Universiteit Utrecht

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Improving critical-thinking skills in process modeling

Bachelor's Thesis

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Information Sciences

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Abstract

This thesis presents the problem that novice designers have difficulty creating process models from a case text. Novice designers cannot explain choices made during modeling. Indicating that they have not thought critically enough about their decisions. We present a solution to help novice designers create process models and think critically about them; The Reflective Modeling Cycle. We conduct an exploratory research that shows signs that the cycle might help novice designers in thinking more critically about their models. A quantitative research into the perceived usefulness and the usability of the presented solution shows that it is still unclear if novice designers perceive usefulness from the cycle. The usability of the cycle, however, is good.

Abstract

Deze thesis presenteert het probleem dat beginnende modelleurs het lastig vinden om procesmodellen te maken van casusen. Beginnende modelleurs kunnen niet uitleggen waarom zij bepaalde keuzes hebben gemaakt tijdens het modelleren. Wat aangeeft dat ze niet kritisch genoeg hebben nagedacht over hun beslissingen. We presenteren een oplossing om beginnende modelleurs te helpen bij het maken van procesmodellen en om er kritisch over na te denken; De Reflectieve Modelleer Cyclus. We voeren een exploratief onderzoek uit wat tekenen vertoont dat de cycles wellicht helpt om beginnende modelleurs kritischer na te laten denken over hun modellen. Een kwantitatief onderzoek naar het ervaren nut en de gebruiksvriendelijkheid van de gepresenteerde oplossing geeft aan dat het nog onduidelijk is of beginnende modelleurs nut ervaren van de cyclus. De gebruiksvriendelijkheid van de cyclus is wel goed.

Contents

1 Introduction

Process modeling is both a *creative process* and a *thorough assignment*. An art, because it requires creativity to understand, analyze and find solutions. On the other hand it requires thoroughness and a systematic approach: Is my solution indeed a good option? Are there better solutions? Does my solution solve the entire problem? We could call this thoroughness: *The art of posing questions*. It requires a *critical view* from the modeller. Modelers need to constantly look at their model and ask themselves the aforementioned, reflective, questions.

Modeling is a wicked problem (Sølvberg & Kung, 2012), a problem that has no single right solution. The more competent the modeler, the more feasible it is to achieve a valid and complete model (Lindland, Sindre, & Solvberg, 1994) and to create a better solution to that wicked problem.

New modellers need to learn the creativity and need to practice the systematic approach required for modeling. A recent study by Dumitr et al. (2018) shows that European employees feel that there is a gap between the critical thinking skills required for starters in the professional work-field and the actual skills that new graduates have when they graduate from universities and other schools.

In this thesis, we want to study how to improve critical thinking skills of novice designers, we first have to define what critical thinking is. We need to research how problem-solving is taught and what extra skills are required to think critically. Then we can research how we can improve the teaching of those skills.

1.1 Context

The bachelor of Information Sciences *(Informatiekunde)* at Utrecht University contains the introductory course Information Systems *(Informatiesystemen)* as a compulsory course for all first-year students. Furthermore, some other non-Information Science students from the department of Informatics choose this course as an elective (or as part of their minor Information Science).

Every year, the number of students enrolled in the course grows. This year (2019), about 200 students are enrolled in the course. Students that enroll the course have, in general, no experience in Process Modeling and can be seen as novice designers. Almost all students that enroll in the course are native-Dutch speakers. At least, all students should be able to understand Dutch, because all lectures are in Dutch.

Course goals, loosely translated from course page ("Informatiesystemen", n.d.):

> Information Systems are omnipresent in society; they serve people in their need for information. One important part of information is the flow of information: providing the right information at the right time and place. An information system assists in this need.
>
> This course teaches you to model and analyze those information flows within an organization or system. You will learn:
>
> - Fundamentals of process-based information systems: what are information systems and how to represent those.
> - Modelling and analyzing processes
> - Applying specification techniques to design and build an information system

Bloom's Taxonomy is a much used tool to categorize educational goals (Figure 1). The most basic type of knowledge is remembering and recalling facts. Next in the taxonomy is understanding of these facts (for example; interpreting, exemplifying, classifying, summarizing, inferring, comparing and explaining). The next type of knowledge is applying the obtained knowledge in new situations by executing or implementing. Fourth is analyzing by drawing connections between ideas and differentiating between concepts.

Evaluating is the fifth step in Blooms Taxonomy, which entails justifying a decision by checking and critiquing choices. Last in the taxonomy is creating or producing original work.

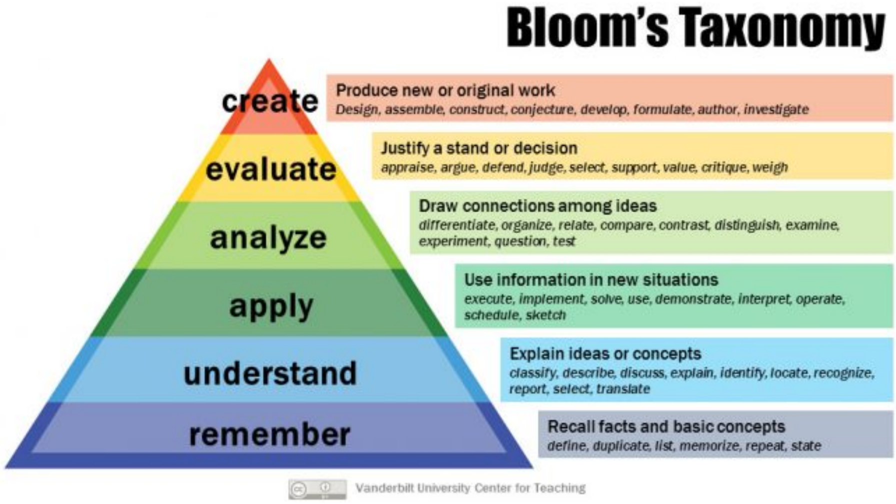


Figure 1: Blooms Taxonomy of Educational Objectives, image from Armstrong (n.d.)

If we look at the course goals presented above, they range from remembering up to applying. Although not explicitly stated on the course page, students should also learn to *evaluate* their models. Is my model correct? What are the shortcomings in my model? Does my model encapsulate the entire case? Etcetera. Modeling is a combination of Applying, Analyzing and Evaluating; applying knowledge to create a model, analyze and evaluate the model and making adjustments based on that. In short, thinking critically about models.

One of the types of process models students are taught are called Petri nets (van der Aalst & Stahl, 2011). In the course, these models are used to specify and analyze systems. One of the course-goals is that students can translate any given case into a Petri net from scratch. Like with every skill, the skill of creating Petri nets (and any process language for that matter) should be practiced.

In recent years, the teaching methods of the course has been altered to further improve the understanding of process models and the development of the students' modeling skills. Below is a summary of the transformation of the teaching forms over the years.

- 2016 & 2017: Lectures (6 hours) and tutorials (4 hours). During the tutorials, students made assignments individually from a textbook and checked them individually as well. They are allowed to ask questions to a lecturer or teaching assistant.
- 2018: Lectures (6 hours), tutorials (2 hours) and modeling sessions (2 hours). The tutorials are the same as previous years, however modeling sessions were introduced. Students were divided over three modeling sessions, during which one or two cases are presented. Students create a model in pairs from those cases. After they created the models, two pairs are randomly chosen from the group to present their created model. After the presentations, a lecturer or teaching assistant will guide a discussion about the two models. What is different between the models? What could be improved? How can the models be combined to create a new model? Etc.

The modeling sessions were added in 2018 to improve the critical thinking skills of the students. Students are tested on their skills during tests and assignments. These modeling sessions appear to be successful, according to the test results. Every year the mid-term test contains a question that requires students to translate a case text to a Petri net (just like the modeling sessions).

Figure 2 indicates that students scored higher on the modeling question in 2018 than students in the previous years did. More students received a higher score for their model than in the previous years.

This does not show, however, that students also really think critically about their models.

In 2019 the modeling sessions have continued with some minor modifications. In order to lower the number of students per group, there are now six modeling groups. The lower number of students per

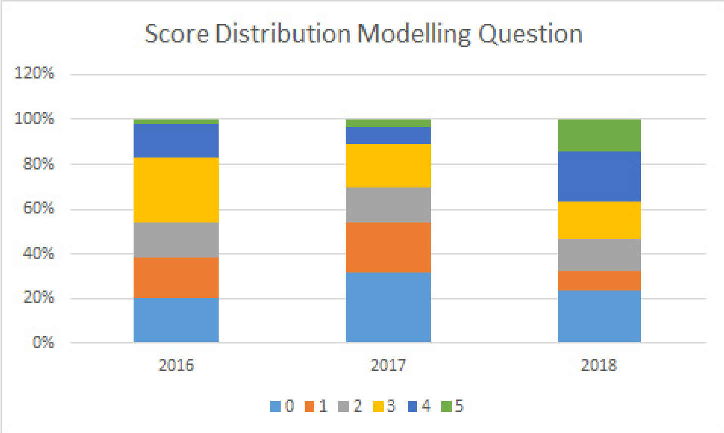


Figure 2: Points obtained for the modeling question, normalized to a 5-point scale

group ensures that every student has more chance to say something about his or her model. Furthermore, the presentations are substituted by a role-playing game. The group is divided into two halves that each defend one of the two randomly chosen models.

1.2 Problem Statement

Over the different years the course has been taught in, course staff noticed that students, novice designers, have a hard time creating Petri nets and other process models from scratch. They struggle with starting the model and identifying the important points in a case text. Additionally, when students are asked why they chose a certain modeling construction in favor of another one they cannot explain themselves.

Furthermore, the question was raised if students just simply *apply a trick* or really understand what they are doing and think critically about the models they have created. To put it in terms of Bloom's Taxonomy; it is unclear if students reach the *evaluate* level in the Taxonomy.

It is not possible to individually guide every student to make sure that they all think critically about their model, simply because there would not be enough staff to do so. Therefore, a tool must be developed that can help all students with creating their models and learning how to think critically about them.

1.3 Research Approach

The *Design Science* approach (Hevner, March, Park, & Ram, 2004) aims to create new and innovative *artifacts* to improve a *problem context*. As identified in the problem statement, in this thesis we will be creating such an artifact to help students with creating process models and learning how to think critically about them. This involves knowledge and understanding of the problem domain and results in the creation and application of the artifact.

This section defines the aims and objectives of this thesis, the research question to address these aims and objectives. Next, the corresponding research methods are introduced.

1.3.1 Aims and Objectives

To define the aims and objectives of this thesis, we use the template provided by Wieringa (2014):

> *This thesis aims to improve* critical thinking skills of novice designers in process modeling *by* designing and testing a modeling tool, called the Reflective Modeling Cycle (Treatment) *that* helps novice designers to structurally think more critically about their created models *in order to* improve the overall quality of the created models.

1.3.2 Research Question

In order to address our main objective, the research is structured with a main research question (RQ):

RQ1 *How can the critical thinking skills of novice designers be improved in process modeling?*

This main research question is answered by answering seven subquestions (SQs). The first 4 subquestions require literature research into the current state-of-the-art in respectively critical thinking (SQ1), current problem-solving frameworks (SQ3) and critical thinking frameworks (SQ2). SQ4 considers literature about how tools can contribute to improving skills of novice designers.

SQ6, SQ5 and SQ7 analyze the created artifact (Treatment): the former surveys the perceived usefulness of the treatment by novice designers. SQ5 researches the usability of the artifact and the latter researches if novice designers would recommend the Treatment to other novice designers. The effectiveness of the treatment is surveyed in SQ8.

SQ1 *What is meant by critical thinking in the context of Education?*
We survey literature in order to find a definition for critical thinking, especially in the context of education.

SQ2 *What are abilities one should have to think critically?*
Literature is surveyed for skills that one should have in order to think critically. These skills will be intertwined in the artifact.

SQ3 *What are current frameworks to solve problems, like modeling?*
We search literature for existing frameworks for problem-solving in similar contexts to process modeling. These frameworks will be used as a basis for our artifact.

SQ4 *How can a tool contribute to the critical thinking skills of novice designers?*
Why do novice designers find it hard to think critically about their models? And how exactly can a tool, that we intent to create, help to contribute to critical thinking skills in novice designers?

SQ5 *Do novice designers think that the Treatment helps them think more critically about their model?*
After the tool has been created we will assess the perceived usefulness of the artifact in a user survey.

SQ6 *Do novice designers think that the Treatment is user friendly?*
The tool will also be tested for usability using various statements.

SQ7 *Would novice designers recommend the presented Treatment to other novice designers?*
This subquestion will be answered by calculating the Net Promoter Score for the Reflective Modeling Cycle.

SQ8 *Does the presented Treatment show signs that it helps novice designers think critically about their process models?*
We conduct an exploratory research to assess if the developed Treatment might help novice designers thinking more critically about their models.

1.3.3 Research Methods

In order to answer our research questions, we apply various research methods (illustrated in Table 1).

Research method	SQ1	SQ3	SQ2	SQ4	SQ5	SQ6	SQ7	SQ8
Literature research	✓	✓	✓	✓				
Quantitative user experiment					✓	✓	✓	
Exploratory controlled experiment								✓

Table 1: Research methods used to answer the subquestions (SQs)

To answer SQ1 to SQ4, a background study will be conducted. Based on the conducted background study, a tool will be developed that helps novice designers with creating models. The perceived usefulness (SQ5), the usability (SQ6) and the Net Promoter Score (SQ7) will be accessed during a quantitative user experiment. SQ8 is answered using an exploratory controlled experiment.

1.4 Outline

This thesis starts with a chapter about critical thinking (Chapter 2), followed by a Chapter 3 about problem-solving. Chapter 4 provides some background information about process modeling that is required to understand the concepts in this thesis.

Following from the problem statement in this chapter and the literature study in Chapter 2 and Chapter 3, a solution is proposed in Chapter 5: The Reflective Modeling Cycle. The chapter explains how it was created and provides an example on how to use it.

Next we will test the created solution in Chapter 6 and Chapter 7, respectively a quantitative research into the perceived usefulness and usability of the created solution and an exploratory research into the effectiveness.

In Chapter 8 we will conclude this thesis by summarizing the conclusions from the research and providing suggestions for future work.

2 Critical Thinking

This chapter aims to search literature for various definitions of critical thinking, in order to answer SQ1 and SQ2. It also elaborates upon the differences between critical thinking and reflective thinking. It concludes with existing knowledge about teaching critical thinking and what skills should be obtained in order to think critically.

2.1 Defining Critical Thinking in the Context of Education

In educational theory, critical thinking, as an overall idea, is a trait that should be taught in schools whenever possible (McPeck, 2016). However, not everybody uses the same definition for critical thinking (Halpern, 2013; Ahern, Dominguez, McNally, O'Sullivan, & Pedrosa, 2019).

Jones, Dougherty, Fantaske, and Hoffman (1997) asked 500 policy makers, employers and educators to define critical thinking. They agree that:

> **Definition 2.1.1** (Critical thinking according to Jones et al. (1997))**.** Critical thinking is a broad term that describes reasoning in an open-ended manner and with an unlimited number of solutions. It involves constructing a situation and supporting the reasoning that went into a conclusion.

Fischer, Spiker, and Riedel (2000) found in their literature review that most definitions of critical thinking include reasoning or logic, judgment, meta-cognition, reflection, questioning and mental processes.

McPeck (2016) defines critical thinking by splitting the definition into two parts. He first defines thinking as thinking about something: a problem, activity or subject area. He then defines *critical* a skepticism towards a given statement, to some extent. This means that the statement might ultimately be accepted, but other hypotheses and possibilities are explored as well. It involves, partly, seeing when a certain common procedure does not apply to the specific problem by considering alternatives.

Skepticism is, however, not synonym to critical thinking. Always applying skepticism does not mean that someone is thinking critically. Furthermore, the question raised by the skepticism should reflect on the provided solution.

> **Definition 2.1.2** (Critical thinking according to McPeck (2016))**.** Critical thinking entails applying said skepticism when needed, such that is used in a productive manner and leads to a more satisfactory solution to the problem at hand. Therefore, the question asked is important.

Halpern (2013) formulates the following definition:

> **Definition 2.1.3** (Critical thinking according to Halpern (2013))**.** Critical thinking is the use of those cognitive skills or strategies that increase the probability of a desirable outcome. It is used to describe thinking that is purposeful, reasoned, and goal directed the kind of thinking involved in solving problems, formulating inferences, calculating likelihoods, and making decisions, when the thinker is using skills that are thoughtful and effective for the particular context and type of thinking task.

Another proposed definition for critical thinking by Ennis (1985) is:

> **Definition 2.1.4** (Critical thinking according to Ennis (1985))**.** Critical thinking is reflective and reasonable thinking that is focused on deciding what to believe or do

Another definition by Michael Scriven (1987) encapsulates all previous definitions and is also used by The Foundation for Critical Thinking ("Defining Critical Thinking", n.d.).

> **Definition 2.1.5** (Critical thinking according to Michael Scriven (1987))**.** Critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action. In its exemplary form, it is based on universal intellectual values that transcend subject matter divisions: clarity, accuracy, precision, consistency, relevance, sound evidence, good reasons, depth, breadth, and fairness.

The definition contains, furthermore, that critical thinking entails the examinations that are implicit in reasoning: purpose, problem or question-at-issue; assumptions; concepts; reasoning leading to conclusions; implications and consequences; objections from alternative viewpoints; and frame of reference. Critical thinking is one mode of thinking, among, for example, scientific and mathematical thinking ("Defining Critical Thinking", n.d.).

Critical thinking is not the pure retention of information or possession and applying of a set of skills. Nobody applies critical thinking always, everybody is subject to episodes of undisciplined or irrational thought. Its quality is therefore dependant upon the quality and depth of experience in a given domain of thinking. Michael Scriven (1987): "No one is a critical thinker through-and-through, but only to such-and-such a degree, with such-and-such insights and blind spots, subject to such-and-such tendencies towards self-delusion. For this reason, the development of critical thinking skills and dispositions is a life-long endeavor."

2.2 Reflective Thinking

Critical Thinking and Reflective Thinking are often used synonymous. They are, however, not the same. Reflective thinking is part of the critical thinking process, specifically the processes of analyzing and making judgments about what happened (past decisions). Dewey (1933) suggests that:

> **Definition 2.2.1** (Critical thinking according to Dewey (1933))**.** Reflective thinking is an active, persistent, and careful consideration of a belief or supposed form of knowledge, of the grounds that support that knowledge, and the further conclusions to which that knowledge leads.

Learners are aware of and control their learning by actively participating in reflective thinking assessing what they know, what they need to know, and how they bridge that gap during learning situations (Dewey, 1933).

2.3 Teaching Critical Thinking

Critical thinking in itself is hard (Gelder, 2005). People are not very good at it. According to a large study by Kuhn (1991), people find it hard to see the general structure of evidence and do not know what properly counts as evidence for their point of view.

Humans are not naturally critical thinkers. Shermer (2002) describes us as pattern-seeking, story-telling animals. We tend to be comfortable with the first try that seems right, and we rarely pursue the matter further.

To become an expert in critical thinking is very hard (Gelder, 2005). Critical thinking is, what cognitive scientist call, a *higher-order skill*. A complex activity built up out of other simpler and easier to learn skills. Even is these *lower-order skills* are mastered, people still have to learn how to combine these skills to master critical thinking.

Critical thinking is a lifelong journey and not something that you learn in one course module.

Every skill requires practising. This is also true for critical thinking. The statement *Practice makes perfect*, perfectly applies to critical thinking. Learning about critical thinking is, therefore, not enough. To learn critical thinking, someone should practise these skills.

Excellence in a skill forms from a special type of practice, called *deliberate* practice. Ericsson and Charness (1994) characterizes deliberate practise like this:

1. It is done with full concentration and is aimed at generating improvement.
2. It is not only engaging in the skill itself but also doing special exercises designed to improve performance in the skill.
3. It is graduated, in the sense that practiced activities gradually become harder, and easier activities are mastered through repetition before harder ones are practiced.
4. There is close guidance and timely, accurate feedback on performance.

These characteristics are not studied for critical thinking specifically, but we can reasonably assume that these characteristics also apply to the critical thinking skill (Gelder, 2005). Gelder (2005): "Critical thinking must be studied and practiced in its own right; it must be an explicit part of the curriculum".

2.4 Critical Thinking Skills

Ennis (1985) proposes in his paper "A logical basis for measuring critical thinking skills" goals for a critical thinking curriculum. These goals are the lower-order skills that Gelder (2005) refers to.

Figure 3 presents the dispositions and the elementary clarification abilities from this paper. The other abilities are omitted as they are not relevant for this case.

Dispositions

1. Seek a clear statement of the thesis or question
2. Seek a reason
3. Try to be well-informed
4. Use credible sources and mention them
5. Take into account the total situation
6. Try to remain relevant to the main point
7. Keep in mind the original and/or basic concern
8. Look for alternatives
9. Be open minded
   (a) Consider seriously other points or view than ones own dialogical thinking
   (b) Reason from premises with which one disagrees - without letting the disagreement interfere with ones reasoning
   (c) Withhold judgment when evidence and reasons are insufficient
10. Take a position and change a position when the evidence and reasons are sufficient to do so
11. Seek as much precision as the subject permits
12. Deal in an orderly manner with the parts of a complex whole
13. Be sensitive to the feelings, level of knowledge, and degree of sophistication of others

Abilities (elementary clarification)

1. Focusing on a question
   (a) Identifying or formulating a question
   (b) Identifying or formulating criteria for judging possible answers
   (c) Keeping the situation in mind
2. Analyzing arguments
   (a) Identifying conclusions
   (b) Identifying stated reasons
   (c) Identifying unstated reasons
   (d) Seeing similarities and differences
   (e) Identifying and handling irrelevance
   (f) Seeing the structure of an argument
   (g) Summarizing
3. Asking and answering questions or clarifications, for example:
   (a) Why?
   (b) What is your main point?
   (c) What do you mean by ...?
   (d) What would be an example?
   (e) What would not be an example (tough close being to one)?
   (f) How does that apply to this case (describe case, which might well appear to be a counterexample)?
   (g) What difference does it make?
   (h) What are the facts?
   (i) Is this what you are saying ...?
   (j) Would you say some more about that?

Figure 3: Dispositions and abilities, excerpt from Ennis (1985)

2.5 Conclusions

This chapter about critical thinking has provided a literature study into critical thinking. With the literature we have obtained in this chapter, we can answer some of the research questions posed in Chapter 1.

SQ1: *What is meant by critical thinking in the context of Education?*

Literature teaches us that Critical Thinking is definitely a skill that should be taught in education.

We have found different definitions for Critical Thinking that all have a slightly different emphasis. Critical thinking involves *constructing a situation and supporting the reasoning that went into a conclusion* (Jones et al., 1997). Learning to think critically is learning to be *skeptical at the right moments* (McPeck, 2016), so that it *improves the desired outcome* (Halpern, 2013) and *knowing what sort of questions should be asked* (Ennis, 1985). Knowing when a question should be asked, implies that there should be *knowledge about the field in question*. Therefore, a critical thinking skill is *tied to the subject in question*. Learning to think critically in subject X does not necessarily mean that one can think critically in subject Y.

We particularly highlight the definition by Michael Scriven (1987) (Definition 2.1.5), because it encapsulates and summarizes most definitions.

Reflective Thinking is not the same as Critical Thinking. It is the process of analyzing and making judgments about past decisions (Dewey, 1933).

SQ2: *What are abilities one should have to think critically?*

Ennis (1985) provides us with a list of goals for critical thinking in terms of abilities and dispositions. This list is mainly focused on societal issues.

- Important abilities include: focusing on a question, analyzing arguments and asking and answering questions or clarifications.
- Some important dispositions from his list are: seek a clear statement of the question, seek a reason, try to be well-informed, take into account the whole situation, try to remain relevant to the main point, look for alternatives, be open minded, take a position and change that position when the reasons are sufficient to do so and deal in an orderly manner with the parts of a complex whole.

3 Problem-Solving

This chapter is on problem-solving. It introduces the concept of *wicked problems*, elaborates upon a problem-solving framework and provides some theory about coginitive load and how cogintive load can be changed.

3.1 Wicked Problems

In design science (creating models), there exists a concept called "wicked problem" (Coyne, 2005). A definition for wicked problems is formulated by Rittel and Webber (1973) in their 1972 paper "Dilemmas in a general theory of planning" about public policy.

1. Wicked problems have no definitive formulation but every formulation of a wicked problems corresponds to the formulation of a solution.
2. Wicked problems have no stopping rules.
3. Solutions to wicked problems cannot be true or false, only good or bad.
4. In solving wicked problems there is no exhaustive list of admissible operations.
5. For every wicked problem there is always more than one possible explanation, with explanations depending on the *Weltanschauung* (point of view) of the designer.
6. Every wicked problem is a symptom of another, higher level, problem.
7. No formulation and solution of a wicked problem has a definitive test.
8. Solving a wicked problem is a "one shot" operation, with no room for trial and error.
9. Every wicked problem is unique.
10. The wicked problem solver has not right to be wrong - they are fully responsible for their actions.

The stopping rules, in this definition, entail that it is unkown when a wicked problem is solved. There is always a new way to think about the problem and come up with a different solution. Therefore, the solution cannot be true or false and there is no exhaustive list of all options. The designer must, furthermore, be aware of their *own* Weltanschauung in order to consider all options and not prefer only their own point of view.

Coyne (2005) proposes that wicked problems do not only exist in social problems but also in, for example, mathematics. Some properties of wicked problems, however, do not apply to these types of problems (for example 8 and 10). Coyne (2005) calls this: "Diminished versions of *wickedness*. Problems applicable to highly constrained contexts in which we sometimes choose to make up a formulation in terms of goals, constraints, rules and structures."

3.2 Problem-Solving Frameworks

Problem-solving skills are valued by employees (Cappel, 2002). Companies rely heavily on the ability from their employees to identify and solve problems. Pólya (1945) proposes a framework for problem-solving in his book *How to solve it: A New Aspect of Mathematical Method.* This book (and the framework) is mainly focused on mathematical or logical problem-solving. It consists of four steps, presented below:

1. Understanding the Problem.
   (a) You have to understand the problem.
   (b) What is the unknown? What are the data? What is the condition?
   (c) Is it possible to satisfy the condition? Is the condition sufficient to determine the unknown? Or is it insufficient? Or redundant? Or contradictory?
   (d) Draw a figure. Introduce suitable notation.

   (e) Separate the various parts of the condition. Can you write them down?

2. Devising a Plan.
   (a) Find the connection between the data and the unknown. You may be obliged to consider auxiliary problems if an immediate connection cannot be found. You should obtain eventually a plan of the solution.
   (b) Have you seen it before? Or have you seen the same problem in a slightly different form?
   (c) Do you know a related problem? Do you know a theorem that could be useful?
   (d) Look at the unknown! Try to think of a familiar problem having the same or a similar unknown.
   (e) Here is a problem related to yours and solved before. Could you use it? Could you use its result? Could you use its method? Should you introduce some auxiliary element in order to make its use possible?
   (f) Could you restate the problem? Could you restate it still differently? Go back to definitions.
   (g) If you cannot solve the proposed problem, try to solve first some related problem. Could you imagine a more accessible related problem? A more general problem? A more special problem? An analogous problem? Could you solve a part of the problem? Keep only a part of the condition, drop the other part; how far is the unknown then determined, how can it vary? Could you derive something useful from the data? Could you think of other data appropriate to determine the unknown? Could you change the unknown or data, or both if necessary, so that the new unknown and the new data are nearer to each other?
   (h) Did you use all the data? Did you use the whole condition? Have you taken into account all essential notions involved in the problem?
3. Carrying Out the Plan.
   (a) Carry out your plan.
   (b) Carrying out your plan of the solution, check each step. Can you see clearly that the step is correct? Can you prove that it is correct?
4. Looking Back.
   (a) Examine the solution obtained.
   (b) Can you check the result? Can you check the argument?
   (c) Can you derive the result differently? Can you see it at a glance?
   (d) Can you use the result, or the method, for some other problem?

3.3 Cognitive Load

Cognitive load theory (Sweller, 1988) is a set of theories and assumptions about how the brain is taxed during learning or when executing (learning) activities (such as making exercises). It is based on the the functioning of the brain, the three box model by Atkinson and Shiffrin (1968) (Illustrated in Figure 4). Information / stimuli reaches the sensory memory, sending a subset of that information to the short-term memory. The short-term memory has limited capacity. When it is full, no more information can be stored. It takes time to transfer this information to long-term memory (virtually unlimited storage); only at that time, new information can be stored in short-term memory.

There are three types of cognitive load:

- **Intrinsic (inherent) cognitive load** is cognitive load that is inherent to the learning-task. It entails the complexity of the materials that must be learned (and not how that material is presented). Sweller (2010): "For a given task and given learner knowledge levels, it is fixed and cannot be altered other than by either changing the basic task or changing knowledge levels. Intrinsic cognitive load only can be altered by changing the nature of what is learned or by the act of learning itself." The complexity is based on the number of elements (a concept or procedure) that must be learned and the relations between those elements.

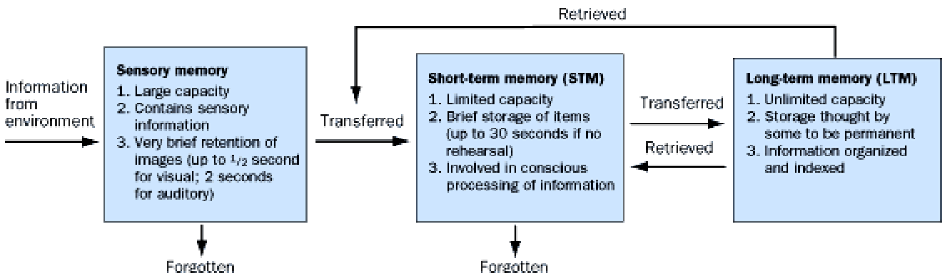


Figure 4: Three box model of memory, image from Dineva and Stoikova (2011)

- **Germane (useful) cognitive load** is cognitive load that promotes and helps learning. "If instruction is organised to allow working memory resources to deal primarily with the elements that impose an intrinsic cognitive load, germane cognitive load and so learning will be maximised" (Sweller, 2010).
- **Extraneous (irrelevant) cognitive load** is cognitive load that does not contribute to the learning or even hinders learning. In other words; it is unnecessary load.

3.3.1 Optimizing Cognitive Load

Because the intrinsic cognitive load cannot be altered if the same learning-task must be learned, you can supply smaller learning-tasks to divide the intrinsic cognitive load. The extraneous cognitive load can be influenced by trying to reduce the provided amount of irrelevant information. The germane cognitive load can be directly influenced by changing or adapting teaching methods (Van Merrienboer & Sweller, 2005).

3.4 Conclusions

In this chapter, we discussed several frameworks about problem-solving; we can use this information to answer SQ3. We have also found literature, supporting that changing

SQ3: *What are current frameworks to solve problems, like modeling?*

There is a framework by Pólya (1945) on problem-solving. This framework mainly involves mathematical and logical problem-solving. The framework consists of four main steps: Understanding the Problem, Devising a Plan, Carrying Out the Plan and Looking Back.

SQ4: *How can a tool contribute to the critical thinking skills of novice designers?*

Cognitive load theory (Sweller, 1988, 2010) provides an explanation for the taxing of the brain during learning activities by defining three types of cognitive load: intrinsic cognitive load, germane cognitive load and extraneous cognitive load.

Germane cognitive load can be influenced by changing or adapting teaching methods. A tool can thus contribute to the critical thinking skills of novice designers by changing the germane cognitive load.

4 Process Modeling

Process modeling is a collection of various methods and techniques to model (business)processes. Process models are typically used to analyze or design information systems. In this chapter, we introduce Petri nets, a process modeling tool with clear semantics and analytic properties. We conclude with a framework for quality goals in (process) models.

4.1 Petri nets

Petri nets are named after Carl Adam Petri in 1962 (Reisig, 2012). Petri nets are a way to model processes, they have a mathematical foundation (van der Aalst & Stahl, 2011) which allows for thorough analysis. Moreover, it has a graphical and a formal notation, allowing mathematical analysis as well as an easy way to understand the models for non-experts. The language also has some software tools available to model and analyze the created models (for example Yasper by van Hee, Oanea, Post, Somers, and van der Werf, 2006). This subsection will further define the very basics of Petri nets, as this is enough to understand Petri nets to the extend that is needed to understand the concepts and examples used in this thesis.

Definition 4.1.1 (Petri nets)**.** A Petri net is a 3-tuple (P, T, F), where P is the set of *places* and T the set of *transitions*. Sets P and T are disjoint ($F \cap T = \emptyset$). F is the multiset of *flows*, mapping each place-transition and transition-place pair to a certain *weight*. F is therefore defined as $F : (P \times T) \cup (T \times P) \rightarrow \mathbb{N}$. We write $f \in F$, if $F(f) > 0$. $F(t, p)$ retrieves the weight of the flow from transition $t \in T$ to place $p \in P$. $F(p, t)$ retrieves the weight of the flow from the place p to transition t.

Definition 4.1.2 (Marked Petri nets)**.** A *marked* Petri net, is a Petri net N and a *marking* m, represented in a tuple (N, m). A marking assigns a number of *tokens* to each place in the Petri net ($m : p \rightarrow \mathbb{N}$). The distribution of the tokens over the net (the marking) denotes the state of the net. Marking m_0 denotes the initial marking of the Petri net.

Places are graphically represented by a bordered circle. Transitions are represented by a rectangle (often with a background color). Tokens in places are represented by filled circles, or by a number written in the place. Flows are represented by arrows between places and transitions or vice-versa. The weight of a flow is labeled on the arrow; if the weight is omitted, a weight of 1 is implied.

An example of a formal representation of a Petri net $((P, T, F), m_0)$ is provided in Figure 5. The graphical representation is presented in Figure 6.

The Petri net contains four places, four transitions and nine flows. Please note the "double" arrow between $t2$ and $p2$, which represents the the transition $t2$ both consumes a token and produces one. Sometimes, this behavior (bi-flow) is visualized using two separate arrows and sometimes by a "double" arrow

$$P = \{p_1, p_2, p_3, p_4\}$$
$$T = \{t_1, t_2, t_3, t_4\}$$
$$F = [(p_1, t_1), (t_1, p_2), (p_2, t_2), (p_2, t_3), (t_2, p_2), (t_2, p_3), (t_3, p_3), (p_3, t_4), (t_4, p_4))]$$
$$m_0 = [2 \cdot p_1, p_2]$$

Figure 5: Mathematical representation of Petri net 1

Definition 4.1.3 (Pre- and postsets in Petri nets)**.** All transitions in a Petri net have a preset ($\bullet t$) and a postset ($t\bullet$). The preset of a transition $t \in T$ is defined as $\bullet t = \{p \in P | (p, t) \in F\}$. Similarly, $t\bullet = \{p \in P | (t, p) \in F\}$. In our example (Figure 6) $\bullet t_3 = \{p_2\}$ and $t_3\bullet = \{p_3\}$.

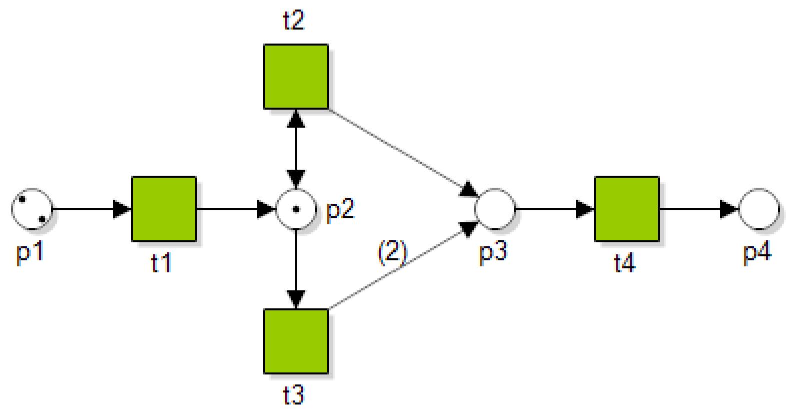


Figure 6: Graphical representation of Petri net 1

To be able to *fire* a transition, it needs to be enabled. This means that for all places in the preset of that transition ($\bullet t$), there needs to be at least as many tokens in that place as the weight of the flow between the place and the transition requires. Transition $t \in T$ is therefore enabled if $\forall p \in \bullet t : F((p,t)) \leq m(p)$. In our example, transition t_1, t_2 and t_3 are enabled, because all places in their preset have at least the number of tokens required for the flow between them and the transition. There is no order in which transitions need to fire. Any enabled transition can be fired arbitrarily.

When a transition is fired, a new marking is produced (m'). The required tokens in the preset are consumed and the tokens are produced according to the weight of the flows between the place and the transitions in the postset (i.e. $\forall p \in P : m'(p) = m(p) - F(p,t) + F(t,p)$). The example Petri net has initial marking $[2p_1, p_2]$. We arbitrarily choose transition t_2 to fire, which produces the following marking $m' : [2p_1, p_2, p_3]$. The firing of transition t in marking m and arriving at marking m' by $m \xrightarrow{t} m'$.

4.2 Analyzing Petri nets

Various analysis methods exist for Petri nets. This subsection will introduce those analysis methods that are relevant for this thesis.

Some analysis methods are used to analyze the state-space of a Petri net. These methods entail making explicit what states are reachable within a Petri net or making statements about those reachable states. Three of these statements or properties are called *boundedness*, *deadlock freedom* and *liveness*. Other analysis methods analyze the structure of a Petri net; one of these analysis methods is called *place invariants*.

4.2.1 Boundedness

If a place in a Petri net is *bounded*, this place can only have a limited number of tokens at any stage of the Petri net's execution. The place p should not contain more than $k \in \mathbb{N}$ tokens. If any *unbounded* (places with no upper limit) exist in a Petri net, this is often a sign of a flaw in the design of the net.

A Petri net is *k-bounded* or *bounded* if and only if in all markings, each place $p \in P$ contains at most k tokens. Otherwise, the net is *unbounded*.

4.2.2 Deadlock freedom

A *deadlock* is a marking, from which no other marking can be reached. In other words; in a *deadlock* there are no transitions enabled to fire. A Petri net is therefore *deadlock free* if and only if at least one transition is enabled in every reachable marking.

4.2.3 Liveness

The *liveness* property entails that any transition must always be able to be enabled again. A transition t is *live* if and only if from every reachable marking m, there is a reachable marking m' that enables transition t. A Petri net is *live* if and only if every transition $t \in T$ is *live*.

4.2.4 Place Invariants

There are several methods to analyze Petri nets on validity. One of these methods is the place invariants (Desel & Esparza, 2005). Place invariants examine the structure of a Petri net.

Figure 7 shows a simple Petri net, illustrating the forming of project groups (couples) of *Information Science* and *Computing Science* students. Tokens in the place *IS* represent Information Science students; tokens in the place *CS* represent Computing Science students. Each token in the place *couple* represents a project group, consisting of one Information Science student and one Computing Science student. The transition *form group* takes a token from the place *IS* and one token from the place *CS* and produces one token in the place *couple*. The transition *split up* reverses this process, by consuming one token from the place *couple* and producing one token in the place *IS* and one token in the place *CS*.

When forming groups, the total number of people involved in the model does not change. This means that the total number of tokens in the places *IS*, *CS* and $2 \cdot$ *couple* is constant at 7. This constancy is called a place invariant: the number of tokens is invariant in all reachable markings.

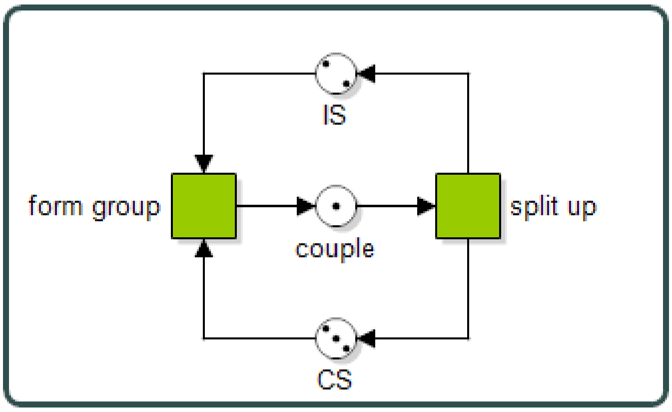


Figure 7: A Petri net modeling the forming of project groups

Every place in the invariant should have a *weight* (integer ($\mathbb{Z}$), including 0) (van der Aalst & Stahl, 2011). As discussed above, the places *IS* and *CS* have a weight of 1 and the place *couple* has the weight of 2. If a weight z is assigned to a place p, we can calculate the product $z \cdot m(p)$ to determine the *weighted number of tokens* in that place p. If we do this for place p_1 to p_k, we obtain the following equation: $z_1 \cdot m(p_1) + ... + z_k \cdot m(p_k) = z_0$, where z_0 represents the *weighted token sum* in marking m.

In Figure 7 in that marking, this results in the following equation: $(2 \cdot 1) + (3 \cdot 1) + (1 \cdot 2) = 7$. Two tokens in the place *IS*, with a weight of one. Three tokens in the place *CS*, also with a weight of one. And one token in the place *couple* with the weight of two.

Each *place invariant* assigns a weight z to each place p in Petri net P ($p \in P$), such that the *weighted token sum* remains constant in every reachable marking. A place may have a weight of zero.

The place invariant can be derived from the structure of the Petri net, therefore the initial marking is only used to derive the constant. A place invariant should hold in every imaginable initial marking.

4.3 Quality in Process Modeling

Lindland et al. (1994) introduced a framework with quality-improvements goals and the means to achieve them, which is presented in Figure 8. The quality-goals are divided into three categories and each goal has several means to improve the quality.

	Goals	Means	
		Model properties	**Modeling activities**
Syntactic quality	Syntactic correctness	Formal syntax	Syntax checking
Semantic quality	Feasible validity Feasible completeness	Formal semantics modifiability	Consistency checking Statement insertion Statement deletion
Pragmatic quality	Feasible comprehension	Executability Expressive economy Structuredness	Inspection Visualization Animation Explanation Simulation Filtering

Figure 8: Framework for distinguishing quality-improvement goals and the means to achieve these by Lindland, Sindre, and Solvberg (1994)

1. *Syntactic* quality: how more a model adheres to the language rules, the higher the syntactic quality

   - **Syntactic correctness:** the model must not contain any symbols that are not defined in the language (morphological errors) and the model must not lack any constructs or information that are required in the language (syntactic completeness).

   Syntactic correctness can be influenced by the model's formal syntax and can be ensured by constant checking for said syntax errors.

2. *Semantic* quality: the more similarities between the model and the domain, the better the semantic quality

   - **Feasible validity:** all statements made by the model are correct and relevant to the problem
   - **Feasible completeness:** the model contains all the statements about the domain that are correct and relevant.

   It is not possible (in a feasible amount of time) to create a model that is 100% valid and 100% complete. Therefore, *feasible validity* and *feasible completeness* represents a trade-off between the benefits and drawbacks for achieving a given model quality.

   To ensure high semantic quality, a model must be checked for consistency and statements could be inserted or deleted; to make a model more complete or more valid.

3. *Pragmatic* quality: affects how to choose from among the many ways to express a single meaning.

   - **Feasible comprehension:** a model must be understandable to all concerned parties. This holds to a certain degree; it is (for large models) not feasible to make a model comprehensible to all parties.

   Pragmatic means are whatever makes the model easier to understand:

   - *Inspection:* you must read the model to (begin to) understand it. Which can be, for large models, quite hard.
   - *Visualization:* showing a visual of a textual or logical definition of a model makes it easier to grasp.

- *Animation:* moving pictures to make system dynamics explicit.
- *Explanation:* explaining the model (verbally).
- *Simulation:* a simulation of how a system (built according to the model) would behave if implemented.
- *Filtering:* concentrating on specific parts or aspects at a time.

4.4 Conclusions

In this chapter we have provided an introduction to one of many process modeling languages. We have described the mathematical principles of Petri nets and how Petri nets are visually represented. Additionally, we have presented some properties of Petri nets models. Petri nets can be analyzed for validity by using place invariants, which ensures that the weighted total number of tokens in the model is constant.

We have also introduced the framework by Lindland et al. (1994) for quality-improvement goals and the means to achieve them. These goals are divided into three categories: syntactic, semantic and pragmatic quality.

5 Proposed Solution: The Reflective Modeling Cycle

As identified in the Chapter 1, an artifact should be developed to assist novice designers to learn to think critically about their models. Using the background research, conducted in Chapter 2, Chapter 3 and Chapter 4, we propose a tool that aims to achieve this goal.

5.1 Applying Critical Thinking in Problem Solving

In the background research, we have identified that such tools do not currently exist. We did find a general definition for Critical Thinking (Definition 2.1.5). Adapting this general definition results in the fol owing definition:

> **Definition 5.1.1** (Reflective Modeling)**.** Critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, synthesizing, analyzing, and evaluating models, based on observations, experience, reflection, reasoning and communication.

We have found the concept of *wicked problems* and *diminished wicked problems*. Modeling is certainly a diminished wicked problem, as it conforms to criteria 1 to 6, 7 and 9 (formulated in Chapter 3). The problems in process modeling are not definitive; they can be formulated in various ways and viewed at from a number of angles. A model is never *done*, as there is always something to improve.

Furthermore, we have introduced the cognitive load theory. This theory learns us that combined concepts are harder to learn, because the intrinsic cognitive load is higher. The intrinsic cognitive load during modeling is illustrated in Figure 9. In process modeling, novice designers face two problems: (1) They have limited knowledge of the (concepts of the) modeling language and (2) the concepts of the problem are new to them. They have limited experience and try to learn multiple things at a once.

The cognitive load theory also introduced the concept of germane cognitive load, which learns us that the way concepts are taught influences learning. Organizing concepts in such a way that short-term memory can process it more easily, increases the germane cognitive load and thus helps learning.

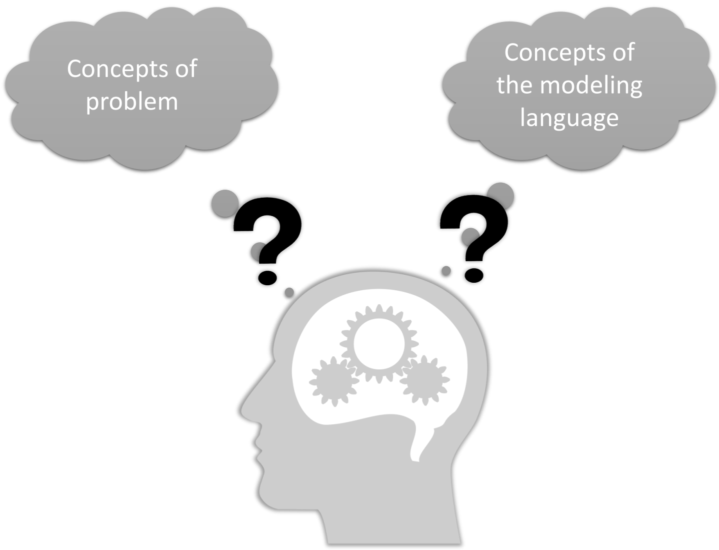


Figure 9: Illustration of intrinsic cognitive load in process modeling

In the Chapter 3, we have also introduced The framework of Pólya (1945). We have expanded and divided the steps in his framework to better separate the different steps in modeling, as can be seen in Table 2.

Steps by Pólya (1945)	**Steps in modeling**
1. Understanding the Problem.	0. Problem Identification
	1. Understanding
2. Devising a Plan.	2. Devising a Plan
3. Carrying Out the Plan.	3. Attack!
	4. Solve the Problem
4. Looking Back.	4. Reflection

Table 2: Comparison between Pólya (1945) and the Reflective Modeling Cycle

The first step of Pólya (1945) (Understanding the Problem) is divided into two separate steps in the Reflective Modeling Cycle: Problem Identification and Understanding. This was done to further clarify that first the requirements should be made clear (Problem Identification), after which you should gather all information (Understanding). The same goes for third step in the framework of Pólya (1945). This step is divided in a step to carry out the plan (Attack!) and a step to answer the question (Solve the Problem).

The names of the steps are not directly copied from Pólya (1945). This was done to make an analogy (that works best in Dutch) with strategic planning. The literal translations are displayed in Table 3. Not all of those translations work / convey the message in English so those terms are changed from these literal (Dutch) translations.

Steps in modeling	**Dutch translation**	**Literal translation from Dutch**
0. Problem Identification	0. Probleemidentificatie	0. Problem Identification
1. Understanding	1. Verkennen	1. Scouting
2. Devising a Plan	2. Aanvalsplan opstellen	2. Devising an Attack Plan
3. Attack!	3. Aanvallen!	2. Attack!
4. Reflection	4. Leermoment	2. Teachable moment

Table 3: Literal translation from Dutch names

Furthermore, the list of abilities and dispositions by Ennis (1985) provide guidelines for the - to be created - tool to follow. In Chapter 4 we have identified goals for quality-improvements and the means to achieve them. These general goals and modeling activities can also be used in the tool.

5.2 The Reflective Modeling Cycle

This section proposes a treatment that could aid novice designers to think (more) critically and reflective about their created models. It should increase the germane cognitive load, by providing a clear step-by-step guide of how to tackle a problem in (process) modeling.

The tool is presented in Figure 10. The full-size version can be found in Appendix A. The Dutch version can be found in Appendix B. We have called the tool: The Reflective Modeling Cycle. The modeling part of the name is quite clear; it is a tool to assist in creating models. The tool has a cyclical appearance (Side A), which represents the cyclical process of modeling. Gathering information, creating a (sub-)model, adapting it, creating other sub-models and combining them into one large model. We have added *Reflective* to the name, to emphasize the reflective steps in the cycle; which should improve critical thinking and in turn improve the overall model.

Every step in this cycle contains pointers for novice designers to think about. Side A (Figure 10a) contains a summary and graphical representation of Side B (Figure 10b). Side A does not contain any additional information to Side B. It only summarizes the questions from Side B and represents them in a graphical manner.

(a) Side A

Modeling Cycle

A schematic view is presented on the other side of this paper.

0 Problem identification

- What is the **problem**?
- Which **questions** should I answer in order to solve the problem?
- Which **conditions** are there?

- Can I **divide** the problem into smaller parts?
  - > What is the **relation** between the parts?
  - > How are the parts mutually **dependent**?

2 Devise a plan

- Which **modeling language** am I going to use?
  - > How does it help solve the problem?
  - > What are **advantages** in solving this case?
  - > What are **disadvantages** in solving this case?
  - > Which language do I choose, and why?

- How does the part **fit** into the current model?

- What are possible **pitfalls**?
- What are the **options** to model this part?
  - > What are the **advantages** of this option?
  - > What are the **disadvantages** of this option?
  - > Which option do I choose, and why?

- Does the chosen option cover the part **sufficiently**?

4 Solve the Problem

- Can I **answer the questions** with this model?
- Can I phrase the answer using **main concepts**?
- What is the **solution** to the problem?
- Does my solution solve the problem? Why?

1 Understanding

- **How** does this part fit in the bigger picture?
- **What information** do I need to model this part?
- What are the properties the model needs to satisfy to be **correct**?

- What are the **main concepts**?
- Can I define all concepts in my own words?
- What is the **relation** between the concepts?
  - > What are their **dependencies**?
  - > Does the relation imply an **order**?
  - > What is the **intention** of the relation?
  - > Can I rephrase the questions with these concepts?
  - > How can I represent this in my model?

- Do I have sufficient information to answer the questions?
  - > Can I **omit** information?
  - > Can I **merge** information?

3 Attack!

- Create the chosen option.
- How do I merge this part into the model?
  - > When is the merger **correct**?

- Did I satisfy all **conditions**?

- Is all given information in my model?
  - > Are all of the **main concepts** present?
  - > Are all the **relations** represented?
- Did I model this part sufficiently?

- Can I **simplify** the model without losing information?
  - > Should I add elements?
  - > Can I leave out elements?

- Am I **satisfied** with the model? Why?

5 Reflection

- Could I model the problem **differently**?
- Did I **divide** the model in a correct manner?
- Which **abstractions** did I use? Why?
- What are **good aspect** of my model?
- What could be **improved** in my model?
- What can I **reuse** for a next time?

(b) Side B

Figure 10: The Reflective Modeling Cycle

Table 4 shows where all the questions in the Reflective Modeling Cycle originate from. The first column contains the questions from the cycle (Figure 10b). The second column refers to the steps and questions from the framework of Pólya (1945). The number refers to the step, the letter to the question / sub-step in his framework. The third column contains the references the dispositions and abilities from Ennis (1985). The 'D' refers to a disposition, the 'A' to an ability. The number and following letters refer to the numbers and letters in Figure 3. In the last column, we present the corresponding modeling activity, as identified by Lindland et al. (1994).

	Pólya	**Ennis**	**Modeling activity**
0 Problem identification			
What is the problem?	1a	D1, A1	
Which questions should I answer in order to solve the problem?		A1	
Which conditions are there?	1b		
Can I divide the problem into smaller parts?	1e	D12	Filtering
What is the relation between the parts?		D7	Consistency checking
How are the parts mutually dependent?			
1 Understanding			
How does this part fit in the bigger picture?	2g	D5, D6	Filtering
What information do I need to model this part?		A2bc	
What are the properties the model needs to satisfy to be correct?	1c		
What are the main concepts?	1a	A2b	Explanation
Can I define all concepts in my own words?	1a, 2f	D1	
What is the relation between the concepts?			Consistency checking
What are their dependencies?			
Does the relation imply an order?			Explanation
What is the intention of the relation?			
Can I rephrase the questions with these concepts?	2f	D1	
How can I represent this in my model?			
Do I have sufficient information to answer the questions?	1c	A2bc	Inspection
Can I omit information?	1c	A2e	Statement deletion
Can I merge information?	1c	A2d	
2 Devise a plan			
Which modeling language am I going to use?	(1d)		Explanation
How does it help solve the problem?			
What are advantages in solving this case?			
What are disadvantages in solving this case?		A2d	
Which language do I choose, and why?			
How does the part fit into the current model?		D5	Consistency checking
What are possible pitfalls?	2b, 2c, 2d, 2e		Explanation
What are the options to model this part?		D9, A2d	
What are the advantages of this option?		D10, A2d	
What are the disadvantages of this option?			
Which option do I choose, and why?			
Does the chosen option cover the part sufficiently?	2h		

3 Attack!			
Create the chosen option.	3a		All
How do I merge this part into the model?		D7, A1c	Explanation
When is the merger correct?			Consistency checking
Did I satisfy all conditions?	3b		
Is all given information in my model?			
Are all of the main concepts present?			
Are all the relations represented?			
Did I model this part sufficiently?			Explanation
Can I simplify the model without losing information?		A2de	Statement deletion
Should I add elements?			Simulation
Can I leave out elements?		A2e	
Am I satisfied with the model? Why?			Explanation
4 Solve the Problem			
Can I answer the questions with this model?		D7	
Can I phrase the answer using main concepts?		A1b	
What is the solution to the problem?			
Does my solution solve the problem? Why?	3b		
5 Reflection			
Could I model the problem differently?	4c		Pragmatic activities
Did I divide the model in a correct manner?	4b		Filtering
Which abstractions did I use? Why?			Explanation
What are good aspect of my model?	4b		Inspection
What could be improved in my model?			
What can I reuse for a next time?	4d		

Table 4: Justification for all steps in the Reflective Modeling Cycle

Some questions cannot be directly derived from the presented frameworks in Chapter 2 and Chapter 3, because we have combined those questions and adapted them to better fit the context of (process) modeling.

We have explicitly chosen to make the tool a bit abstract. We did not include any specific questions that only apply to certain modeling languages. This way, this tool can be used for all (process) modeling activities and is language agnostic.

5.3 Illustrative Example

To further illustrate how the Reflective Modeling Cycle works, this subsection presents a case and an example of how a model could be created using the Reflective Modeling Cycle using a think-aloud style approach. This example is also our first analysis of the Reflective Modeling Cycle, as it illustrates if the Reflective Modeling Cycle can be used to create good quality models.

The case is presented in Figure 11 (a Dutch version of the case can be found in Appendix C).

We apply the Reflective Modeling Cycle in a think aloud style to highlight its usage, and way of thinking rather than explicit documentation.

The Princess and the Frog

From a bridge, eternally living frogs jump into a pond. They choose non-deterministically one of the two banks to swim to, and then hop to the bridge to start over again.
A princess, looking for they one and only, picks up every third frog that climbs on the bridge, kisses the frog in the idle hope that it becomes the ideal partner, and disappointed puts the frog back on the bridge.

Model this fairy tale.
- Suppose that five frogs are initially on the bridge. What happens to your model? What happens to your model if you only have two or four frogs?
- Is it possible, in your model, that every frog will eventually be kissed by the princess at least once?

Figure 11: The Princess and the Frog

0 Problem identification

What is the problem?

This case starts with five frogs that jump into a pond and swim to either bank. A princess picks up frogs, kisses them and puts them back on the bridge.

I assume that frogs do not disappear in this case; they cannot escape or go anywhere else than the banks and the bridge.

Which questions should I answer in order to solve the problem?

Q1 Is it possible, in my model, that every frog will eventually be kissed by the princess?

Q2 How does my model change when I have two frogs?

Q3 How does my model change when I have four frogs?

Which conditions are there?

C1 The princess picks up every third frog.

C2 Frogs eternally follow the process

Can I divide the problem into smaller parts? What is the relation between the parts? How are the parts mutually dependent?

Part 1 Frogs jump into a pond, choose either side A or side B and climb back on the bridge.

Part 2 The princess picks up every third frog, kisses it and puts it back on the bridge.

Part 1 is cyclical. Part 2 only takes place for every third frog. Part 2 can only be carried out after part 1 has been executed.

Round 1, Part 1

1 Understanding

For this round, I choose the first part to model (Part 1).

How does this part fit in the bigger picture?

This part is the start of the model.

What information do I need to model this part? What are the properties the model needs to satisfy to be correct? What are the main concepts? Can I define all concepts in my own words?

- There are 5 frogs
- Frogs jump into a pond, chose either side A or side B and climb back on the bridge.

What is the relation between the concepts?

Not applicable

How can I represent this in my model?

I could use places for the frogs. For the two sides, I could use a transition.

Do I have sufficient information to answer the questions? Can I omit information? Can I merge information?

I think that I have enough information to model this part of the model.

2 Devise a plan

Which modeling language am I going to use? How does it help solve the problem? What are advantages in solving this case? What are disadvantages in solving this case? Which language do I choose, and why?

As hinted in the previous questions, I think I could use a Petri net to solve this problem. With Petri nets I can easily add and remove frogs, by adding or removing tokens from the place. Which is part of the requirement for this case.

How does the part fit into the current model?

Not applicable as this is the first part.

What are possible pitfalls?

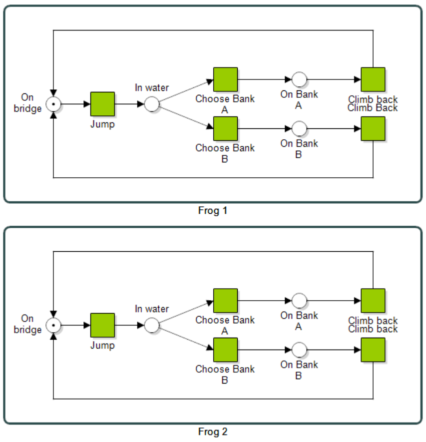
I do not think that there are any pitfalls in this part of the model.

What are the options to model this part? What are the advantages of this option? What are the disadvantages of this option? Which option do I choose, and why?

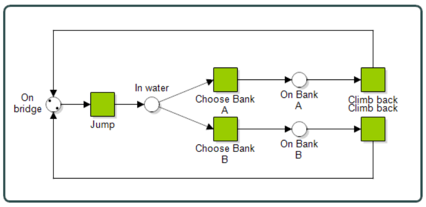
One option would be to model each frog as a separate place and transition (see Figure 12a for two of the frogs). This would mean that it would be very easy to individually track every frog in the model. It would, however, make it quite hard to add or remove frogs as this would entail changing parts of the model. Furthermore, the model would grow very big if additional frogs are added.

Another options would be, as mentioned before, to have one place that holds all frogs (only two frogs in Figure 12b). This would allow changing the number of frogs easily, without adding more to the model.

I think that option 2 is the best options in this case.



(a) Round 1, iteration 1 (Option 1)



(b) Round 1, iteration 2 (Option 2)

Figure 12: Round 1, iteration 1 & 2: different options (using two frogs)

Does the chosen option cover the part sufficiently?

I think that the chosen option covers the part sufficiently.

3 Attack!

Create the chosen option.

See Figure 13.

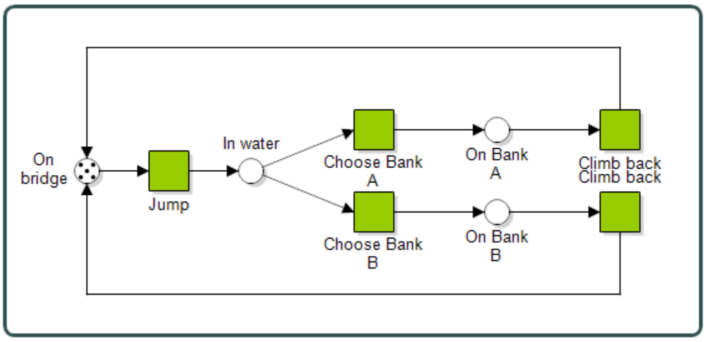


Figure 13: Round 1, iteration 3

How do I merge this part into the model? When is the merger correct?

Not applicable, as this is the first part of my model.

Did I satisfy all conditions?

My model does not yet satisfy all conditions. It does not satisfy condition C1, as this is not yet part of my model. It does however satisfy C2 (Frogs eternally follow the process), because there exists a place invariant; namely: $1 \cdot On\ bridge + 1 \cdot In\ water + 1 \cdot On\ Bank\ A + 1 \cdot On\ Bank\ B = 5$. This means that frogs cannot leave my model. Tokens do not appear or disappear.

Is all given information in my model? Are all of the main concepts present? Are all the relations represented?

Yes, all information is in my model. All main concepts and relations are present.

Did I model this part sufficiently?

Yes, I think I did.

Can I simplify the model without losing information? Should I add elements? Can I leave out elements?

I think I could remove the choice between side A and side B. It does not add anything to the model, as both the incoming and the outgoing flows go to the same places.

Am I satisfied with the model? Why?

No, I think I should remove the choice described before.

4 Solve the Problem

Can I answer the questions with this model?

Not yet, I need to model the rest of the case.

5 Reflection

Could I model the problem differently?

I think that I have considered all options.

Did I divide the model in a correct manner?

For now, I think I divided my model in a correct manner.

Which abstractions did I use? Why?

None.

What are good aspect of my model?

I think that my model is clear and easily extendable.

What could be improved in my model?

I think I should remove the choice between Side A and Side B.

What can I reuse for a next time?

I do not think that I can identify a pattern in this solution.

Round 2, refining Part 1

1 Understanding

For this round, I choose to further refine the first part (Part 1).

What information do I need to model this part? What are the properties the model needs to satisfy to be correct? What are the main concepts? Can I define all concepts in my own words?

I think I can abstract away the difference between Side A and Side B. I can test if this is the case by checking if my place invariant still works after the change.

How can I represent this in my model?

I could remove the transitions and corresponding places for Side A and Side B.

2 Devise a plan

What are the options to model this part? What are the advantages of this option? What are the disadvantages of this option? Which option do I choose, and why?

By removing the transitions and places for Side A and Side B, the model is simplified. I do not think that I loose any functionality because of this. I do, however, loose some information that is provided in the case. However, in order to answer the questions this information is redundant.

3 Attack!

Create the chosen option.

See Figure 14.

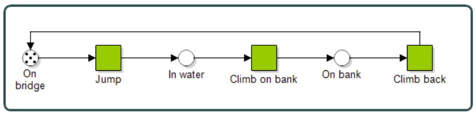


Figure 14: Round 2, iteration 1

Did I satisfy all conditions?

I can test this by checking if my place invariant still works: $1 \cdot \mathit{On\ bridge} + 1 \cdot \mathit{In\ water} + 1 \cdot \mathit{On\ Bank} = 5$. The place invariant is still valid. Removing the choice between Side A and Side B did not remove any functionality from the model.

Is all given information in my model? Are all of the main concepts present? Are all the relations represented?

Yes, all information that I have now identified to be relevant is in my model.

Did I model this part sufficiently?

Yes, I think I did.

Can I simplify the model without losing information? Should I add elements? Can I leave out elements?

I do not think that I can further simplify the model without losing information.

Am I satisfied with the model? Why?

Yes, I am satisfied.

4 Solve the Problem

Can I answer the questions with this model?

Not yet, I need to model the rest of the case.

5 Reflection

Could I model the problem differently?

I think that I have thought of all options now and that this is the best model for this part of the case.

Which abstractions did I use? Why?

I abstracted away the two sides. They are not relevant in order to answer the questions posed in the case.

What are good aspect of my model?

I think that my model is clear, small and easily extendable.

What could be improved in my model?

I do not think I could improve anything else in my model.

Round 3, Part 2

1 Understanding

I will now continue with the next part of the case: "The princess picks up every third frog, kisses it and puts it back on the bridge." (Part 2).

How does this part fit in the bigger picture?

If I look at the solution in Figure 14, I think that this part should add a choice to climb back on to the bridge or to be picked up by the princess.

What information do I need to model this part?

The princess picks up every third frog, kisses it and puts it back on the bridge.

What are the properties the model needs to satisfy to be correct?

The princess should only be able to pick up the third frog. Not the second, not the fourth.

What are the main concepts? Can I define all concepts in my own words? What is the relation between the concepts? What are their dependencies? Does the relation imply an order? What is the intention of the relation? Can I rephrase the questions with these concepts?

- Frogs
- Princess

The princess and the frogs are related, because the princess picks up the frogs.

How can I represent this in my model?

The princess could be a transition in my model.

Do I have sufficient information to answer the questions? Can I omit information? Can I merge information?

I think that I have sufficient information to model this part. I do not think that I can either omit or merge information.

I am, however, not quite sure about how to model the condition that the princess may only pickup the third frog (C1). For now I will, therefore, omit this and add it later in my model.

2 Devise a plan

How does the part fit into the current model?

The *Climb back* transition should be complemented by a transition that represents the princess picking up the frog.

What are possible pitfalls?

I do not think there are any possible pitfalls in this part.

What are the options to model this part? What are the advantages of this option? What are the disadvantages of this option? Which option do I choose, and why?

The princess would pickup the frog and kiss it and put it back on the bridge. This would add some additional places and transitions. I cannot think of any other options to model this part.

Does the chosen option cover the part sufficiently?

No, I still need to implement C1. But I will do that in the next round!

3 Attack!

Create the chosen option.

See Figure 15. The *On bridge* and *In water* come from the previous part.

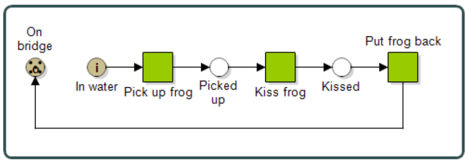


Figure 15: Round 3, iteration 1

How do I merge this part into the model? When is the merger correct?

The model can slot right in the previous model using the *Waiting* and *Jumped* places. See Figure 16

The merger is correct when the whole model works; there are no deadlocks and the condition that only the third frog can be kissed can be fulfilled. We can, furthermore, prove that frogs do not disapear in this model by the folowing place invariant: $1 \cdot On\ bridge + 1 \cdot In\ water + 1 + \cdot On\ bank + 1 \cdot Picked\ up + 1 \cdot Kissed = 5$.

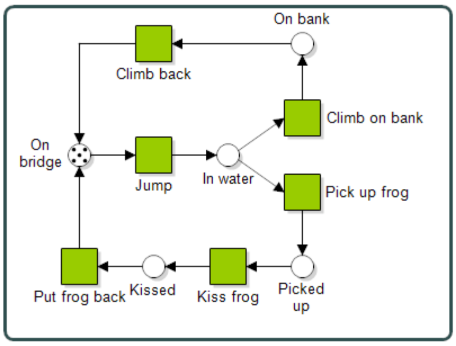


Figure 16: Round 3, iteration 2

Did I satisfy all conditions?

No, I still need to add C1.

Is all given information in my model? Are all of the main concepts present? Are all the relations represented?

Yes, all given information is presented in my model.

Did I model this part sufficiently?

No, not yet! It is not entirely complete.

Can I simplify the model without losing information? Should I add elements? Can I leave out elements?

If I compressed the *Pick up frog*, *Kiss frog* and *Put frog back* transitions into one, the model would functionally still be the same. I do not think that I should do this, however, because this makes the model harder to read and to relate back to the case.

Am I satisfied with the model? Why?

Not entirely. I think that I did model it okay, however. I think that I will be more satisfied after I have added the last condition.

4 Solve the Problem

Can I answer the questions with this model?

No, not yet. I still have to satisfy C1.

5 Reflection

Could I model the problem differently?

I do not think that I can really change this part of the model. As said before, I do not think that I should compress the *Pick up frog*, *Kiss frog* and *Put frog back* transitions into one transition, because this abstracts away the case too much.

Did I divide the model in a correct manner?

I do think that I did divide my model in a correct way. The two separate parts made the case more easy to grasp.

Which abstractions did I use? Why?

I abstracted away the two sides that the frog can swim to. I did not need this to answer the questions.

Round 4, refining Part 2

1 Understanding

I will further refine Part 2 in this round.

What information do I need to model this part?

The princess picks up every third frog, kisses it and puts it back on the bridge.

What are the properties the model needs to satisfy to be correct?

The princess should only be able to pick up the third frog. Not the second, not the fourth.

How can I represent this in my model?

I do not think that I have to change the model that I have created in 16. I only have to add something to limit the princess from picking up any other frog than the third frog. And I should add something to make sure that the frogs do not climb back on the bridge by themselves.

Maybe I can use some sort of counter?

Do I have sufficient information to answer the questions? Can I omit information? Can I merge information?

I think that I have sufficient information to model this part. I do not think that I can either omit or merge information.

2 Devise a plan

How does the part fit into the current model?

I could add the counters near the *Pick up frog* and *Climb back* transitions.

What are possible pitfalls?

A possible pitfall in this part is that the princess should only be able to pick up the third frog and not the second or fourth. Furthermore, there should not exist any deadlocks in the model.

What are the options to model this part? What are the advantages of this option? What are the disadvantages of this option? Which option do I choose, and why?

One option would be to let three frogs jump at once (Figure 17). The *Jump* transition would consume 3 tokens and produce 2 tokens in the *In water* place and 1 token in a new, *In water, waiting for princess* place. This would ensure that every third frog is kissed, but this would not work with only 2 frogs. As the transition *Jump* would always be dead.

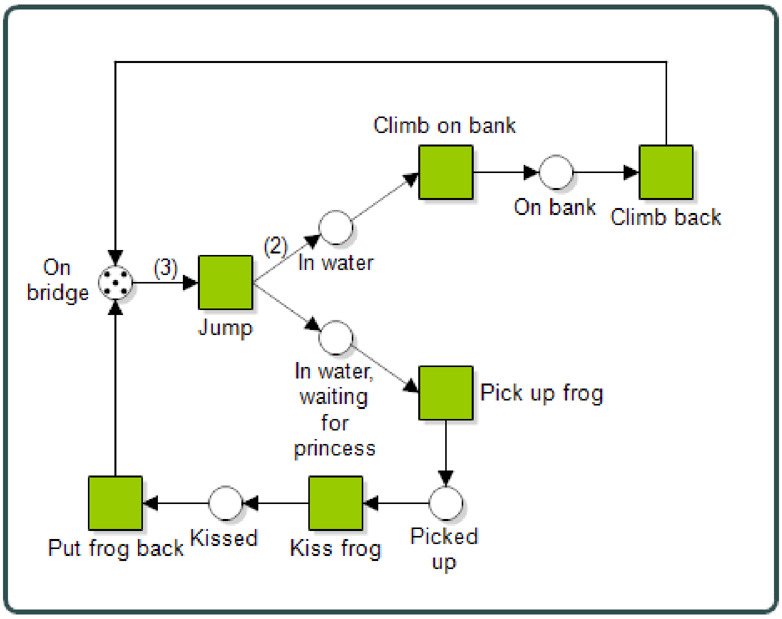
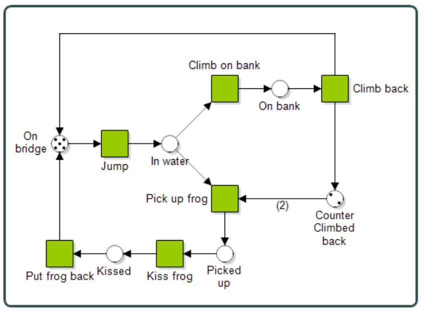


Figure 17: Round 4, iteration 1

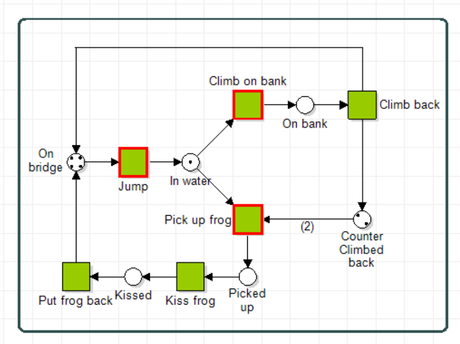
I should add a counter that makes sure that the princess can only pick up the third frog; maybe something like Figure 18a.

But this does not entirely satisfy C1, because the princess is not required to pick up the third frog. I have now modeled that, on average, every third frog might be picked up by the princess. The frog could also chose to just climb back onto the bridge (See Figure 18b). When two frogs have jumped and climbed back onto the bridge, there are two tokens in the *Counter climbed back* place, therefore the transition *Pick up frog* can fire, but there is nothing that limits the *Climb back* transition from firing. This could mean that the third frog would just climb back onto the bridge himself. We do not want that, of course.

Furthermore, the place *Counter climbed back* is unbounded; there could be a situation, where their are an unlimited amount of tokens in that place, because the loop *On bridge*; *Jump*; *In water*; *Climb on bank*; *On bank*; *Climb back* is not limited and can produce an infinite amount of tokens in *Counter climbed back*.



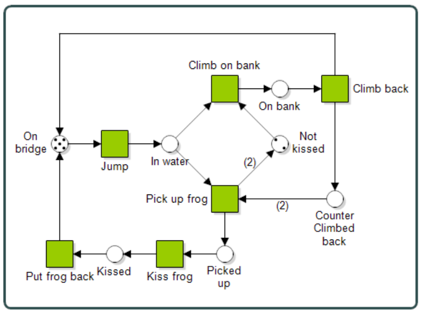
(a) Round 4, iteration 2



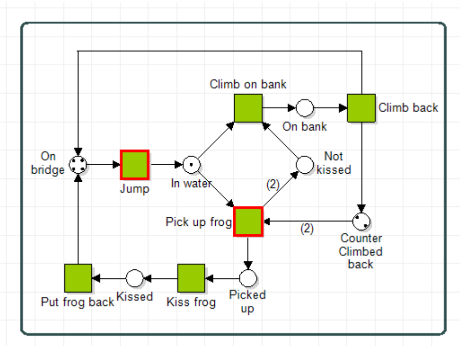
(b) Round 4, iteration 2 problem

Figure 18: Round 4, iteration 2 and problem with iteration 2

Therefore, I must add some counter to ensure that the third frog cannot climb back onto the bridge by himself. Something like in Figure 19a. In this case, the *Not kissed* counter ensures that the frog cannot climb back onto the bridge by himself, if there were already two frogs that climbed back onto the bridge by themselves.



(a) Round 4, iteration 3



(b) Round 4, iteration 3 solves the problem

Figure 19: Round 4, iteration 3 and illustration why this solves the problem

I should, therefore, chose options 2. It covers C1 the best.

Does the chosen option cover the part sufficiently?

I think that this options will sufficiently model this part, because it contains all elements and all constraints.

3 Attack!

Create the chosen option.

See Figure 19a.

How do I merge this part into the model? When is the merger correct?

I have already merged the model in Figure 19a. The merger is correct if all conditions still apply.

Did I satisfy all conditions?

Yes, my model all conditions:

C1 applies, because only the third frog can and must be picked up by the princess. I can also show that the tokens in the counters do not disappear or turn into frogs, because $1 \cdot \mathit{Not\ Kissed} + 1 \cdot \mathit{On\ bank} + 1 \cdot \mathit{Counter\ Climbed\ Back} = 2$

My place invariant for C2 also still applies: $1 \cdot \mathit{On\ bridge} + 1 \cdot \mathit{In\ water} + 1 \cdot \mathit{On\ Bank} + 1 \cdot \mathit{Picked\ up} + 1 \cdot \mathit{Kissed} = 5$.

Is all given information in my model? Are all of the main concepts present? Are all the relations represented?

Yes, all given information is presented in my model.

Did I model this part sufficiently?

I think that my model follows all constraints and is therefore sufficient.

Can I simplify the model without losing information? Should I add elements? Can I leave out elements?

I do not think that I can simplify my model without losing information. If the restriction would be that the princess would kiss every third frog, or fourth, or ...; then the *Not kissed* counted would not need to be there. But yeah; I made that assumption.

Am I satisfied with the model? Why?

I am quite satisfied with my model. I think it solves the constraints quite elegantly.

4 Solve the Problem

Can I answer the questions with this model?

Yes!

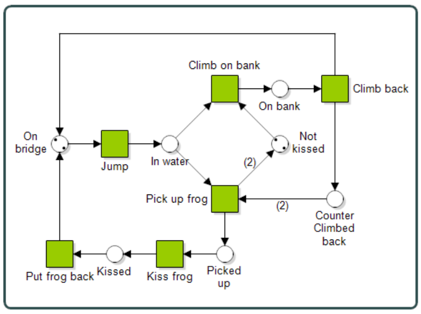
Can I phrase the answer using main concepts?

Yes, my model contains labels that reference the main concepts.

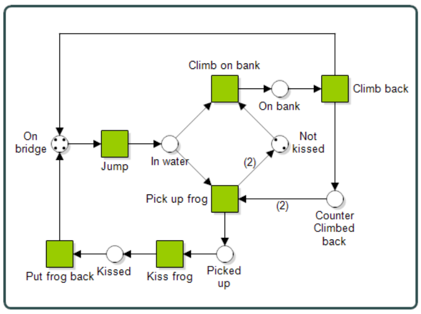
What is the solution to the problem?

My model does not provide a solution to Q1, because you cannot individually track frogs / tokens, adding an id to each token would solve this (Jensen & Rozenberg, 2012).

I can, however, very easily answer Q2 and Q3. When changing the number of frogs to 2 or 4, the number of tokens in the *On bridge* place changes. The rest of the model is unchanged. See Figure 20a and Figure 20b respectively.



(a) Round 4, model with 2 frogs



(b) Round 4, model with 4 frogs

Figure 20: Round 4, models with 2 and 4 frogs

Does my solution solve the problem? Why?

My solution partially solves the problem. I can easily answer the second and third question. The first question, however, cannot be answered unambiguously using my model. You cannot track individual frogs.

My model is bounded, which is a good sign. There exist two place invariants that ensure that frogs cannot escape from the model and that the tokens used in the counters do not escape the counter loop and turn into frogs. My model does not contain any deadlocks and is also live, every place can be enabled again.

5 Reflection

Could I model the problem differently?

I could model every frog individually (like in Figure 12a). This would however make my model really big and hard to alter.

Did I divide the model in a correct manner?

I do think that I did divide my model in a correct way. The two separate parts made the case more easy to grasp.

Which abstractions did I use? Why?

I abstracted away the two sides that the frog can swim to. I did not need this in order to answer the questions.

What are good aspect of my model?

I think that I have modeled the whole case quite elegantly.

What could be improved in my model?

My model does not answer the whole question unambiguously. I could improve this by individually modeling every frog.

What can I reuse for a next time?

I am quite satisfied with the construction with the counters. I think that I could reuse this in some other model sometime.

5.4 Conclusions

This chapter proposes a solution to the problem introduced in Chapter 1. It justifies this cycle using the theoretical background obtained in Chapter 2 and Chapter 3. The provided example illustrates how the cycle can be used to create models and how it should help novice designers think critically about their products.

The cycle can now be tested on perceived usefulness and usability in Chapter 6 and effectiveness in Chapter 7.

6 Perceived Usefulness and Usability

This chapter elaborates on the conducted quantitative research on the perceived usefulness and usability of the cylce in order to answer SQ5, SQ6 and SQ7. It starts with the planning of the experiment; states the hypothesis, the design and the threats to validity to this experiment. Thirdly, it makes some comments about the experiment operation. Followed by the data analysis, which elaborates about how the data was analyzed and presents visualization of those data. The analyzed data is then interpreted and followed by this chapter's conclusions.

6.1 Research Question

This chapter uses the general research question, formulated in Chapter 1 and SQ5, SQ6 and SQ7 to explore the perceived usefulness and the usability of the cycle.

RQ1: *How can the critical thinking skills of novice designers be improved in process modeling?*

SQ5: *Do novice designers think that the Treatment helps them think more critically about their model?*

To answer this subquestion we use the following statements:

P1 I think the Reflective Modeling Cycle adds value next to the existing lectures and modeling sessions.

P2 I think I will keep using the Reflective Modeling Cycle during practice.

P3 I think others will also quickly learn to use the Reflective Modeling Cycle.

P4 I felt annoyed using the Reflective Modeling Cycle.

P5 While modeling, I felt more confident about my choices because of the Reflective Modeling Cycle.

P6 I think my model is better than if I had not used the Reflective Modeling Cycle.

SQ6 *Do novice designers think that the Treatment is user friendly?*

To answer this subquestion, we use the following statements:

U1 I thought the Reflective Modeling Cycle was unnecessarily complex.

U2 I thought the Reflective Modeling Cycle was easy to use.

U3 I could use the Reflective Modeling Cycle without any further explanation.

U4 I understood the order of the Reflective Modeling Cycle.

U5 I thought the Reflective Modeling Cycle was inconsistent.

SQ7 *Would novice designers recommend the presented Treatment to other novice designers?*

We will determine the Net Promoter Score, by asking the following question:

N1 How likely is it that you would recommend using the Reflective Modeling Cycle to fellow students?

6.2 Experiment Planning

This section elaborates on the planning of the experiment. It starts with stating the hypothesis for both research questions, followed by the experiment design and concluded with the threats to validity.

6.2.1 Hypotheses

For every statement introduced above we have formulated a hypothesis which can be found in Table 5, Table 6 and Table 7.

	Hypothesis
P1	We expect that novice designers perceive that the Reflective Modeling Cycle adds value next to existing lectures and modeling sessions.
P2	We expect that novice designers think that they will keep using the Reflective Modeling cycle during practice.
P3	We expect that novice designers think that others will also quickly learn how to use the Reflective Modeling Cycle.
P4	We expect that novice designers do not feel annoyed when using the Reflective Modeling Cycle.
P5	We expect that novice designers perceive to feel more confident about their choices because of the use of the Reflective Modeling Cycle.
P6	We expect that novice designers think that their models are better, than if they had not used the Reflective Modeling Cycle.

Table 5: Hypotheses for statements belonging to SQ5

	Hypothesis
U1	We expect that novice designers will not think that the Reflective Modeling Cycle is unnecessarily complex
U2	We expect that novice designers think that the Reflective Modeling Cycle is easy to use
U3	We expect that novice designers could us the Reflective Modeling Cycle without any further explanation
U4	We expect that novice designers do understand the order of the Reflective Modeling Cycle
U5	We expect that novice designers will not think that the Reflective Modeling Cycle is inconsistent

Table 6: Hypotheses for statements belonging to SQ7

	Hypothesis
N1	We expect to have a positive Net Promoter Score.

Table 7: Hypotheses for statements belonging to SQ5

We will accept a certain hypothesis if the group of participants that answered *Agree* or *Completely agree* is greater than the group that answered *Completely disagree* or *Disagree* in case of questions where a higher score is better. With the statements where a lower score is better, we will flip the scale and accept hypotheses where the group that answered *Completely disagree* or *Disagree* is greater than the group of participants that answered *Agree* or *Completely agree*.

6.2.2 Design

The experiment is conducted during two modeling sessions during the *Information systems* course in 2018/2019. Due to the size of the cohort, the sessions are randomly divided by the Utrecht University administration into two sets of three parallel sessions, on Monday and Tuesday (group A and group B, respectively). Both sessions follow the strucuture as described in Table 8. In total 180 students are divided into these 6 groups. The experiment is conducted over two weeks.

15:15 - 15:55	Creating the model	40 minutes
15:55 - 16:10	Answering the questionnaire	15 minutes

Table 8: Time schedule for the modeling sessions

In the first week, all students have to craft a solution for the frog-and-the-princess problem (as described in Chapter 5, Figure 11). The students have to create a solution individually, after which they have to fill in a set of questions to prepare the group discussion. During the sessions on Tuesday, i.e., in group B, the Reflective Modeling Cycle is introduced and used by the students. After the initial questionnaire, the students have to fill in the questionnaire on the Reflective Modeling Cycle. In the week thereafter, the students have to work on the ceaseless-studying-students problem (Figure 21, Dutch version in Appendix C), inspired from the Dining Philosophers case (introduced by Dijkstra, 1971). These two cases are of the same degree of complexity, according to the course coordinator). This time, the students of group A are equipped with the Reflective Modeling Cycle, and consecutively are asked to fill in the same questionnaire. This way, we guaranteed that all students were all equally trained with the Reflective Modeling Cycle.

The Ceaseless Studying Students

A group, consisting of, five students decides to study eternally at a big round table. In between every two students is one earplug. Because it is a round table, there are as much earplugs as there are students. Every student either drinking or studying. A student is only able to study if he has an earplug in both his left and right ear. If he wants to start studying, he grabs the earplug on his left and the one on his right, puts them in his ears en start studying. When the student is done studying, he puts both earplugs back on the table and starts drinking again. You may assume that the student can drink and study unlimited. There is enough money and booze to study eternally.
Of course, a student should not only be drinking, he has to study once in a while as well.

Create a model of this problem. Show that every student has eventually the opportunity to study.

Figure 21: The Ceaseless Studying Students

The questionnaire on the Reflective Modeling Cycle focuses on its effectiveness and use:

- System Usability Score
- Net Promoter Score
- Recommendations

The System Usability Score (Brooke et al., 1996) is a quick way to determine the usability of a system on a 5-point likert Scale. The Net Promoter Score (Reichheld, 2003) asks participants if they would recommend the Reflective Modeling Cycle to fellow students. A field for recommendations was provided for participants to provide any feedback on the Reflective Modeling Cycle.

The questions for perceived usefulness and usability were on the same questionnaire, presented in Appendix A and Appendix B (in Dutch).

6.2.3 Participants

For this experiment, the students of the course *Information systems* participated. The students are all between 18 and 24. Most students are first year information sciences students (Table 9). Most participants are first-year students at Utrecht University (Table 11). Most participants are enrolled in this course for the first time. These students have little to no experience in process modeling prior to starting the course. A portion of the enrolled students have failed the course in the past and have enrolled for a second or third time. They have a little more experience with process modeling. The division of those students is displayed in Table 10.

	#
Information Science	167
Computing Science	21
Other bachelors	12

Table 9: Students' bachelor

	#
1st	147
2nd	35
3th	17
4th	1

Table 10: Number of students and their trials for the course

	#
1st year	103
2nd year	43
3th year	29
4th year	15
5th year	5
6th year	3
7th year	1
8th year	1

Table 11: Distribution of students according to their study length

6.2.4 Threats to Validity

When executing any experiment, the validity of the results is always a concern.

Conclusion validity *Conclusion validity* concerns the statistical analysis of results and the composition of subjects. We used quite a big test-group in this exploratory research (180 participants). Therefore, we might expect that we will be able to reveal patterns in the participants' answers. We do not expect that any individual differences within participants will influence the interpretation of the results.

Internal validity Matters that may affect the independent variable with respect to causality affect the *internal validity*. The subjects were told in the survey that their course grade would not be affected by their answers on the questionnaire. They were, however, required to attend the session and answer the questions. This introduces the risk that a participant lacks motivation, because they feel the experiment is a waste of time. To mitigate this issue as much as possible, we have made sure that the experiment felt as much like a "normal" modeling session.

Not all participants, filled-out the questionnaire on the same day. Half of the participants participated on Monday, the other half on Tuesday. The participants on Tuesday had one more lecture than the participants on Monday. Furthermore, the participants on Monday also filled-out a questionnaire for the research in Chapter 7. Those participants might lack even further motivation, because they have already filled-out a quite lengthy survey.

Furthermore, participants might create better models using the cycle, but do not contribute this to the Reflective Modeling Cycle (and thus not reflect this in the given answers on the questionnaire). They might simply think that they came up with the idea themselves, when actually the systematic approach of the cycle made them think about this idea.

Construct validity *Construct validity* concerns all generalization of experiment results to theory behind the experiment. For this experiment, we have not identified any *construct validity* concerns.

External validity Generalization of the experiment results to other environments affects *external validity*. The experiment is focused at novice designers. The test group consists of (mostly) novice designers, the subject of this thesis. We therefore think that external validity is not of big concern in this case.

6.3 Experiment Operation

The experiment was ran on the 13th (Monday session) and the 14th (Tuesday session) of May 2019. The experiment was part of the "normal" modeling session. Group A (the Monday session) filled out the questionnaire at the end of the other experiment from this thesis (described in Chapter 7). The participants in the Tuesday session filled out the questionnaire right after creating a model during the modeling session (as described in Chapter 1).

Some other important remarks about the experiment operation:

- Every participant has filled-out a consent form (Appendix K and Dutch version in Appendix L)
- Every session (3 in total) had one lecturer and one teaching assistant. These people were not allowed to answer substantive questions about the case or the models. When questions like these arose, they told the participant to check the case description.
- The session was totally in Dutch; the case text was in Dutch, the questionnaires were in Dutch and the (oral) instructions were given in Dutch.
- The Reflective Modeling Cycle (the Treatment) was handed out on paper.
- Participants filled out the questionnaire via Blackboard (an online learning environment that is used at Utrecht University; [1]). This ensured that all enrolled participants could access the questionnaire only during the experiment.

6.4 Results

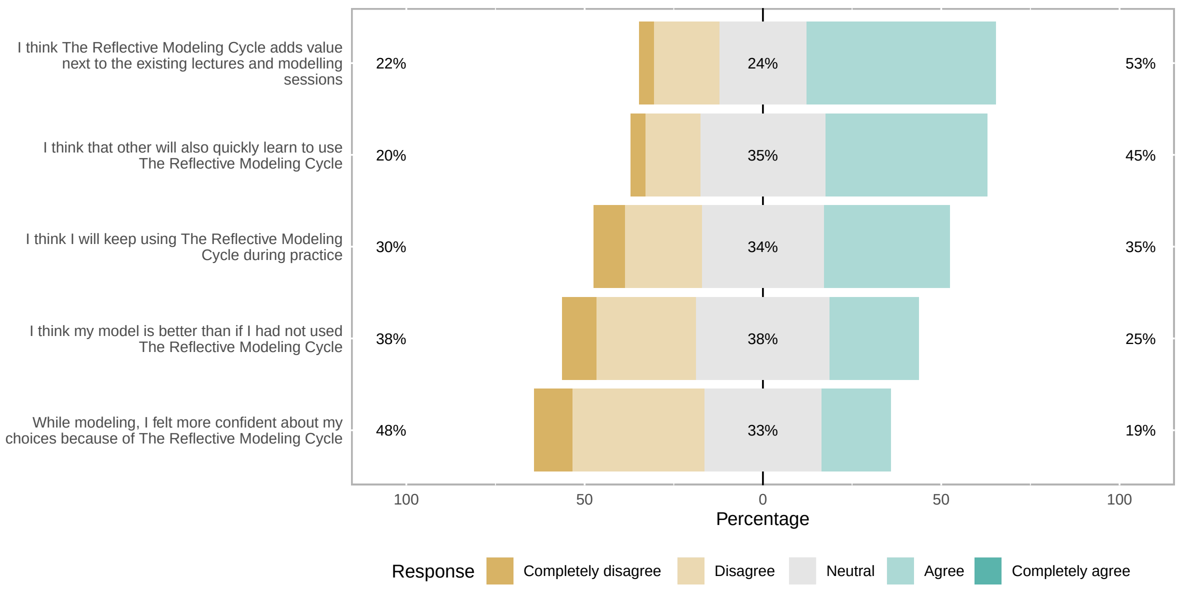
This section presents the results from the analysis of the answers to the questions by the participants. In total 105 (out of a possible 200) students participated and filled out the questionnaire.

The data was analyzed and visualized using the R scripting language ("R: The R Project for Statistical Computing", n.d.) and the likert package by Bryer (n.d.). Plots of the questions were grouped by the subject (perceived usefulness and usability) and by the "direction" of the scale (higher is better or lower is better) and sorted from a higher score to lower score. Figure 22 presents the plots for the perceived usefulness, Figure 24 shows the answers to the Net Promoter Score Question and Figure 23 visualizes the usability questions. Please note that due to rounding errors, not all percentages add up to 100%.

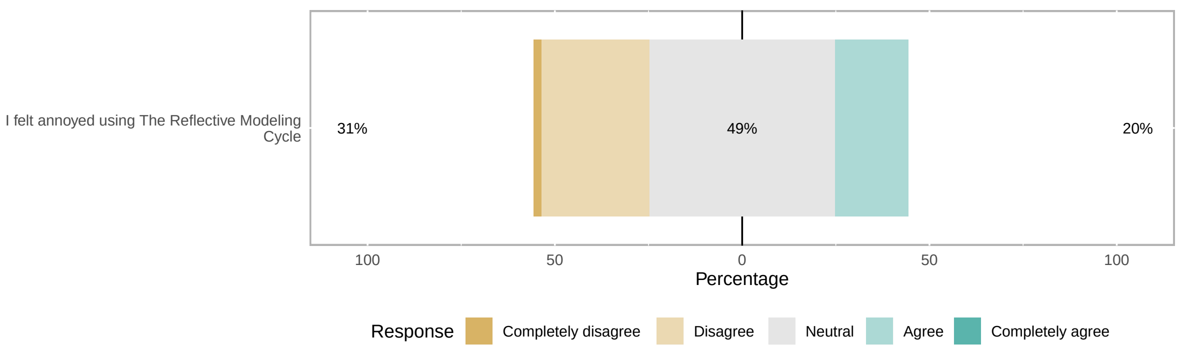
The raw data from the questionnaire can be found in Appendix M. The R-code used for the analysis and the compiled data of the questions can be found in Appendix O.

The most interesting answers on the last, open-text question about recommendations, are categorized and listed in Figures 25, 26, 27 and 28 (translated to English).

[1] https://www.blackboard.com/

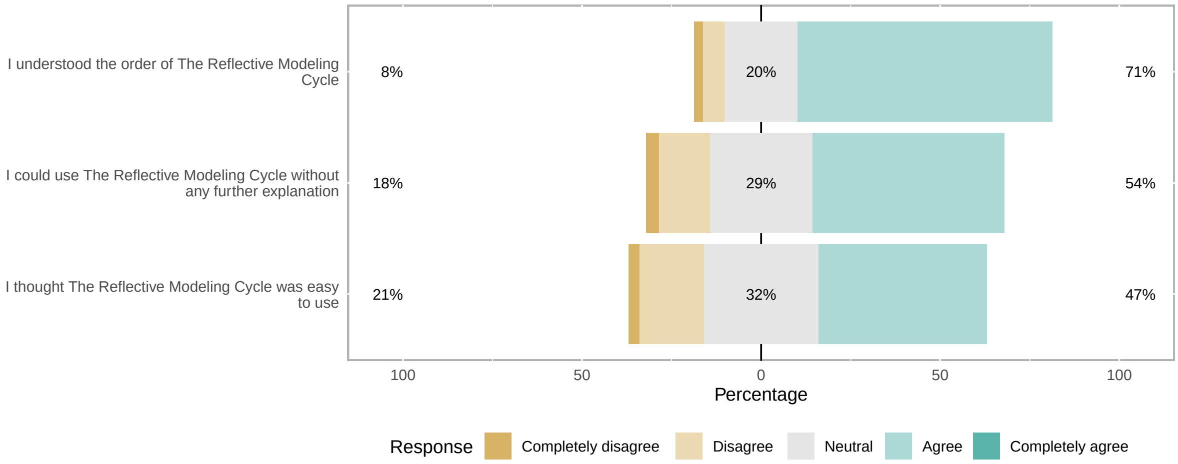


(a) Perceived Usefulness (higher is better)

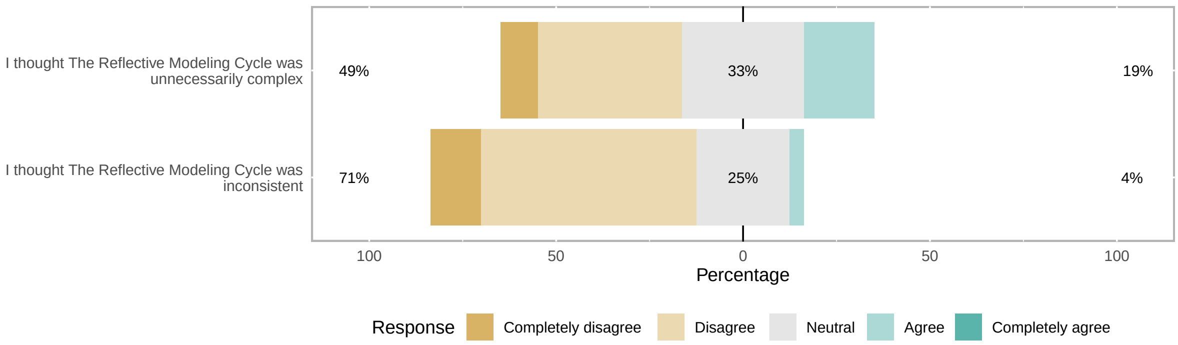


(b) Perceived Usefulness (lower is better)

Figure 22: Perceived Usefulness



(a) Usability (higher is better)



(b) Usability (lower is better)

Figure 23: Usability

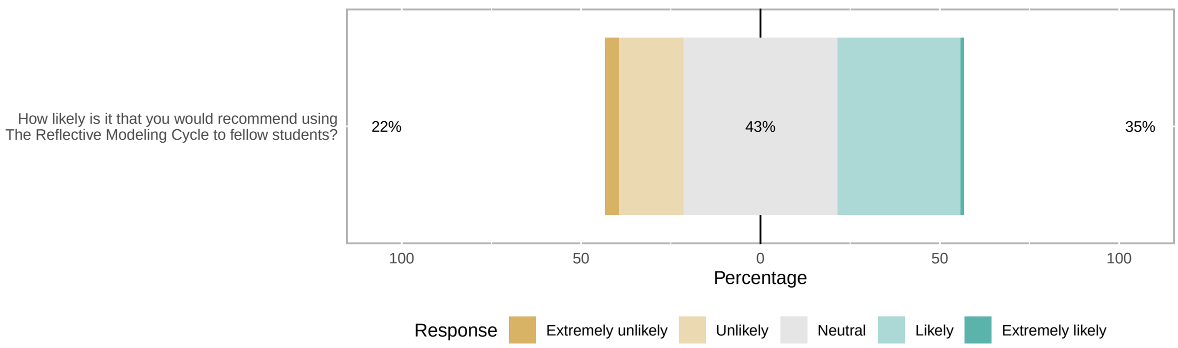


Figure 24: Net Promoter Score

Negative remarks

1. **Participant 4:** Unnecessary, teacher's help with modeling is more appreciated (solutions on the blackboard)
2. **Participant 10:** I have not really looked at it, perhaps it is because I already did the course last year and this situation is not new, nor difficult enough to use the modeling process.
3. **Participant 16:** Completely unnecessary and has 0 added value
4. **Participant 17:** I have applied this process relatively naturally. Now I think that learning a process is not the same as understanding it completely. The process may help, but should not be supposed to replace it.
5. **Participant 18:** I didn't actually use it because I didn't see the added value in it.
6. **Participant 24:** I find everything in the modeling process clear. It may also help me to tackle problems in a more structured way, but I doubt that my modeling skills will immediately improve with the modeling process document.
7. **Participant 25:** I found the modeling process to have no added value, especially with a model of this small size. For a larger project such as the assignment I can imagine that it is useful, but today I did not use it (I thought it was something that delayed me).
8. **Participant 54:** Too abstract.
9. **Participant 65:** It may be very helpful, but if I only have about 30 minutes to model, it takes a little too long to go through all the steps. I have not really used the Modeling process for this exercise.
10. **Participant 76:** I have not used it so cannot have an opinion about the modeling process
11. **Participant 86:** I didn't use it
12. **Participant 94:** No, I didn't really use it
13. **Participant 103:** I tried it with the first question but I didn't really get that far so I didn't use this sheet for the assignment

Figure 25: Negative remarks

Positive remarks

1. **Participant 17:** I have applied this process relatively naturally. Now I think that learning a process is not the same as understanding it completely. The process may help, but should not be supposed to replace it.
2. **Participant 24:** I find everything in the modeling process clear. It may also help me to tackle problems in a more structured way, but I doubt that my modeling skills will immediately improve with the modeling process document.
3. **Participant 31:** It is pretty obvious, but it is nice to see the steps you would normally take in your head in front of you on paper.
4. **Participant 50:** Nice addition
5. **Participant 51:** Well actually I did not know that we had received the A4, but having read it back retroactively I noticed that I had used similar steps (or learned from last year's experience). I think it's a good memory aid in general.
6. **Participant 72:** It is a useful tool, but to become much better at modeling, continuing to practice is the best way.
7. **Participant 78:** Yes a pity that it [the Reflective Modeling Cycle] is mandatory [to use] but otherwise quite handy
8. **Participant 101:** I didn't know we had to use this for this assignment, but I think it certainly helped and it looks clear.

Figure 26: Positive remarks

Neutral remarks

1. **Participant 92:** It can only be used with prior knowledge that all modeling languages are well under control.
2. **Participant 98:** The idea was good, but the assignment was too abstract and the modeling process too general, making it difficult to use

Figure 27: Neutral remarks

Suggestions

1. **Participant 3:** I would explain, in stead of just handing it out.
2. **Participant 7:** Maybe a little unnecessary, maybe an example?
3. **Participant 19:** I'd rather have it as a flowchart
4. **Participant 21:** Backside is quite superfluous front was sufficient for me, back is a lot of info which can be a bit overwhelming. step 2: Would be nice if there might be tips about which choice you can make.
5. **Participant 47:** It could be a little more concrete depending on which modeling 'language' you use (AND / OR constructions, processing deadlocks etc), but then it may become too specific / easy
6. **Participant 61:** Maybe a little explanation about the bold print terms, this makes it a little easier to understand immediately as soon as you see it.
7. **Participant 64:** The modeling process is useful to get to grips with, but probably to "bulky" to go through all the questions during the exam, for which a globalized version would be more convenient.
8. **Participant 96:** Some things are a bit abstract. Perhaps it would be better to understand with an example

Figure 28: Suggestions

6.5 Analysis and Discussion

This section starts with the interpretation of the quantitative data on perceived usefulness and usability; we then provide the calculation for the Net Promoter Score for the Reflective Modeling Cycle and conclude with an analysis of the remarks and recommendations by participants.

6.5.1 Perceived Usefulness

Table 12 presents the analysis of the results from Figure 22a and Figure 22b and conclusions to the hypotheses presented in Table 5. The statements are ordered in the same way as the statements are ordered in the figures.

	Analysis	**Result**
	Higher is better	
P1	53% of participants state that they think that cycle adds value, next to existing lectures and modeling sessions. Only 22% says that they do not see any added value.	Accept
P3	45% of participants said that they think that other people will also quickly learn how to use the cycle. Only 20% thinks that others will not learn quickly how to use the cycle.	Accept
P2	35% of participants said that they will keep using the cycle while practicing, however 30% of participants said that they will not do that and 34% says that they are neutral.	Accept
P6	only 25% of the participants think that their model is better because they have used the Reflective Modeling Cycle, whereas 38% think that the cycle is not better because of using the cycle.	Reject
P5	only 19% of respondents said they they felt more confident during the modeling because of the Reflective Modeling Cycle. 48% said that the tool did not make them feel more confident.	Reject
	Lower is better	
P4	20% of participants said they felt annoyed using the cycle. 31% of participant said that they were not annoyed by using the cycle.	Accept

Table 12: Analysis of the statements belonging to SQ5

We get a quite contradictory image about the perceived usefulness of the Reflective Modeling Cycle; we can accept 4 out of 6 hypotheses. Indicating that the perceived usefulness of the Reflective Modeling Cycle is not very obvious.

We must notice that quite a large portion of the participants answered *neutral* to the statements; between 24% to 49% depending on the statement. The data from statement P1 suggests that participants / novice designers do see the added value of the Reflective Modeling Cycle. This would, quite strongly, indicate that novice designers do perceive usefulness of the cycle. The answers to P6, however, present quite the opposite.

We can, therefore, not definitely say that novice designers perceive usefulness of the Reflective Modeling Cycle.

6.5.2 Usability

Table 13 presents the analysis of the results from Figure 23a and Figure 23b and conclusions to the hypotheses presented in Table 6. The statements are ordered in the same way as the statements are ordered in the figures.

	Analysis	Result
	Higher is better	
U2	71% of participants understands the order of questions in the Reflective Modeling Cycle. Only 8% did not understand the order of the cycle.	Accept
U3	54% could use the cycle without any explanation; 18% said that that was not the case for them.	Accept
U4	47% of participants thought that the cycle was easy to use, whereas 21% of participant did not find it easy to use.	Accept
	Lower is better	
U1	Only 19% found the Reflective Modeling Cycle unnecessarily complex to use, 49% did not find it unnecessarily complex to use.	Accept
U5	71% thought that the cycle was not inconsistent, only 4% thought this.	Accept

Table 13: Analysis of the statements belonging to SQ6

We accept all hypotheses. The data is quite un-contradictory, the percentages used to accept the hypotheses are quite large. The usability of the Reflective Modeling Cycle is therefore quite good.

6.5.3 Net Promoter Score

To calculate the Net Promoter Score, we use the following formula: $NPS = Promoters - Criticizers$, where the *Promoters* are the participants that were *likely* or *extremely likely* to recommend the cycle to others and the *Criticizers* were *unlikely* or *extremely* unlikely to recommend the cycle to fellow students (see Figure 24). According to the formula, the Reflective Modeling Cycle has a Net Promoter Score of $35\% - 22\% = 13$.

The average score per *sector* is different. For modeling tools we have not found any similar data. Therefore it is quite hard to say whether a score of 13 is bad or good (Reichheld, 2003). We can however assume that a positive NPS indicates that participants recommend the usage of the Reflective Modeling Cycle.

6.5.4 Remarks made by participants

If we look at the negative remarks (Figure 25), quite some participants said that they simply did not use the Reflective modeling cycle at all (6 participants); some of these participants also provide a more thorough explanation about why they did not use the cycle. They said that they think that this problem was too small to use the cycle (number 2, 6, 9 and 13).

The first, second, third, fifth and last positive remark (Figure 26) illustrate nicely the concept of cognitive overload (Introduced in Chapter 1). Remark 7 confirms the threat, mentioned in this chapter, that participants might lack motivation. Positive remark 6 mentions the need to keep practicing; we conform to this. The Cycle certainly does not replace practicing or any other teaching forms. It is solely an addition that can help novice designers getting started with modeling and thinking critically about the created models.

Neutral remark number 1 and suggestion number 5 (Figure 28) states that the cycle was too abstract. This was done intentionally, to have the cycle apply to as many modeling languages as possible. Neutral remark 1 mentions that students should already have knowledge about modeling languages, we agree with this. The cycle is solely an extra tool to use when practicing.

Some suggestions (Figure 28) were made about explaining the cycle better or providing an example about how to use the cycle (1, 2, 6 and 8). We acknowledge the remarks that the session and cycle require a more thorough introduction in the course.

6.6 Conclusions

The quantitative research about the perceived usefulness and usability of the Reflective Modeling Cycle has learned us that:

SQ5: *Do novice designers think that the Treatment helps them think more critically about their model?*

The perceived usefulness of the Reflective Modeling Cycle is quite contradictory. We have accepted 4 out of 6 hypotheses, indicating that novice designers think the Treatment helps them think more critically about their model.

We have found signs that the Reflective Modeling Cycle reduces cognitive load for novice designers, which would mean that the Reflective Modeling Cycle has added value in learning process modeling.

SQ6 *Do novice designers think that the Treatment is user friendly?*

The usability of the Reflective Modeling Cycle is good. We can therefore conclude that novice designers think that the Treatment is user friendly.

SQ7 *Would novice designers recommend the presented Treatment to other novice designers?*

We have calculated a Net Promoter Score of 13. We can therefore assume that novice designers recommend the Reflective Modeling Cycle to other novice designers.

Some other important pointers that we have learned in this research are:

- There are signs that the Reflective Modeling Cycle is not best used on small problems, but rather on more complex cases.
- There are signs that the cycle reduces the cognitive load of novice designers.
- The Reflective Modeling Cycle does not replace any other teaching forms or practicing.
- The cycle would best be introduced with a more elaborate explanation or an example.

7 Effectiveness

In addition to the perceived usefulness, we want to research to what extent the Reflective Modeling Cycle support novice designers in thinking more critically about their models.

We first start by defining the research questions, then we will provide details about the experiment planning and operation. Concluding, we will present the results.

7.1 Research Question

This chapter uses the general research question, formulated in Chapter 1 and the sub-question SQ8 to explore the effectiveness of the Reflective Modeling Cycle.

RQ1 How can the critical thinking skills of novice designers be improved in process modeling?

SQ8 Does the presented Treatment show signs that it might help novice designers think critically about their process models?

7.2 Experiment Planning

This section describes the planning of the experiment where participants create a model and fill out a questionnaire about their model and the process of creating the model. This planning includes the definitions of the dependent and independent variables, hypotheses, the experiment design, instrumentation and an analysis of the threats to validity of the experiment (Wohlin et al., 2000).

7.2.1 Variables

The purpose of this experiment is to test the influence of the Treatment on the critical thinking skills of participants.

- In this experiment, *independent variables* include: *the applied critical thinking skills of participants* and *the created models.*
- *Controlled variables* in this experiment include: *the provided case text to participants*, *the experience of the participant.*
- In this experiment, we have one *dependent variable*: *the applied Treatment.*

7.2.2 Hypotheses

Participants using the treatment can either perform just as well as participants not using the treatment; or they can perform better. This brings us to the following hypotheses:

H_0: Novice designers using the Treatment appear to think as critically about their models as novice designers without the Treatment.

H_1: Novice designers using the Treatment appear to think more critically about their models than novice designers without the Treatment.

7.2.3 Design

The experiment will take place in course week 2 and course week 3. Participants have had their first introduction into process modeling by then and have been explained the Petri net process modeling language. As described in Chapter 6, create a model in both week 2 and week 3. This results in an ATA' test (illustrated in Figure 29), where A is Group A, T (treatment) the Reflective Modeling Cycle and A' Group A after receiving the treatment.

Figure 29: Illustration of A T A' Test

Much effort was put into making these modeling sessions feel as "normal" as the other modeling sessions. The cases that were presented to the participants were equivalent to cases in other modeling sessions. The only difference was the questionnaire and that they created their models individually, without discussing with other people in the room.

The questions are derived from the Reflective Modeling Cycle and designed to test the student on the characteristics that are in the cycle (see Table 14). Some questions are specific about the case in relation to their model and are used to help analyze the participants' model if necessary and are not derived from the cycle. The questionnaire for week 2 is presented in Appendix G and the questionnaire for week 3 in Appendix I. The Dutch versions of these questionnaires are presented in respectively Appendix H and Appendix J

Analysis The given answers on the questionnaires will be scanned for signals that the critical thinking skills of participants are improved. When analyzing the results we pay attention to the problem areas and the expected results presented in Table 15. Depending on the questions, elements will be counted and/or answers will be scored by the researcher based on the expected result. Only participants that participate both in week 2 and 3 will be included in the data-set.

For every analysis we will exclude answers where the question was clearly misunderstood or where the participant answers nothing. Therefore, the n per question might differ per question from the total number of participants in the research.

The score is on a 0-2 scale. When a particular answer scores 0 points, the answer did not conform (enough) to the expected result for that question. An answer that scores 2 points does (perfectly) conform to the expected result for that question.

The change in the scores on a per participant base will also be calculated. This will be done by subtracting the score of week *week* 2 from the score of *week* 3 ($week\ 3\ score - week\ 2\ score$). This differences ranges from -2 (the score in week 3 is 2 points lower than the score in week 2) to 2 (the score in week 3 is 2 points higher than the score in week 2); 0 being no change in the score. Only the participants that were included in the data-set for both weeks will be included in this analysis.

As mentioned in Table 14, question 11 and 12 are used to interpret the models of participants, if necessary, and question 14 is for remarks. Question 13, where participants solve the problem, is heavily dependant on the model that the participant created. These questions are, therefore, excluded from Table 15 and will also not be mentioned in this analysis.

7.2.4 Participants

The characteristics of the participants in this research have already been described in Chapter 6.

#	Question	Origin	Explanation
1	A typical approach is divide & conquer. With this approach, you divide the case into smaller subcases, which you solve separately and merge when you are done. Could you explain briefly if and how you used this technique? If not, could you explain briefly the approach you have used?	0. Problem Identification	Taken from the question "Can I divide the problem into smaller parts?"
2	What are the most important elements in the case and how are they related?	1. Understanding	Taken from "What are the main concepts?" and "What is the relation between the concepts?"
3	During the modeling, you have probably tried or thought about multiple options. Which options did you consider for your model?	2. Devise a plan	Taken from "What are the options to model this part?"
4	Why did you create your model in the way it is now?	2. Devise a plan	Taken from "What option did I choose, and why?"
5	How and where can the elements from question 2 be found in your model?	3. Attack!	Taken from "Is all given information in my model?"
6	What is the reasoning behind the model? Why do you think that your model is a correct model for the situation?	5. Reflection	Taken from "Could I model the problem differently?"
7	Does your model describe the entire situation? Explain.	4. Solve the problem	Taken from "Can I answer the questions with this model?"
8	Which abstraction did you use in your model?	5. Reflection	Taken from "Which abstractions did I use?"
9	What are the good aspects in your model?	5. Reflection	Taken from "What are good aspects in my model?"
10	What would you improve in your model?	5. Reflection	Taken from "What could be improved in my model?"
11	How did you model the frogs in your model?	N/A	Used to better understand the delivered model, if further inspection is required.
	How are students represented in your model?		
12	How did you model the princess in your model?	N/A	
	How are the earplugs represented in your model?		
13	What would you have to change in your model if there aren't 3, but 5 frogs?	4. Solve the problem	A place for participants to provide the answer to the problem.
	How does your model show that every student is eventually always able to study?		
14	Do you have any remarks about this assignment?	N/A	A place for participants to provide feedback about the assignment.

Table 14: Origin from questions in the Questionnaire about the participants' model

#	Question	Problem area	Expected results
1	A typical approach is divide & conquer. With this approach, you divide the case into smaller sub-cases, which you solve separately and merge when you are done. Could you explain briefly if and how you used this technique? If not, could you explain briefly the approach you have used?	Problem division	More (elaborate) answers on how to divide the problem.
2	What are the most important elements in the case and how are they related?	Identified concepts	More (correct) answers about what are the most important elements in the case and more elaborate descriptions of the relations between the elements.
3	During the modeling, you have probably tried or thought about multiple options. Which options did you consider for your model?	Option exploration	More elaborate descriptions and considerations of the considered options.
4	Why did you create your model in the way it is now?	Model intention	More substantiated and reflective answers about what option they chose and why.
5	How and where can the elements from question 2 be found in your model?	Model representation	Better explanation about how the most important elements are modeled.
6	What is the reasoning behind the model? Why do you think that your model is a correct model for the situation?	Rationale	More thorough and critical analysis of the obtained solution and why this is the correct solution for the situation.
7	Does your model describe the entire situation? Explain.	Model completeness	
8	Which abstraction did you use in your model?	Identified abstractions	Better insight in the abstractions that were introduced in the model.
9	What are the good aspects in your model?	Identified positive points	More thorough analysis of the obtained solution.
10	What would you improve in your model?	Possible improvements	

Table 15: Expected results for participants using the Reflective Modeling Cycle

7.2.5 Threats to Validity

When executing any experiment, the validity of the results is always a concern. This section will analyze the threats to this validity.

Conclusion validity *Conclusion validity* concerns the statistical analysis of results and the composition of subjects. We used quite a big test-group in this exploratory research (90 participants). Therefore, we might expect that we will be able to reveal patterns in the participants' answers.

Internal validity Matters that may affect the independent variable with respect to causality affect the *internal validity*. One threat to internal validity is selection bias. We have tried to mitigate this issue by using the randomly assigned groups by the University's administration. We cannot be sure though if all the participants in these groups have equal experience with process modeling.

A very big threat to validity in this experiment is the threat of maturation. Participants create models without the Treatment in week 2, have more lectures, and only then create a new model in week 3 using the Treatment. Furthermore, in week 3, participants have had more experience practicing (besides the regular lectures). We cannot do much to mitigate this issue in this experiment.

Furthermore, the questionnaires in week 2 and 3 are the same (except for the case-specific questions). Participants have therefore more "experience" when answering the questions and have answered the same questions before.

The subjects were told in the survey that their course grade would not be affected by their answers on the questionnaire or the models they created. They were, however, required to attend the session, create the model and answer the questions. This introduces the risk that a participant lacks motivation, because they feel the experiment is a waste of time. To mitigate this issue as much as possible, we have made sure that the experiment felt as much like a "normal" modeling session. As stated before, the only difference was the questionnaire and the requirement to create the models individually.

The two case texts are similar, but we cannot be sure if they are the exactly the same degree of complexity. Moreover, participants may find one case more appealing than the other.

The provided answers on the questionnaires are scored by the researcher. In this work we perform an exploratory study to possible effects of the Reflective Modeling Cycle. To prevent bias, ideally, we would have a second researcher score all the provided answers. It remains future work to scrutinize the results.

Construct validity *Construct validity* concerns all generalization of experiment results to theory behind the experiment. The questions that are used in the questionnaire are (sometimes quite literately) derived from the Reflective Modeling Cycle. In week 2, participants did not use the cycle before answering the questions; in week 3 they did. This inherently means that participants in week 3 have thought about the questions more, because they have used the cycle that asked the same questions. We have tried to mitigate this problem by, as much as possible, trying to use different wordings for the questions in the questionnaire than the words that are used in the Reflective Modeling Cycle.

External validity Generalization of the experiment results to other environments affects *external validity*. The experiment is focused at novice designers. The test group consists of (mostly) novice designers.

The cases presented, however, are quite short (because they have to be completed in time). The cycle is not specifically designed to handle short cases and we expect that the model is more useful for larger cases.

7.3 Experiment Operation

The experiment in week 2 was ran on the 6th of May 2019. The experiment in week 3 was ran on the 13th of May of the same year. The experiment was during / instead of the "normal" modeling session and followed the structure described in Chapter 6.

- Every participant has filled-out a consent form (Appendix K and Dutch version in Appendix L)
- Every session (3 in total) had one lecturer and one teaching assistant. These people were not allowed to answer substantive questions about the case or the models. When questions like these arose, they told the participant to check the case description.
- The session was totally in Dutch; the case text was in Dutch, the questionnaires were in Dutch and the (oral) instructions were given in Dutch.
- Participants were not allowed to collaboratively create models. The model should be created individually.
- In week 3, the Reflective Modeling Cycle (the Treatment) was handed out on paper.
- Participants created their model either on paper or using a modeling tool on their own computer.
- Participants delivered the model via Blackboard (an online course-tool that is used at Utrecht University; https://www.blackboard.com/). This ensured that all enrolled participants could access the assignment only during the experiment. After the participants handed in the model, they were presented with the questionnaire.

7.4 Results

Due to illness and other reasons, only 64 (out of theoretical 90) participants attended both modeling sessions and participated in the research. This section will summarize the answers from participants per question and mention some noteworthy answers from participants. The raw data from the questionnaires can be found in Appendix N. The analysis of the questions can be found in Appendix P.

7.4.1 Problem Division

Table 16 displays the number of participants that have divided their model into smaller sub-models. We both looked at their direct answer (*yes* or *no*), but also their further explanation of their answer. 64 participants answered this question, so no participants were excluded from the data-set.

	Count	**%**
Both weeks	31	48%
Only week 2	14	22%
Only week 3	10	16%
None of the weeks	9	14%
	64	100%

Table 16: Number of participants that divided their model into sub-models (question 1)

The clarification of the question was scored on a 0-2 scale (0 being none or a very bad explanation, 2 being an adequate clarification). Table 17 shows these results for both weeks. Only 45 and 44 participants in respectively week 2 and week 3 provided an explanation. The participants that did not provide an explanation were excluded.

The difference of the score per participant between week 2 and week 3 is displayed in Table 17.

	Week 2		Week 3	
	#	%	#	%
0	7	16%	5	11%
1	11	24%	19	43%
2	27	60%	20	45%
Total	45	100%	44	100%
Weigh. Avg	1.44		1.34	

Table 17: Obtained scores for the clarification of the answers to question 1 in week 2 and week 3

	#	%
-2	1	3%
-1	7	21%
0	21	62%
+1	4	12%
+2	1	3%
	34	100%

Table 18: Difference in the scores between week 2 and week 3 for the clarification of the answers to question 1 per participant

Some interesting remarks that participants made (translated):

> **Participant 39, Week 2:** I didn't do this. I honestly didn't think about that and just looked at the problem as a whole.
>
> **Participant 60, Week 2:** No, I actually just started trying it out and I kept adding some things to make the model as complete as possible.

7.4.2 Identified Concepts

The researchers have determined that:

- The most important elements in the case of week 2 are the *frogs* and the *princess*. The relation between those elements is that the princess picks up every third frog.
- The most important elements in the case of week 3 are the *students* and the *earbuds*. The relation between them is that a student can only study when he has two earbuds.

The answers were coded for the important elements in that week. Table 19 shows the mentioned elements in week 2 (Table 19a) and week 3 (Table 19b). The tables also shows the number of participants that mentioned both, one or none of the elements in that particular week.

In week 2, 5 answers were excluded and in week 3, 3 answers were excluded because the questions was misunderstood by those participants, bringing us to a total of respectively 59 and 61 answers that were included for analysis.

	#	%
Only Frogs	50	85%
Only Princess	43	73%
Avg wrong elements	1.31	
Both elements	40	68%
One element	13	22%
No elements	6	10%
	59	100%

(a) Mentioned elements in week 2

	#	%
Students	49	80%
Earbuds	53	87%
Avg wrong elements	0.18	
Both elements	44	72%
One element	14	23%
No elements	3	5%
	61	100%

(b) Mentioned elements in week 3

Table 19: Mentioned elements for question 2

Table 20 shows the obtained scores for the relation part of question 2 in both weeks. Table 21 shows the difference in the scores between week 2 and week 3.

	Week 2		Week 3	
	#	%	#	%
0	28	47%	29	48%
1	16	27%	15	25%
2	15	25%	17	28%
Total	59	100%	61	100%
Weigh. Avg	0.78		0.80	

Table 20: Obtained scores for the relations between the elements in question 2 in week 2 and week 3

	#	%
-2	5	9%
-1	10	18%
0	24	43%
+1	12	21%
+2	5	9%
	56	100%

Table 21: Differences in the scores between week 2 and week 3 of the relations between the elements in question 2 per participant

7.4.3 Option Exploration

The answers to this questions were rated on a 0-2 scale based on the degree of elaboration and consideration of the options. Table 22 shows these scores for both weeks. In week 2, 58 participants provided a valid response; in week 3, 61 participants were included in the analysis. Table 23 shows the changes in the scores between the weeks per participant. Only 56 participants provided a valid answer in both week 2 and week 3.

	Week 2		Week 3	
	#	%	#	%
0	18	31%	27	48%
1	32	55%	26	25%
2	8	14%	8	28%
Total	58	100%	61	100%
Weigh. Avg	0.83		0.69	

Table 22: Obtained scores for the descriptions of the considered options in question 3 in week 2 and week 3

	#	%
-2	1	2%
-1	19	34%
0	25	45%
+1	11	20%
+2	0	0%
	56	100%

Table 23: Difference in the scores between week 2 and week 3 for the descriptions of the considered options in question 3

Table 24 shows some examples of participants who only mention the modeling languages they considered in their answer to question 3. Table 25 shows some examples of participants that improved their score in week 3 compared to week 2.

ID	Week 2	Week 3
37	Petrinet and BPMN	BPMN and PetriNet
39	LTS and petri net	bpmn and petrinet
53	BPMN or Petrinet	Petrinet, BPMN and eventually: LTS.

Table 24: Participant answers in week 2 and week 3 for question 3 that only mention modeling languages

ID	Week 2	Week 3
6	The choice between a transition system and a petri net	My first idea was a transition that ate from two places and then produced at one place etc. However, there is no state to indicate that the student is studying.
41	-	Create a model per student. Create a model for only 1 student and modeling the "route" of the earbuds
49	In fact, I only considered this option.	Model the earplugs as tokens, model a pair of earplugs as tokens, or model the students as tokens.

Table 25: Participant answers in week 2 and week 3 for question 3 that improved their score

7.4.4 Model Intention

Table 26 shows the obtained scores for both weeks. In week 2 and week 3 respectively, 63 and 64 valid answers were provided and included in the analysis. Table 27 shows the differences in the scores between week 2 and week 3 per participant. 63 participants provided valid answers in both weeks.

	Week 2		Week 3	
	#	%	#	%
0	38	60%	46	72%
1	21	33%	17	27%
2	4	6%	1	2%
Total	63	100%	64	100%
Weigh. Avg	0.46		0.30	

Table 26: Obtained scores for the answers provided to question 4 in week 2 and week 3

	#	%
-2	1	2%
-1	16	25%
0	40	63%
+1	5	8%
+2	1	2%
	63	100%

Table 27: Difference between week 2 and week 3 in the scores for question 4 per participant

Table 28 shows some example answers from participants that did not improve their score between week 2 and week 3. Table 29, on the other hand, shows examples of participants that did improve their score.

ID	Week 2	Week 3
1	This seemed the simplest solution to me	I thought this was the simplest solution
4	It is neat, compact and modeled the situation as you read it.	This seemed the best option, while keeping some sort of oversight over the situation.
8	I couldn't think of anything better	That way it keeps going around easier.
9	Is the clearest	This is correct
27	It seems to work.	It works.
29	Seemed like a logical solution	Seemed logical.
30	This is more compact.	This one seemed better to me.
31	Looked kind of logical	Clear
50	It seemed more educational.	It just came out of nowhere.
51	This seemed logical to me	Small and correct.
55	I think that's right	I think that's right
56	Because that was the easiest way	Because it was simple
63	Because I have no idea how to do it differently	Because I think it's correct and because I don't want to think about it anymore.

Table 28: Answers to question 4 from participants that *did not* improve their score between week 2 and week 3

ID	Week 2	Week 3
2	?	Availability of earplugs using tokens in petri just seemed like a good first step.
45	It is compact, and you can model different tokens (aka frogs).	Clarity, the level of abstraction. And the ability to put the earplugs back. Ear plugs can be modeled with petri nets.
47	Because this model works in my opinion and is correct	Because at least it is now clear which student can study and when, the only thing that is missing now is to see whether the earplugs are actually available.
49	Because this was the only way I could come up with it	Because I think there is no other way than using the earplugs as tokens

Table 29: Answers to question 4 from participants that *did* improve their score between week 2 and week 3

7.4.5 Model Representation

Table 30 shows the scores on a 0-2 scale for the explanation about where the elements from question 2 can be found in the models of the participants. In week 2, 59 valid answers were provided; in week 3 63 valid answers were provided. Table 31 shows the individual changes between the scores of week 2 and week 3 per participant. 58 participants provided a valid answer in both week 2 and week 3

	Week 2		Week 3	
	#	%	#	%
0	4	7%	3	5%
1	29	49%	41	65%
2	26	44%	19	30%
Total	59	100%	63	100%
Weigh. Avg	1.37		1.25	

Table 30: Obtained scores for the answers to question 5 in week 2 and week 3

	#	%
-2	1	2%
-1	19	33%
0	25	43%
+1	12	21%
+2	1	2%
	58	100%

Table 31: Differences in the scores for the answers to question 5 in week 2 and week 3 per participant

In Table 32, some examples of participants that improved their score in week 3 (compared to week 2) are presented.

ID	Week 2	Week 3
5	I don't understand how to answer this question	Earplugs as places, students who study and drink respectively as transitions
17	As places.	The earbuds as tokens, and the students and the table as places where the earbuds are located.
18	??	Student makes a choice between drinking and studying
24	As places and actions.	The earbuds as tokens, the students do not return to the model themselves. They carry out the possible actions.
25	These can be seen as transitions in the model.	I modeled the ears as loose tokens and then the students as well. Students must have two ears (tokens) in order to study.

Table 32: Answers to question 4 from participants that improved their score between week 2 and week 3

7.4.6 Rationale

Table 33 shows the obtained scores for reasoning behind the model (question 6). Respectively 58 participants and 63 participants provided valid responses in week 2 and week 3. Table 34 shows the difference in the scores between week 2 and week 3 for question 6, 62 participants proved valid answers in both week 2 and week 3.

	Week 2		Week 3	
	#	%	#	%
0	14	24%	13	21%
1	40	69%	44	70%
2	4	7%	6	10%
Total	58	100%	63	100%
Weigh. Avg	0.83		0.89	

Table 33: Obtained scores for question 6 in week 2 and week 3

	#	%
-2	0	0%
-1	12	21%
0	31	54%
+1	13	23%
+2	1	2%
	62	100%

Table 34: Differences in the scores between week 2 and week 3 for question 6

7.4.7 Model Completeness

Table 35 shows the obtained scores for question 7, asking if the provided model covers the whole case. 62 participants in week 2 and 63 participants in week 3 provided valid answers. Table 36 displays the differences in the obtained scores between week 2 and week 3 per participant.

	Week 2		Week 3	
	#	%	#	%
0	11	18%	10	16%
1	43	69%	47	75%
2	8	13%	6	10%
Total	62	100%	63	100%
Weigh. Avg	0.95		0.94	

Table 35: Obtained scores for question 7 in week 2 and week 3

	#	%
-2	0	0%
-1	13	21%
0	36	59%
+1	12	20%
+2	0	0%
	61	100%

Table 36: Differences in the scores between week 2 and week 3 for question 7

7.4.8 Identified Abstractions

Notably, quite some participants did not understand what was meant by this question, therefore many participants did not answer this question; only 44 participants in week 2 and 45 participants in week 3. The scores are displayed in Table 37. Only 36 participants provided a answer in both week 2 and week 3, so the differences between their answers in week 2 and week 3 are displayed in Table 38.

	Week 2		Week 3	
	#	%	#	%
0	16	36%	21	47%
1	23	52%	23	51%
2	5	11%	1	2%
Total	44	100%	45	100%
Weigh. Avg	0.75		0.56	

Table 37: Obtained scores for question 8 in week 2 and week 3

	#	%
-2	0	0%
-1	8	22%
0	26	72%
+1	2	6%
+2	0	0%
	36	100%

Table 38: Differences in the scores between week 2 and week 3 for question 8

7.4.9 Identified Positive Points

Table 39 presents the obtained scores for the answers to question 9. 60 participants and 62 participants provided valid answers in respectively week 2 and week 3. Table 40 shows the difference per participant. 59 participants provided valid answers in both week 2 and week 3.

	Week 2		Week 3	
	#	%	#	%
0	30	50%	34	55%
1	24	40%	27	44%
2	6	10%	1	2%
Total	60	100%	62	100%
Weigh. Avg	0.60		0.47	

Table 39: Obtained scores for question 9 in week 2 and week 3

	#	%
-2	2	3%
-1	15	25%
0	31	53%
+1	11	19%
+2	0	0%
	59	100%

Table 40: Differences in the scores between week 2 and week 3 for question 9

7.4.10 Possible Improvements

Table 41 shows the scores obtained by the participants on question 10. 60 participants provided valid responses in week 2 and 57 participants provided valid responses in week 3. Table 42 shows the differences in the individual scores of the participants. 55 participants provided valid responses in both weeks and were included in this table.

	Week 2		Week 3	
	#	%	#	%
0	15	25%	18	32%
1	43	72%	38	67%
2	2	3%	1	2%
Total	60	100%	57	100%
Weigh. Avg	0.78		0.70	

Table 41: Obtained scores for question 10 in week 2 and week 3

	#	%
-2	0	0%
-1	11	17%
0	37	58%
+1	7	11%
+2	0	0%
	55	100%

Table 42: Differences in the scores between week 2 and week 3 for question 10

7.5 Interpretation

7.5.1 Problem Division

Table 16 shows that 31 participants (48%) used the approach in both weeks. 10 participants (16%) did not divide their model in week 2, but did do this in week 3. Unfortunately, this goes the other way to; 14 participants (22%) only used it in week 2 and did not use the approach anymore in week 3. This means that a total of $31 + 14 = 45$ *participants* divided the problem into smaller problems in week 2 and only $31 + 10 = 41$ *participants* did so in week 3. 9 participants (14%) have used the approach in neither week 2 nor week 3.

The weighted average of the scores on clarification in week 2 was 1.44 (Table 17). In week 3, this was 1.34. The weighted average indicates that participants did not better explain how they did divide their model into smaller parts. Most participants (21 participants, 62%) did not change their score between the two weeks (Table 18). There were some participants that improved their scores between week 2 and week 3 (4 participants improved their score by 1, 1 participant improved their score by 2 points, 15% total). More participants, however, decreased their score. 7 participants (21%) decreased their score by 1; 1 participant decreased the score by 2 points.

We expected to see more (elaborate) answers on how to divide the problem into smaller problems. We did not find evidence to support this. Some individual participants did improve their answers in week 3, but there were more participants that did not improve or even provided worse answers in week 3.

7.5.2 Identified Concepts

Table 19a shows that 85% of participants (50) in week 2 mentioned the frogs as an important element. Only 43 participants (73%) mentioned the princess as an important element. The average number of wrong mentioned elements was 1.31. 40 participants (68%) mentioned both the frogs and the princess, 13 participants (22%) failed to mention one of the elements, only 6 participants (10%) mentioned none of the elements.

In week 3 (Table 19b), 49 participants (80%) mentioned the students and 83 participants (87%) the earbuds as important elements. Participants mentioned, on average, 0.18 wrong elements. 44 participants (72%) mentioned all elements; 14 participants (23%) mentioned one of the elements; 3 participants (5%) mentioned none of the elements.

There is quite a significant drop in the average number of wrongly mentioned elements in week 3. The percentage of participants that mentioned both elements also increased slightly.

As can be seen in Table 20, there is not a big difference between the scores (or the weighted average scores) of both weeks. In week 2, 47% (28 participants) obtained a 0-score, 48% (29 participants) did so in week 3. 27% (16 participants) obtained a score of 1 in week 2, 25% (15 participants) obtained that score in week 3. 25% (15 participants) and 28% (17 participants) of participants in respectively week 2 and week 3 obtained a score of 2. The weighted average of the scores is 0.78 in week 2 and 0.80 in week 3. It is noteworthy that in both weeks about half of the participants fail to (correctly) mention the relationship between the elements.

The individual differences between the scores for the participants is quite large (Table 21). Only 24 participants (43%) obtained the same score in both weeks. 12 participants (21%) obtained one point higher in week 3; 5 participants (9%) scored two points higher in week 3. 18% of participants (10 participants) scored one point lower than in week 2; 5 participants (9%) scored two points lower.

We expected to see more (correct) answers about the most important elements in the case and more elaborate descriptions of the relations between those elements. In total, more participants obtained a higher score in week 3 than participants that obtained a lower score. The difference, however, is not very significant.

7.5.3 Option Exploration

Table 22 shows that the average score decreases from week 2 to week 3 from 0.83 to 0.69. The number of participants that obtained 0 points increased in week 3 (27 participants / 48% versus 18 participants 31%). In week 2 32 participants (%) and 26 participants in week 3 (25%) obtained a 1-score on their answer. Only 8 participants obtained 2 points on their answers in both weeks (14% and 28%).

Most participants did not change their score from week 2 to week 3 (25 participants, 45%) as can be seen in Table 23. For example, there are quite some participants that only mention that they considered a couple of modeling languages in both weeks (some examples in Table 24). In total, 20 participants decreased their score in week 3 (19 participants or 34% decreased their score by 1 and 1 participant or 2% decreased his score by 2). 11 participants (20%) increased their scores by one point (see Table 25 for some examples).

We expected to see more elaborate descriptions and considerations of the examined options. The average score of the answers in week 3 was, however, lower than the average score in week 2. So we did not find any evidence to support this expectation as well.

7.5.4 Model Intention

It is remarkable how many participants could not substantiate why their model is created in the way that it is now (Table 26); 60% in week 2 and 72% in week 3. 21 participants (33%) in week 2 and 17 participants (27%) in week 3 scored 1 point for their answers. Only 4 participants (6%) in week 2 and 1 participant in week 3 (2%) obtained the maximum of two points for their answer. Week 2 totaled an average score of 0.46 and week 3 a score of 0.30.

According to Table 27, along to the many low scores in both week 2 and week 3, many participants did not improve their score between the weeks as well (63%, 40 participants did not change their score), some examples in Table 28. Only 6 participants improved their score (5 participants by 1 point and 1 participant by 2 points), some examples can be seen in Table 29. 16 participants (25%) lowered their score by 1 point in week 3 and 1 participant (2%) lowered the score by 2 points in week 3.

We expected to see more substantiated and reflective answers about what option a participant chose and why they chose that option. The average score of the provided answers, however, decreased in week 3 compared to week 2. This does, thus, not support our expectation.

7.5.5 Model Representation

In week 2 and week 3 respectively, only 4 (7%) and 3 participants (5%) obtained 0 points for their answer on where the elements from question 2 can be found in their model (Table 30). Most participants (29, 49% in week 2 and 41, 65% in week 3) obtained 1 point for their answer. Quite some participants obtained 2 points for their answer; 26 participants (44%) in week 2 and 19 participants (30%) in week 3. The weighted average score decreased from 1.37 in week 2 to 1.25 in week 3.

As can be seen in Table 31, 25 participants (43%) did not improve their answers between week 2 and week 3. 12 participants, however, improved their scores by 1 point in week 3 and 1 participant increased their score by 2 points (some examples in Table 32). There were, however, also quite some participants that decreased their scores (19 participant, 33% by 1 point and 1 participant, 2% by 2 points).

We expected better explanations about how the most important elements are modeled by the participants. The average score for the answers for this question, however, decreased. This does not support our expectation.

7.5.6 Rationale & Model Completeness

As displayed in Table 33, only 4 participants (7%) in week 2 and 6 participants (10%) in week 3 obtained the maximum score of 2 points. Most participants obtained 1 point (40 participants, 69% in week 2 and 44 participants, 70% in week 3). Still quite some participants obtained 0 points for their provided answer; 14 participants (24%) in week 2 and 13 participants (21%) in week 3. The average score increased slightly from 0.83 in week 2 to 0.89 in week 3.

More than half of the participants (54%, 31 participants) did not change their score between week 2 and week 3 (Table 34). 23% of participants (13) improved their score by 1 point; 1 participant (2%) improved his score by 2 points. 12 participants scored 1 point lower on their answer from week 3 than they scored in week 2.

Most participants obtained 1 point for their answer to question 7 both in week 2 and week 3 (Table 35); respectively 43 participants (69%) and 47 participants (75%). Some participants scored 2 points; 8 participants (13%) in week 2 and 6 participants (10%) in week 3. Also, some participants obtained 0 points for their proved answers; 11 participants (18%) in week 2 and 10 participants (16%) in week 3. The average score only changed slightly from a 0.95 in week 2 to a 0.94 in week 3.

More than half (59%, 36 participants) of the participants did not change their score (Table 36). 13 participants scored 1 point less for their answer in week 3 than they did in week 2. 20% (12 participants) scored 1 point higher in week 3.

We expected a more thorough and critical analysis of the obtained solution and why this is the correct solution for the situation. We did not observe substantial differences in the answers that were provided in week 3, compared to the answers provided in week 2 per individuals. Participants that were incomplete and curt in week 2, did not change much in week 3. The average score in week 2 and week 3 is quite comparable.

7.5.7 Identified Abstractions

Table 37 shows us that around half of the participants (52% in week 2 and 51% in week 3) scored 1 point for the answer to this question. In week 2, 5 participants (11%) obtained 2 points for their answers. In week 3, only 1 participant (2%) obtained this score. 16 participants (36%) in week 2 and 21 participants (47%) in week 3 scored 0 points for the answers to this question. The average score of the answers also dropped quite substantially from 0.75 to a 0.56.

26 participants (72%) did not increase nor decrease their score from week 2 to week 3, as can be seen in Table 38. Only 2 participants (6%) increased their score by 1 point in week 3. 22% (8 participants) decreases their score by 1 point in week 3.

We expected to see better insights into the abstractions that were introduced in the model. We did, however, find that many participants did not understand this questions. The answers that were provided to this question, resulted in a lower average score in week 3 than in week 2. This does not support our expectations.

7.5.8 Identified Positive Points & Possible Improvements

Table 39 shows that in both week 2 and week 3, most participants obtained 0 points for their answer to question 9 (50% in week 2 and 55% in week 3). Only 6 participants (10%) in week 2 and 1 participant (2%) in week 3 obtained 2 points. 40% of the participants in week 2 (24) and 44% in week 3 (27) obtained 1 point. The average score for question 9 in week 2 was 0.60 and dropped to 0.47 in week 3.

2 participants (3%) obtained a 2 point lower score in week 3 than they did in week 2 (Table 40). 15 participants (23%) lowered their score by 1 point. Most participants did not change their score (31 participants, 48%). Only 11 participants (19%) improved their score by 1 point.

In both weeks, most participants have obtained 1 point for question 10 (72% in week 2 and 67% in week 3). Only 2 participants (3%) in week 2 and 1 participant (2%) in week 3 obtained the maximum of 2 points for their answer. 15 participants (25%) in week 2 and 18 participants (32%) in week 3 obtained 0 points for their answer. The average of 0.78 points in week 2 dropped to 0.70 in week 3.

58% of participants (37 participants) did not change their score from week 2 to week 3. Only 7 participants (11%) increased their score by 1 point. 11 participants decreased their scores by 1 point (17%).

We expected to see a more thorough analysis of the obtained solution. We did, however, not find this in our data. The average score for both questions dropped quite a bit.

7.6 Conclusions

We can conclude several things from this research. First, let us answer the subquestion that was answered in this chapter.

> **SQ8:** *Does the presented Treatment show signs that it helps novice designers think critically about their process models?*

We did not find overall signs that the Reflective Modeling Cycle helped novice designers think more critically about their process model. The average score for almost all questions was lower when the Reflective Modeling Cycle was used.

Although, we did find some individual improvements between week 2 and week 3, which might be attributed to the use of the Reflective Modeling Cycle, this cannot be proved by the results presented in this research.

We can conclude some other things from this research as well:

- There are also quite a lot of respondents that did not improve their answers at all. This could either be because they did not have enough motivation to answer the questions seriously, or because the Reflective Modeling Cycle did not work for them.
- The differences between participants are quite big. Most participants that answer very curt in week 2 are also very likely to answer curt in week 3. Participants that answer very elaborately, however, in week 2 are also very likely to answer elaborately in week 3. Moreover, if a certain participant answers a certain question curt, they are also likely to answer other questions curt; and the other way around.
- We suspect that the two used exercises are not of the same complexity level, contrary to what we thought in advance (the exercise in week 3 was more difficult than the exercise in week 2).

8 Conclusions and Further Research

This chapter provides the answers to the research questions by summarizing all results from the previous chapters and provides some suggestions for future research.

8.1 Answers to research question

This thesis presented a problem in process modeling. Novice designers find it difficult to create process models from a case text. Furthermore, novice designers cannot explain themselves when asked why they chose a certain modeling construction in favor of another. They do not think critically about their decisions.

We have followed the *Design Science* approach and determined the following aims and objectives for the research:

> *This thesis aims to improve* critical thinking skills of novice designers in process modeling *by* designing and testing a modeling tool, called the Reflective Modeling Cycle (Treatment) *that* helps novice designers to structurally think more critically about their created models *in order to* improve the overall quality of the created models.

From these aims and objectives, the following research question followed:

> **RQ1:** *How can the critical thinking skills of novice designers be improved in process modeling?*

8.1.1 Literature Research

We began this thesis with literature research, in order to answer subquestions SQ1 to SQ4.

> **SQ1:** *What is meant by critical thinking in the context of Education?*

We have found that critical thinking is a skill that should be taught in education. We have found different definitions for Critical Thinking that all have a slightly different emphasis. Critical thinking involves *constructing a situation and supporting the reasoning that went into a conclusion* (Jones et al., 1997). Learning to think critically is learning to be *skeptical at the right moments* (McPeck, 2016), so that it *improves the desired outcome* (Halpern, 2013) and *knowing what sort of questions should be asked* (Ennis, 1985). Learning to think critically in subject X does not necessarily mean that one can think critically in subject Y.

Reflective Thinking is not the same as Critical Thinking. It is the process of analyzing and making judgments about past decisions (Dewey, 1933).

> **SQ2:** *What are abilities one should have to think critically?*

Ennis (1985) provides us with a list of goals for critical thinking in terms of abilities and dispositions. This list is mainly focused on societal issues.

- Important abilities include: focusing on a question, analyzing arguments and asking and answering questions or clarifications.
- Some important dispositions from his list are: seek a clear statement of the question, seek a reason, try to be well-informed, take into account the whole situation, try to remain relevant to the main point, look for alternatives, be open minded, take a position and change that position when the reasons are sufficient to do so and deal in an orderly manner with the parts of a complex whole.

> **SQ3:** *What are current frameworks to solve problems, like modeling?*

There is a framework by Pólya (1945) on problem-solving. This framework mainly involves mathematical and logical problem-solving. The framework consists of four main steps: Understanding the Problem, Devising a Plan, Carrying Out the Plan and Looking Back.

SQ4: *How can a tool contribute to the critical thinking skills of novice designers?*

Cognitive load theory (Sweller, 1988, 2010) provides an explanation for the taxing of the brain during learning activities by defining three types of cognitive load: intrinsic cognitive load, germane cognitive load and extraneous cognitive load.

Germane cognitive load can be influenced by changing or adapting teaching methods. A tool can thus contribute to the critical thinking skills of novice designers by changing the germane cognitive load.

8.1.2 Quantitative User Experiment

The Reflective Modeling Cycle was also tested for perceived usefulness and usability in a quantitative research.

SQ5: *Do novice designers think that the Treatment helps them think more critically about their model?*

The perceived usefulness of the Reflective Modeling Cycle is quite contradictory. However, we did find evidence indicating that novice designers think the Treatment helps them think more critically about their model.

We have found signs that the Reflective Modeling Cycle reduces cognitive load for novice designers, which would mean that the Reflective Modeling Cycle has added value in learning process modeling.

SQ8: *Do novice designers think that the Treatment is user friendly?*

We can conclude that novice designers think that the Treatment is user friendly. We do, however, recommend a more elaborate introduction of the cycle, with an example.

The research also showed signs that the Reflective Modeling Cycle works best on more complex cases, rather than the small cases we have used in this research. Furthermore, the cycle should never replace any other teaching forms and only assists with practising process modeling.

SQ7: *Would novice designers recommend the presented Treatment to other novice designers?*

We have calculated a Net Promoter Score of 13. We can therefore assume that novice designers recommend the Reflective Modeling Cycle to other novice designers.

8.1.3 Exploratory Controlled Experiment

In the exploratory research into the effectiveness of the cycle, the following sub-question was answered using an ATA experiment:

SQ8: *Does the presented Treatment show signs that it helps novice designers think critically about their process models?*

We did not find overall signs that the Reflective Modeling Cycle helped novice designers think more critically about their process model. The average score for almost all questions was lower when the Reflective Modeling Cycle was used.

Although, we did find some individual improvements between week 2 and week 3, which might be attributed to the use of the Reflective Modeling Cycle, this cannot be proved by the results presented in this research.

8.1.4 Answer to Research Question

We can now answer our main research question:

RQ1: *How can the critical thinking skills of novice designers be improved in process modeling?*

The Reflective Modeling Cycle looks promising to improve the critical thinking skills of novice designers in process modeling. It is largely supported by literature on critical thinking skills, problem solving and cognitive load. In our quantitative user experiment, we have shown that there are signs that novice designers perceive usefulness from the Reflective Modeling Cycle. We have, furthermore, shown that the Reflective Modeling Cycle is user friendly and that novice designers would recommend the Reflective Modeling Cycle to other novice designers. We have not yet shown the effectiveness of the Reflective Modeling Cycle.

8.2 Suggestions for Future Research

There are quite some suggestions for future research. There are still some questions left after the research into the effectiveness and perceived usefulness of the Reflective Modeling Cycle. Furthermore, during the process of writing this thesis, we have thought of other interesting research ideas to further test the Reflective Modeling Cycle.

- Does the Reflective Modeling Cycle show signs that it is effective on the longer-term?

  In this thesis, we have conducted an exploratory research to search for signs that the Reflective Modeling Cycle might help novice designers think more critically about their process models. We have not found these signs. We suspect that we have not found these signs, because the Reflective Modeling Cycle will work best on the longer term. Novice designers should learn how to work with the cycle.

  This could be researched by comparing two (large) groups during a course-module, where one group will use the Reflective Modeling Cycle and the other group will not use the cycle. This does, however, provide some ethical issues.

- Is the perceived usefulness of the Reflective Modeling Cycle bigger with more complex cases than with the small cases we have used in this research?

  During the process of creating this thesis, we have wondered if the (perceived) usefulness and effectiveness of the Reflective Modeling Cycle is more apparent for larger cases than for small cases. Some participants in the research also made this remark.

  We could test this by comparing the results (the quality of the models and the perceived usefulness) of larger case text against the results of a smaller case text.

- Does the Reflective Modeling Cycle actually help with learning to think critically about models?

  In this research, we did not find an definitive answer on the effectiveness of the Reflective Modeling Cycle. We did find evidence that suggests that the Reflective Modeling Cycle might help learning critical thinking skills on models. But to be sure about this further long-term research, with a larger test group, is necessary.

- Does it also help novice designers create better models?

  We suspect that when novice designers think more critically about their models, that the quality of their models also improves. We did, however, not research that in this thesis.

A research could be conducted that compares (in-depth) models of novice designers that did not use the Reflective Modeling Cycle and those of novice designers that did use the Reflective Modeling Cycle.

- What could be improved in the cycle? Should certain wordings be altered? Are the questions, the right questions to ask?

  The contents of the Reflective Modeling Cycle is, mainly, based on existing research. We did not, however, test the cycle with novice designers before conducting this research. We have, therefore, not elaborately tested if the current wording of the cycle is the best wording to convey the message of the Reflective Modeling Cycle.

  In-depth interviews with novice designers that have used the Reflective Modeling Cycle or think-aloud research might help to find bottlenecks in the current wording and questions of the Reflective Modeling Cycle.

  Furthermore, a think-aloud experiment with expert-designers could be carried out. The steps that these experts take should be monitored and could be used as an inspiration for the Reflective Modeling Cycle.

- Should the cycle be introduced better to novice designers?

  We found some evidence indicating that the cycle should be better introduced (with an example). We suspect that a better introduction would never hurt the (perceived) usefulness of the Reflective Modeling Cycle, but we do not know how big of an impact that introduction would have and what a “good” introduction is.

- Does the Reflective Modeling Cycle only assist with process modeling? Or are other modeling activities (for example data modeling) also positively influenced by it?

  We have, purposely, designed the Reflective Modeling Cycle to not be specific to any one modeling language. We do think that it best fits process modeling; but the cycle is quite generic, so one might wonder if it would also be effective on other modeling activities.

  This could be researched by conducting a similar research to this one with, for example, data modeling.

- Why did participants not feel more confident using the Reflective Modeling Cycle?

  We would expect that the usage of the Reflective Modeling Cycle would improve the confidence of its users. In this research we did not find evidence to support that. We suspect that this might be because of the large number of questions that makes users doubt their choices.

  This could be further researched by having in-depth interview with novice designers that have used the Reflective Modeling Cycle or using a think-aloud type of research that would follow the steps novice designers take using the cycle.

Modeling requires a critical mindset. Tools like the Reflective Modeling Cycle, presented in this thesis, show promising results in teaching novice designers critical-thinking skills. As this thesis highlights, more research is required to understand the critical mindset needed for the art of modeling and shape future generations of modelers.

A The Reflective Modeling Cycle

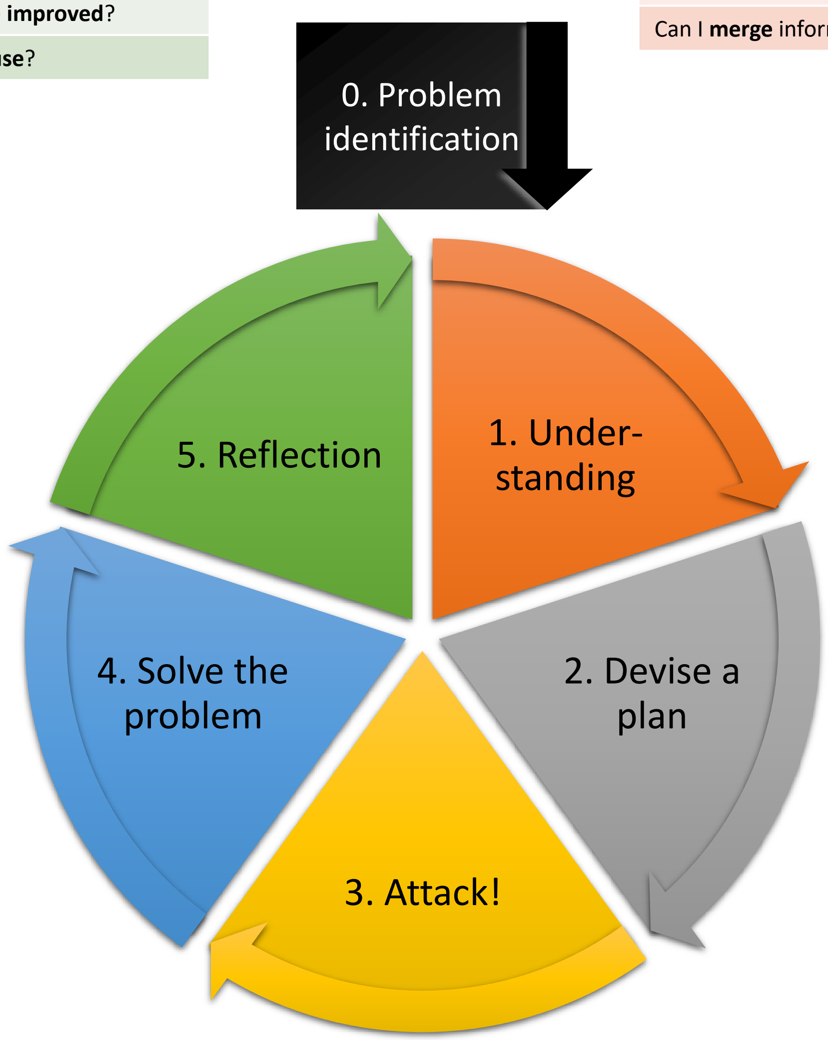
Modeling Cycle

More extensive questions and more information are provided on the other side

5. Reflection
Could I model the problem **differently**?
Which **abstractions** have I used?
What are **good aspects**?
What could be **improved**?
What can I **reuse**?

0. Problem identification
What is the **problem**?
Which **quotaions** should I answer in order to solve the problem?
How can I **divide** the problem?

1. Understanding
What **information** do I need?
What are the **main concepts**?
Which **relations** are important?
Can I **omit** information?
Can I **merge** information?



4. Solve the problem
Is the solution **correct**?
Does it describe the situation **sufficiently**?
Does it **solve** the **questions**?

3. Attack!
Have I **used** all information
Do is satisify all **conditions**?
Can I **simplify** my model?
Am I **satisfied**?

2. Devise a plan
What are the **pitfalls**?
What are possible **options**?
Is the chosen option **sufficient**?

Modeling Cycle

A schematic view is presented on the other side of this paper.

0 Problem identification

- What is the **problem**?
- Which **questions** should I answer in order to solve the problem?
- Which **conditions** are there?

- Can I **divide** the problem into smaller parts?
  > What is the **relation** between the parts?
  > How are the parts mutually **dependent**?

1 Understanding

- **How** does this part fit in the bigger picture?
- **What information** do I need to model this part?
- What are the properties the model needs to satisfy to be **correct**?

- What are the **main concepts**?
- Can I define all concepts in my own words?
- What is the **relation** between the concepts?
  > What are their **dependencies**?
  > Does the relation imply an **order**?
  > What is the **intention** of the relation?
  > Can I rephrase the questions with these concepts?
  > How can I represent this in my model?

- Do I have sufficient information to answer the questions?
  > Can I **omit** information?
  > Can I **merge** information?

2 Devise a plan

- Which **modeling language** am I going to use?
  > How does it help solve the problem?
  > What are **advantages** in solving this case?
  > What are **disadvantages** in solving this case?
  > Which language do I choose, and why?

- How does the part **fit** into the current model?

- What are possible **pitfalls**?
- What are the **options** to model this part?
  > What are the **advantages** of this option?
  > What are the **disadvantages** of this option?
  > Which option do I choose, and why?

- Does the chosen option cover the part **sufficiently**?

3 Attack!

- Create the chosen option.
- How do I merge this part into the model?
  > When is the merger **correct**?

- Did I satisfy all **conditions**?

- Is all given information in my model?
  > Are all of the **main concepts** present?
  > Are all the **relations** represented?
- Did I model this part sufficiently?

- Can I **simplify** the model without losing information?
  > Should I add elements?
  > Can I leave out elements?

- Am I **satisfied** with the model? Why?

4 Solve the Problem

- Can I **answer the questions** with this model?
- Can I phrase the answer using **main concepts**?
- What is the **solution** to the problem?
- Does my solution solve the problem? Why?

5 Reflection

- Could I model the problem **differently**?
- Did I **divide** the model in a correct manner?
- Which **abstractions** did I use? Why?
- What are **good aspect** of my model?
- What could be **improved** in my model?
- What can I **reuse** for a next time?

B The Reflective Modeling Cycle (Dutch)

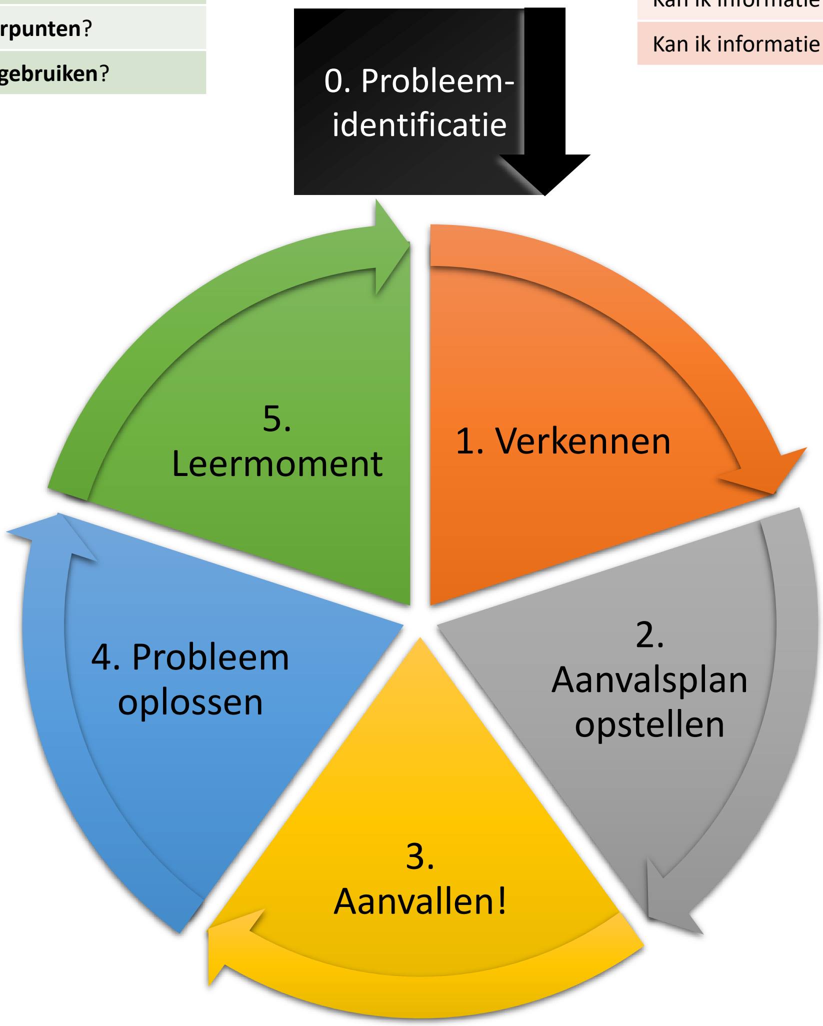
Modelleer Cyclus

Voor uitgebreidere vragen en meer informatie kijk op de andere kant.

5. Leermoment
Kan ik het probleem **anders** modelleren?
Welke **abstracties** heb ik gebruikt?
Wat zijn de **goede aspecten**?
Zijn er **verbeterpunten**?
Wat kan ik **hergebruiken**?

0. Probleemidentificatie
Wat is het **probleem**?
Welke **vragen** moeten beantwoord worden?
Hoe kan ik het probleem **opsplitsen**?

1. Verkennen
Welke **informatie** heb ik nodig?
Welke **kernbegrippen** zijn van belang?
Welke **relaties** zijn van belang?
Kan ik informatie **weglaten**?
Kan ik informatie **samenvoegen**?



4. Probleem oplossen
Is de oplossing **correct**?
Beschrijft het de situatie **voldoende**?
Beantwoordt het de **vragen**?

3. Aanvallen!
Heb ik alle informatie **gebruikt**?
Voldoe ik aan de **voorwaarden**?
Kan ik mijn model **versimpelen**?
Ben ik **tevreden**?

2. Aanvalsplan opstellen
Wat zijn **valkuilen**?
Wat zijn mogelijke **opties**?
Is de gekozen optie **voldoende**?

Modelleer Cyclus

Voor een schematische weergave kijk op de andere kant.

0 Probleemidentificatie

- Wat is het **probleem**?
- Welke **vragen** moet ik beantwoorden om het probleem op te lossen?
- Welke **voorwaarden** zijn er?

- Kan ik het probleem in delen **opsplitsen**?
  - > Wat is de **relatie** tussen de delen?
  - > Hoe zijn ze van elkaar **afhankelijk**?

1 Verkennen

- **Hoe** past het deel in het grote geheel?
- **Welke informatie** heb ik nodig om dit deel te modelleren?
- Waaraan moet het model voor dit deel voldoen om **correct** te zijn?

- Welke **kernbegrippen** zijn van belang?
- Kan ik een definitie geven van ieder begrip?
- Wat is de **relatie** tussen de begrippen?
  - > Hoe zijn ze van elkaar **afhankelijk**?
  - > Geeft de relatie een **volgorde** aan?
  - > Geeft de relatie een **betekenis** aan?
  - > Kan ik de vragen uitdrukken met deze begrippen?
  - > Hoe geef ik dit weer in mijn model?

- Heb ik voldoende informatie om de vragen te beantwoorden?
  - > Kan ik informatie **weglaten**?
  - > Kan ik informatie **samenvoegen**?

2 Aanvalsplan opstellen

- Welke **modelleertaal** ga ik gebruiken?
  - > Hoe kan ik de taal gebruiken om het probleem op te lossen?
  - > Wat zijn **voordelen** voor dit probleem?
  - > Wat zijn **nadelen** voor dit probleem?
  - > Welke taal kies ik en waarom?

- Hoe **past** het deel in het huidige model?

- Wat zijn mogelijke **valkuilen**?
- Wat zijn de verschillende **opties** om het deel te modelleren?
  - > Wat zijn de **voordelen** van de optie?
  - > Wat zijn de **nadelen** van de optie?
  - > Welke optie kies ik en waarom?

- Is de gekozen optie **voldoende**?

3 Aanvallen!

- Werk de gekozen optie in het model uit.
- Hoe voeg ik dit deel toe?
  - > Wanneer is de samenvoeging **correct**?

- Heb ik aan alle **voorwaarden** voldaan?

- Zit alle informatie in het model?
  - > Komen alle **kernbegrippen** terug?
  - > Komen alle **relaties** tot hun recht?
- Heb ik het deel voldoende gemodelleerd?

- Kan ik het model **versimpelen** zonder informatie te verliezen?
  - > Moet ik elementen toevoegen?
  - > Kan ik elementen weglaten?

- Ben ik **tevreden** met dit model? Waarom?

4 Probleem oplossen

- Kan ik met het model de **vragen beantwoorden**?
- Kan ik deze uitdrukken in de **kernbegrippen**?
- Wat is de **oplossing** voor het probleem?
- Lost mijn oplossing het probleem op? Waarom?

5 Leermoment

- Kan ik het probleem ook op een **andere manier** modelleren?
- Heb ik het model goed **opgesplitst**?
- Welke **abstracties** heb ik gebruikt? Waarom?
- Wat zijn **goede aspecten** in mijn model?
- Zijn er **verbeterpunten** aan mijn model?
- Wat kan ik **hergebruiken** voor een volgend moment?

C The Princess and the Frog (Dutch)

Vanaf een brug springen eeuwig levende kikkers in een vijver. Zij kiezen willekeurig n van de twee kanten uit om naartoe te zwemmen, waarna ze weer teruggaan naar de brug om het opnieuw te doen.

Een prinses op zoek naar de ware pakt iedere derde kikker die de brug op klimt en kust deze in de hoop dat dit de ware partner is en zet de kikker teleurgesteld terug op de brug.

Modelleer dit sprookje. Stel je voor dat er vijf kikkers op de brug zitten. Wat gebeurt er in je model? Hoe werkt je model met maar twee kikkers of vier kikkers? Kan in je model uiteindelijk iedere kikker een keer gekust worden door de prinses?

D The Ceaseless Studying Students (Dutch)

Een groep van vijf studenten besluit om voor eeuwig te studeren aan een grote ronde tafel. Tussen elke twee studenten ligt er n oordopje. Omdat het een ronde tafel is, zijn er evenveel oordopjes als studenten. Elke student drinkt of studeert afwisselend. Een student kan echter alleen studeren als hij in zijn linker- en rechteroor een oordopje heeft. Als hij wilt studeren pakt hij het oordopje links van hem en het oordopje rechts van hem, stopt ze in zijn oren en gaat studeren. Wanneer de student klaar is met studeren, legt hij de beide oortjes terug op de tafel en gaat weer drinken. Je kunt ervan uitgaan dat de studenten ongelimiteerd kunnen leren en drinken. Er is genoeg geld en drank om voor altijd te kunnen studeren.

Natuurlijk kan het niet zo zijn dat een student alleen maar drinkt, hij moet af en toe ook studeren.

Modelleer dit probleem. Toon aan dat elke student uiteindelijk altijd een mogelijkheid heeft om te studeren.

E Questionnaire about the Reflective Modeling Cycle

During the experiment you have used the "Reflective Modeling Cycle". This questionnaire contains questions about this document. We would like to know how you have used the model and if you found it helpful during the modeling.

Your model or the answers you provide in this questionnaire are of no influence to your grade for the course Information Systems.

	Completely agree → ← Completely disagree
1. I think the Reflective Modeling Cycle adds value next to the existing lectures and modeling sessions	☐ ☐ ☐ ☐ ☐
2. I think I will keep using the Reflective Modeling Cycle during practice	☐ ☐ ☐ ☐ ☐
3. I thought the Reflective Modeling Cycle was unnecessarily complex	☐ ☐ ☐ ☐ ☐
4. I thought the Reflective Modeling Cycle was easy to use	☐ ☐ ☐ ☐ ☐
5. I could use the Reflective Modeling Cycle without any further explanation	☐ ☐ ☐ ☐ ☐
6. I understood the order of the Reflective Modeling Cycle	☐ ☐ ☐ ☐ ☐
7. I thought the Reflective Modeling Cycle was inconsistent	☐ ☐ ☐ ☐ ☐
8. I think others will also quickly learn to use the Reflective Modeling Cycle	☐ ☐ ☐ ☐ ☐
9. I felt annoyed using the Reflective Modeling Cycle	☐ ☐ ☐ ☐ ☐
10. While modeling, I felt more confident about my choices because of the Reflective Modeling Cycle	☐ ☐ ☐ ☐ ☐
11. I think my model is better than if I had not used the Reflective Modeling Cycle.	☐ ☐ ☐ ☐ ☐
	Extremely likely → ← Extremely unlikely
12. How likely is it that you would recommend using the Reflective Modeling Cycle to fellow students?	☐ ☐ ☐ ☐ ☐

13. Do you have any further remarks about the Reflective Modeling Cycle?

____

____

F Questionnaire about The Reflective Modeling Cycle (Dutch)

Tijdens het experiment heb je het document “Reflectieve Modelleer Cyclus” gebruikt. Deze vragenlijst bevat vragen over dit document. We willen graag weten hoe jij met het model hebt gewerkt en of je er wat aan hebt gehad tijdens het modelleren.

Jouw model of de antwoorden op deze vragen hebben natuurlijk geen consequenties voor het vak Informatiesystemen.

	← Helemaal oneens / Helemaal eens →				
1. Ik denk dat het Reflectieve Modelleerproces toegevoegde waarde heeft, naast de bestaande colleges en modelleersessies	☐	☐	☐	☐	☐
2. Ik denk dat ik het Reflectieve Modelleerproces blijf gebruiken tijdens het oefenen	☐	☐	☐	☐	☐
3. Ik vond het Reflectieve Modelleerproces onnodig ingewikkeld	☐	☐	☐	☐	☐
4. Ik vond het Reflectieve Modelleerproces makkelijk te gebruiken	☐	☐	☐	☐	☐
5. Ik kon het Reflectieve Modelleerproces zonder uitleg gebruiken	☐	☐	☐	☐	☐
6. Ik snapte de volgorde van vragen in het Reflectieve Modelleerproces	☐	☐	☐	☐	☐
7. Ik vond het Reflectieve Modelleerproces inconsistent	☐	☐	☐	☐	☐
8. Ik denk dat anderen het Reflectieve Modelleerproces ook snel leren te gebruiken	☐	☐	☐	☐	☐
9. Ik vond het hinderlijk om Modelleerproces te gebruiken	☐	☐	☐	☐	☐
10. Ik voelde me tijdens het modelleren zekerder over mijn keuzes door het Reflectieve Modelleerproces	☐	☐	☐	☐	☐
11. Ik denk dat mijn model beter is geworden door het Reflectieve Modelleerproces te gebruiken	☐	☐	☐	☐	☐
	← Zeer onwaarschijnlijk / Zeer waarschijnlijk →				
12. Hoe waarschijnlijk is het dat je het gebruik van het Reflectieve Modelleerproces zou aanraden aan andere studenten?	☐	☐	☐	☐	☐

13. Heb je verder nog opmerkingen over het Reflectieve Modelleerproces?

____

____

G Questionnaire about the model in week 2

This questionnaire is about your model.

Your model or the answers you provide in this questionnaire are of no influence to your grade for the course Information Systems.

1. A typical approach is divide & conquer. With this approach, you divide the case into smaller sub-cases, which you solve separately and merge when you are done. Could you explain briefly if and how you used this technique? If not, could you explain briefly the approach you have used?

2. What are the most important elements in the case and how are they related?

3. During the modeling, you have probably tried or thought about multiple options. Which options did you consider for your model?

4. Why did you create your model in the way it is now?

5. How and where can the elements from question 2 be found in your model?

6. What is the reasoning behind the model? Why do you think that your model is a correct model for the situation?

7. Does your model describe the entire situation? Explain.

8. Which abstraction did you use in your model?

9. What are the good aspects in your model?

10. What would you improve in your model?

11. How did you model the frogs in your model?

12. How did you model the princess in your model?

13. What would you have to change in your model if there aren't 3, but 5 frogs?

14. Do you have any remarks about this assignment?

H Questionnaire about the model in week 2 (Dutch)

Deze vragenlijst gaat over je model.

Jouw model of de antwoorden op deze vragen hebben natuurlijk geen consequenties voor het vak Informatiesystemen.

1. Een typische aanpak is divide & conquer. Hiermee knip je de situatie in kleinere deelproblemen die je afzonderlijk oplost en daarna samenvoegt. Kun je kort uitleggen of en hoe jij deze aanpak hebt gebruikt? Zo niet, kun je kort jouw aanpak beschrijven?

2. Wat zijn de belangrijkste elementen in deze situatie, en hoe zijn deze aan elkaar gerelateerd?

3. Waarschijnlijk heb je tijdens het modelleren meerdere opties geprobeerd of over nagedacht. Welke opties heb je overwogen voor jouw model?

4. Waarom heb je ervoor gekozen om je model te maken zoals het nu is?

5. Hoe komen de elementen uit vraag 2 terug in jouw model?

6. Wat is de redenering achter het model? Waarom denk je dat jouw model de situatie goed modelleert?

7. Beschrijft jouw oplossing de gehele situatie? Leg uit.

8. Welke abstracties heb je gebruikt in jouw model?

9. Wat zijn goede aspecten van jouw model?

10. Wat zou je nog willen verbeteren aan jouw model?

11. Hoe heb je in jouw model de kikkers gemodelleerd?

12. Hoe heb je in jouw model de prinses gemodelleerd?

13. Wat zou je aan jouw model moeten veranderen als er niet 3, maar 5 kikkers zijn?

14. Heb je opmerkingen over deze opdracht?

I Questionnaire about the model in week 3

This questionnaire is about your model.

Your model or the answers you provide in this questionnaire are of no influence to your grade for the course Information Systems.

1. A typical approach is divide & conquer. With this approach, you divide the case into smaller sub-cases, which you solve separately and merge when you are done. Could you explain briefly if and how you used this technique? If not, could you explain briefly the approach you have used?

2. What are the most important elements in the case and how are they related?

3. During the modeling, you have probably tried or thought about multiple options. Which options did you consider for your model?

4. Why did you create your model in the way it is now?

5. How and where can the elements from question 2 be found in your model?

6. What is the reasoning behind the model? Why do you think that your model is a correct model for the situation?

7. Does your model describe the entire situation? Explain.

8. Which abstraction did you use in your model?

9. What are the good aspects in your model?

10. What would you improve in your model?

11. How are students represented in your model?

12. How are the earplugs represented in your model?

13. How does your model show that every student is eventually always able to study?

14. Do you have any remarks about this assignment?

J Questionnaire about the model in week 3 (Dutch)

Deze vragenlijst gaat over je model.

Jouw model of de antwoorden op deze vragen hebben natuurlijk geen consequenties voor het vak Informatiesystemen.

1. Een typische aanpak is divide & conquer. Hiermee knip je de situatie in kleinere deelproblemen die je afzonderlijk oplost en daarna samenvoegt. Kun je kort uitleggen of en hoe jij deze aanpak hebt gebruikt? Zo niet, kun je kort jouw aanpak beschrijven?

2. Wat zijn de belangrijkste elementen in deze situatie, en hoe zijn deze aan elkaar gerelateerd?

3. Waarschijnlijk heb je tijdens het modelleren meerdere opties geprobeerd of over nagedacht. Welke opties heb je overwogen voor jouw model?

4. Waarom heb je ervoor gekozen om je model te maken zoals het nu is?

5. Hoe komen de elementen uit vraag 2 terug in jouw model?

6. Wat is de redenering achter het model? Waarom denk je dat jouw model de situatie goed modelleert?

7. Beschrijft jouw oplossing de gehele situatie? Leg uit.

8. Welke abstracties heb je gebruikt in jouw model?

9. Wat zijn goede aspecten van jouw model?

10. Wat zou je nog willen verbeteren aan jouw model?

11. Hoe worden studenten gerepresenteerd in jouw model?

12. Hoe worden in jouw model de oordopjes gerepresenteerd?

13. Hoe toont jouw model aan dat elke student uiteindelijk altijd een mogelijkheid heeft om te studeren?

14. Heb je opmerkingen over deze opdracht?

K Consent Form

Consent form for participation in research

Research Team

Lead researcher:	Jan Martijn van der Werf (j.m.e.m.vanderwerf@uu.nl)
Involved researcher:	Mitchell Klijs (m.klijs@uu.nl)

Description of the research

In this research we focus on gaining insight and improving the modeling process and modeling education. For this we ask you to develop a model of a given situation and to answer a few questions about it.

Consent

- I have read this document and the research has been explained to me. I have been able to ask questions and my questions have been answered. I have been told who to contact if I have more questions.
- I understand that I can stop participating in this study at any time
- I understand that the results of this research are not used in any way to determine the rating for Information Systems.
- I agree that my models will be used in this research, and can only be shared anonymously with other researchers within the main investigator's research group, and can be shared anonymously in public.

Furthermore:

- All personal information that can identify you as a person will be deleted before data from this study is shared with other researchers or made public.
- The principal investigator retains a connection that connects you to your anonymized data, but this is kept securely and is only available to the aforementioned researchers. All information or documents that contain your identity will be treated confidentially.
- The information from this research is only used in ways that cannot be traced to you. You are not identified in publications related to this research or in data that is shared with other researchers. Your participation in this study is confidential.
- By answering yes here, I agree to participate in the research described above.

Answer:

Yes ☐ No ☐

L Consent Form (Dutch)

Toestemmingsformulier voor deelname aan onderzoek

Onderzoeksteam

Hoofdonderzoeker:	Jan Martijn van der Werf (j.m.e.m.vanderwerf@uu.nl)
Betrokken onderzoeker:	Mitchell Klijs (m.klijs@uu.nl)

Omschrijving van het onderzoek

In dit onderzoek richten we ons op het inzichtelijk krijgen en het verbeteren van het modelleerproces en modelleeronderwijs. Hiervoor vragen we je om van een gegeven situatie een model te ontwikkelen en hier een aantal vragen over te beantwoorden.

Toestemming

- Ik heb dit document gelezen en het onderzoek is aan mij uitgelegd. Ik heb vragen kunnen stellen en mijn vragen zijn beantwoord. Er is mij verteld met wie ik contact kan opnemen als ik nog meer vragen heb.
- Ik begrijp dat ik op elk moment kan stoppen met de deelname aan dit onderzoek
- Ik begrijp dat de resultaten voor dit onderzoek op geen enkele manier gebruikt worden om het cijfer voor Informatiesystemen te bepalen.
- Ik ga ermee akoord dat mijn modellen gebruikt worden bij dit onderzoek, en alleen anoniem gedeeld kunnen worden met andere onderzoekers binnen de onderzoeksgroep van de hoofdonderzoeker, en geanonimiseerd openbaar gedeeld kunnen worden.

Verder:

- Alle persoonlijke informatie die jou als persoon kan identificeren zal worden verwijderd, voordat data uit dit onderzoek gedeeld wordt met andere onderzoekers of openbaar worden gemaakt.
- De hoofdonderzoeker behoudt een verbinding die jou aan jouw geanonimiseerde gegevens verbindt, maar deze wordt veilig bewaard en is alleen beschikbaar voor de hierboven genoemde onderzoekers. Alle informatie of documenten die jouw identiteit bevatten zullen vertrouwelijk behandeld worden.
- De informatie uit dit onderzoek wordt alleen gebruikt op manieren die niet naar jou te traceren zijn. Je wordt niet gedentificeerd in publicaties gerelateerd aan dit onderzoek of in data die wordt gedeeld met andere onderzoekers. Jouw deelname aan dit onderzoek is vertrouwelijk.
- Door hier met ja te antwoorden, ga ik akkoord mee te doen aan het onderzoek zoals hierboven beschreven.

Antwoord:

Ja ☐ Nee ☐

M Raw Data (Perceived Usefulness and Usability)

This appendix is a digital appendix, called `raw_data_evaluation.xlsx`. The headers are in Dutch, because (almost) all data, provided by the participants, is also in Dutch.

The first row of the Excel file contains the headers for the data. All questions are in row 1. The first column contains the participantID that is used in this thesis.

N Raw Data (Effectiveness)

This appendix is a digital appendix, called `raw_data_effectiveness.xlsx`. The headers are in Dutch, because (almost) all data, provided by the participants, is also in Dutch.

The first two rows of the Excel file contains the headers for the data. All questions are in row 1. If a question was asked in both week 2 and week 3, row 2 contains the week-number. The first column contains the participantID that is used in this thesis.

O Analysis Perceived Usefulness and Usability

This appendix is a digital appendix, called `analysis_evaluation_r_studio_project.zip`. The ZIP-file contains an R Studio project.

The R project contains a `data.xlsx` file with, on separate tabs, the data ordered per category.

On line `5`, the sheet number can be specified (numbered from 1). On line `6`, the title of the plot can be specified. Lines `7` and `8` can be commented out depending on the question. Line `10` reads the data from the correct sheet in the Excel file. Line `12` stores the correct labels (to later restore them). Line `14` filters out any unanswered (*Onbeantwoord*) items. Line `16` converts the data into factors. Line `18` restores the, earlier stored, labels. And finally, line `20` plots the plot.

P Analysis Effectiveness

This appendix is a digital appendix, called `analysis_effectiveness.xlsx`. The ZIP-file contains the data (from Appendix N) and several columns to calculate the data presented in this thesis.

List of Figures

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