "was a waste of my time"? I would like to have this in the skill circuit.
A: Yeah I fully agree.
Me: Yeah you could link to a survey externally but it would be nicer to have it in the circuit.
B: So it will be nicer if, in the skill circuit, it shows me "Hey students were unhappy about this task". And then you could look at the corresponding analytics views about that. So like "Show me the tasks that students dislike" and then I can look at the feedback there.

B.7.1. Final question: "What did I miss?"

B: I especially like your analytics overviews, I would like to get that extra information out and I like the idea of the learning objectives, but I think there are still some details to figure out... (*B got interrupted*)