UNIVERSITEIT TWENTE.

Research Proposal

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Contents

Preface

In this document the reader can find a proposal for designing a course on quantum mechanics in a qCraft learning environment. This is an assignment executed for a bachelor thesis. The document contains a table with general information, a short summary of the assignment, a detailed description of the assignment, the design approach and a planning. The general information section contains a table with data about the context of the assignment. The summary provides a short description of the product. The detailed description contains background information, information about the content of the instruction, a description of the technology used for the instruction and a conceptual framework. The design approach gives an outline of what will take place in order to develop the instruction: what analyses will take place, how the literature study will be conducted, how the information of the analyses and the literature study will be used in the design, how the instruction will be developed, how the instruction will be evaluated, and what the conclusion and discussion section will contain. Finally, there is a planning included for the process of the bachelor thesis.

General Information

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Date	August 3, 2015
First supervisor	Dr H. H. Leemkuil
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Keywords	Quantum mechanics, Middle school Education, Netherlands
Title	Teaching quantum mechanics using qCraft

Table 1: General information about the bachelor thesis

Summary

This assignment will revolve around the creation of an instruction about quantum mechanics. This creation is necessary because of the implementation of the new domain "kwantumwereld" (quantum world) within the Central Exam of the Netherlands. The topic of the instruction is quantum teleportation, and it will focus itself on the three principles observer dependency, superposition and quantum entanglement. The instruction will make use of qCraft, a modification of the game Minecraft. This modification is designed to teach the principles to Minecraft players. The instruction will make use of constructivist theories (?, ?).

The assignment will take place in different steps from the generic model by ? (?) (see figure **??** on page **??**). First analyses will take place. These are an analysis of the context, an analysis of the learner and an analysis of the learning task. On the basis of these analyses and the conceptual framework, a literature study will take place. The results of the literature study will then be used to phrase design principles. After this, a global outline will be made for the instruction. This outline will then be developed, and the resulting instruction will be formatively evaluated.

Description

This chapter contains a short description of the background of the subject matter on middle schools in the Netherlands, the content of the instruction itself, the technology which will be used for the instruction, and an outline of the conceptual framework for the literature study.

Background

In the Netherlands, quantum mechanics always used to be a topic which schools themselves could choose to teach or not to teach. The only skill students had to know for the Centraal Eindexamen (the national central exams at the end of high school) which comes close to quantum mechanics is to elucidate the photoelectric effect and the wave-particle duality, mentioned within point 20 under subdomain E3 (?, ?). However, one of the changes in the Centraal Eindexamen of 2016 was the addition of domain F1, which is called Quantum world (?, ?). For this subdomain the candidate has to be able to apply the wave-particle duality and the uncertainty principle of Heisenberg, and to explain the quantization of energy levels in some examples with a simple quantum physical model. In order to give all candidates a chance of passing this subdomain, schools have to alter their programs in order to meet the expectations of the Centraal Eindexamen.

However, when searching the internet using the search machine Google concerning the implementation of quantum mechanics in Dutch high schools, the quantity and the quality of the results are very low. There are also no results to be found in the Dutch papers. An example is the Dutch site http://www.quantumuniverse.nl/, where teachers can find a small amount of brief courses on fundamental quantum mechanics, and where the forums are very quiet with only 5 discussions, of which 4 are just started threads from the site administrator.

Upon finding this information, an expert was consulted to confirm this conjecture. The expert was researching the implementation of quantum mechanics on middle schools, and she also a first degree physics teacher. She stated that within her school there were no initiatives to bring this topic in their classrooms, and that their school was no exception as well.

The fact that next year domain F1 has to be fully implemented and taught to all vwo students who chose physics as an examination subject is therefore slowly turning into a sword of Damocles. This stresses the urgency for the development of new course material.

Content

Quantum mechanics is not the most easy topic to introduce to physics. The subject is very counterintuitive, and still poses headaches to many physicists today. The great physicist Richard Feynman is known for saying: "I think I can safely say that nobody understands quantum mechanics" (1965), and this statement still holds. Quantum mechanics is this counterintuitive because it contradicts a lot of axioms we inherited from classical physics. These contradictions are highlighted by an article written by ? (?), which states that the current understanding of quantum mechanics contradict the criterion of reality and the hypothesis of locality.

There are a lot of resources available for teaching quantum mechanics. Most of these resources are academical and focus on teaching the mathematics. Their philosophy is that the student can only really get a grasp on quantum mechanics if he understand the underlying mathematical mechanics. An example of such a resource is ? (?). These resources are not very useful when teaching middle school students, because it demands an understanding of mathematics which is beyond the knowledge of middle school students, for example the integration of Schröder equations.

The other way of teaching quantum mechanics is by teaching the key principles of quantum mechanics. A fashion in which this could be achieved is by only considering the perfectly correlating instances. An example of such an instance is quantum teleportation. ? (?) explains this phenomenon without having to resort to very complex mathematics, but still explaining the fundamentals of quantum mechanics, namely observer dependency, superposition and quantum entanglement. The instruction will therefore use quantum teleportation to explain these three fundamental principles, so the learner will gain a conceptual understanding of quantum mechanics.

One way of making principles more accessible for the learner is by using an educational game (?, ?). By using games, the content can be visualised, the learner can interact with the content and the content can be structured according to instructional theories. One game which exists to explain the fundamental principles of quantum mechanics is the modification qCraft for the game Minecraft. There are already resources which use qCraft to explain quantum mechanics, developed by the qCraft team. However, they lack use of educational resources like ? (?). The resources also depend on different external resources, which makes it very

complex and causes a lack of structure. Finally, it could make more use of the possibilities within Minecraft, like books presented in the game. Therefore, a new instruction will make an effort to replace these resources with a higher educational value for Dutch middle school students by analysis, using instructional theories and conducting a literature study.

Design approach

A model which describes the process of developing educational resources is the Generic Model (?, ?) (see figure **??**). It describes the phases Analysis, Design, Development, Implementation and Evaluation. This model will be partly used for this project. Because of time constraints and the limited size of the project it will only go as far as the horizontal bar of development, this will be elaborated further later in this chapter.
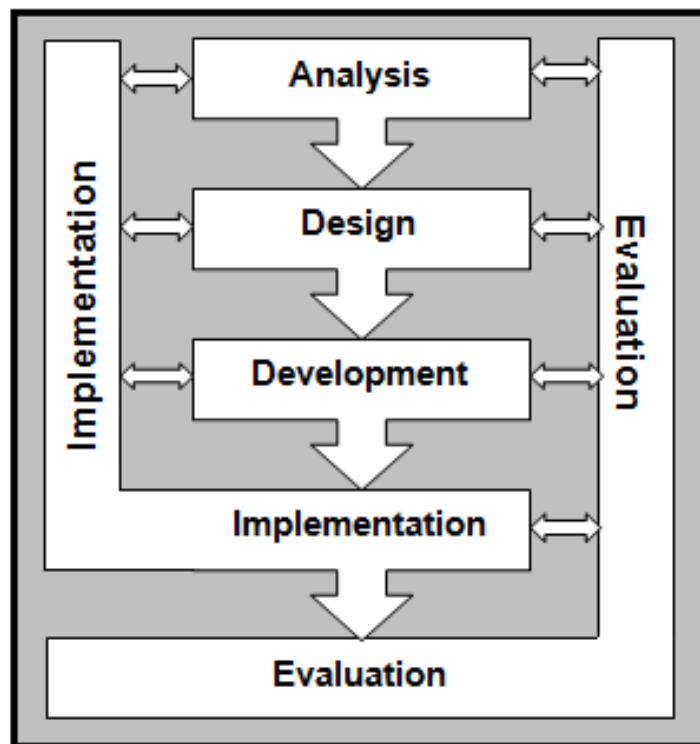

Figure 1: The generic model by ? (?)

Analyses

The first step in the Generic Model (?, ?) is the step Analysis. In this step, data is gathered which is necessary for designing an effective solution. ? (?) mention three different kinds of analysis, namely analyzing the learning context, analyzing the learners and analyzing the learning task.

Analyzing the learning context

A learning task always takes place in a certain learning context. In this case this is the middle school. It entails not only the place, but also the temporal and social environment (?, ?). The analysis of the learning context can provide the instructional needs and a description of the different factors influencing the instruction. With the instructional needs, the designer can establish the main learning goals for the instruction. The description of the learning environment can provide the learning opportunities and constraints which have to be taken into account for the instruction.

Analyzing the learners

The second analysis is that of the learners (?, ?). The purpose of this analysis is the characterization of the end user of the instruction, which is in this case the middle school students. For this analysis it is important to determine the similarities and differences between the learners. ? (?) provide a list of factors which play a role in designing the instruction. These factors are catagorized by stable similarities, stable differences, changing similarities and changing differences, and contain factors like sensory capacities, aptitudes, development processes an d development states.

Analyzing the learning task

The final step is analyzing the learning task (?, ?). In this analysis the goals from the needs assessment during the analysis of the learning context have to be translated to test specifications, with which the content of the instruction can be established. In order to achieve these test specifications, first the type of learning has to be established. Having this established, the information-processing analysis can be conducted. Every type of learning has its own kind of information-processing analysis. ? (?) provides a clear conceptual understanding of quantum teleportation, and will therefore be used to conduct this information-processing analysis. The next step is the prerequisite analysis. The outcome of this has to correspond to the outcome of the learner analysis. Finally, the learning objectives can be written, which form the test specifications. Every learning objective has to contain a

description of the terminal behaviour or actions that will demonstrate learning, a description of the conditions of demonstration of that action and a description of the standard or criterion (?, ?). Every learning objective will fall into a category of Bloom his taxonomy of learning objectives (?, ?) (see figure **??**), and will use appropriate action verbs. Most learning objectives within will be knowledge objectives, because there is a lot of new knowledge which has to be provided and it forms the basis for all other objectives. There will be no or very few synthesis and evaluation objectives, because these objectives would take too much time within the instruction to achieve to be feasible to use.
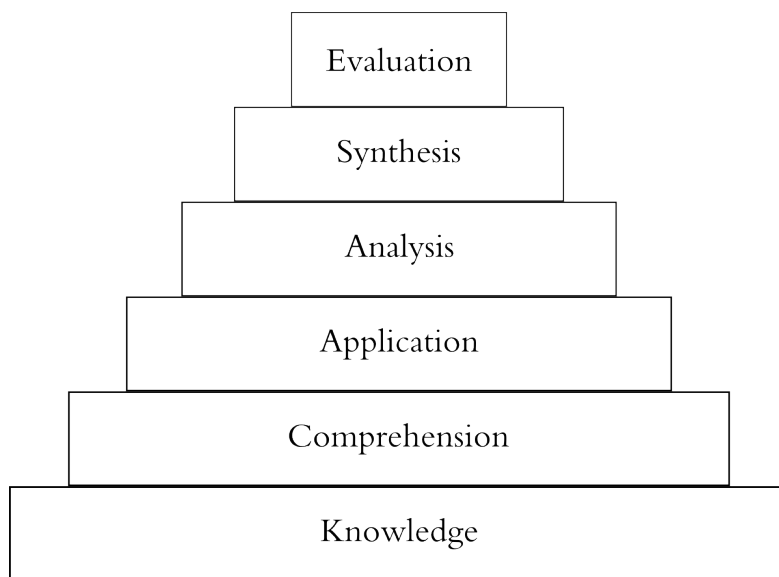

Figure 2: The Taxonomy of ? (?)

Literature Study

After the analyses have been conducted, the literature study will take place. The aim of this literature study is to find scientific articles concerning teaching quantum mechanics, and thereby grant insights, for example by stating different misconceptions that middle school students have about quantum mechanics. ? (?) state the different steps which go into doing literature research and writing the theoretic framework. The first step of the literature study will be considering the search terms. For this, the results of the analyses will have to be taken into account, especially the characterizations of the learners and the learning task. It will also make use of the conceptual framework, described earlier. The search terms will then be expanded by finding synonyms and similar relevant terms by using the

Thesaurus. After the search terms are determined, it has to be established which databases will provide useful results. Then a cyclic process will take place in which the amount of results will be assessed with these databases and search terms and then if needed the results are limited or expanded by using more search terms and filters. The results will always be constrained to peer-reviewed articles. Other filters could than be the recency of the articles or the educational level of the test subjects. When there is an appropriate amount of results, they will be filtered manually. First, the articles which seem relevant by their title and keywords will be selected. This will be done in a very broad sense, so only the really irrelevant results will be filtered out. These selected articles will then be skimmed by their abstract, introduction and conclusion and will be filtered out when they actually are not relevant. The remaining articles will then be used for constructing the theoretic framework. It could be that new keywords can be found in these articles. In this case this keyword will be added to the search terms in order to find even more results.

From the resulting articles a literature matrix will be constructed (?, ?). This matrix will contain research questions in the top row and the resulting articles in the left row. By using this technique, every question can be answered per resulting article. The columns can then be summarized in order to answer every question separately. These answers ultimately are the content of the theoretic framework.

Design

The second phase of the Generic Model (?, ?) (see figure **??** on page **??**) is the design phase. In this phase the results from the analyses are used to form design principles, which can be used to develop the instruction. There will be design principles for:

- a pretest for information about the preknowledge and the experience with playing games of the participants;

- the text of the instruction;

- the learning environment within Minecraft;

- the posttest for testing the resulting knowledge of the participants.

Furthermore, a global design plan will be made, which is a distribution of the learning objectives over the course of the instruction. The instruction will be structured according to the events of instruction (?, ?) (see table **??** on page **??**). These events can be filled in in a supplantive manner or in a generative manner. When the event is supplantive, the instruction will already supply the education

Expanded Events of Instruction	
Generative	Supplantive
Introduction	
Activate attention to activity	Gain attention to learning activity
Establish purpose	Inform learner of purpose
Arouse interest and motivation	Stimulate recall of prior knowledge
Preview learning activity	Provide overview
Body	
Recall relevant prior knowledge	Stimulate recall of prior knowledge
Process information and examples	Present information and examples
Focus attention	Gain and direct attention
Employ learning strategies	Guide or prompt use of learning strategies
Practice	Provide for and guide practice
Evaluate feedback	Provide feedback
Conclusion	
Summarize and review	Provide summary and review
Transfer learning	Enhance transfer
Remotivate and cease	Provide remotivation and closure
Assessment	
Assess learning	Conduct assessment
Evaluate feedback	Provide feedback and remediation

Table 2: The Expanded Events of Instruction (?, ?)

in such a way that the learner does not have to elaborate for himself, for example by using scaffolding. A generative event however will let the learner elaborate the education for himself, for example by asking questions about the material. It is important to note that most events are not entirely supplantive or generative but are somewhere in between.

Development

After the design phase comes the development phase (?, ?) (see figure **??** on page **??**), in which all the resources are finally fully developed, based on the earlier

made design. This will be the developing of the pre- and posttest, the writing of the text and the developing of the learning environment in Minecraft. The development of the resources will be based on the earlier developed design principles and the global design plan.

Formative Evaluation

After the first development phase, the formative evaluations will take place. These evaluations are derived from the *Evaluation Matchboard* (?, ?). After each evaluation, adjustments of the products have to take place as well. First, the resources will be screened to check whether the resources confirm to the design principles. Then, a focus group evaluation will take place. In this evaluation a subject matter expert will be interviewed to check whether the text contains statements which have to be adjusted or corrected with the current knowledge on quantum teleportation. Finally, a micro-evaluation will take place, in which the final product will be tested upon members of the target audience, or people similar to the target group audience. With this evaluation, the actual practicality can be tested by interviewing the participants. The actual effectiveness will also be tested by letting the participants make the posttest. The posttest will be open book, and ask mostly about learning objectives within *understanding*, *application* and *analysis*.

Implementation and Summative Evaluation

The implementation and summative evaluation will not take place during this project. Implementation would be outside of the scope of the project, and could only be executed in a follow-up project. When proven to be successful, the resources developed will be offered to MinecraftEdu, an organisation which has the mission to bring Minecraft into schools.

Because the lack of implementation, a summative evaluation is also out of the question. In order to conduct a successful summative evaluation, the resources would have to be fully in use in the actual context, which is not the case for this project.

Conclusion and Discussion

When the micro-evaluation has taken place, the resulting data has to be processed and analyzed. With these results, a conclusion will be written down to summarize the advantages and drawbacks of the instruction. There also will be suggestions for improvement and for implementation.

Planning

All the steps in the design approach are to be ready in the week numbers mentioned in table **??**.

Analyses	Week 18
Literature research	Week 20
Design	Week 21
Development	Week 22
Formative Evaluation	Week 24
Conclusion/Discussion	Week 25
Presentation	Week 26

Table 3: A general planning for the bachelor thesis

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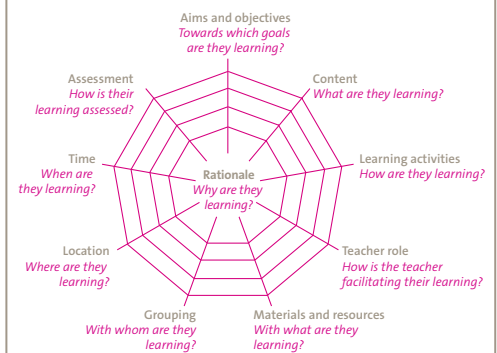
Appendix A: Evaluation matchboard

1 Stage of development

○ **Design proposal**
General idea of the product.

○ **Global design**
First elaboration of the product.

○ **Partly detailed product**
Parts of the product have been specified and could be used by the target group.

○ **Completed product**
The product is ready for use in practice.

2 Quality aspects

○ **Relevance**
There is a need for the product and its design is based on state-of-the-art (scientific) knowledge.

○ **Consistency**
The product is 'logically' designed.

○ **Expected practicality**
The product is expected to be usable in the settings for which it has been designed.

○ **Expected effectiveness**
Using the product is expected to result in desired outcomes.

○ **Actual practicality**
The product is usable in the settings for which it has been designed.

○ **Actual effectiveness**
Using the product results in desired outcomes.

3 Curricular components

Aims and objectives
Towards which goals are they learning?

Content
What are they learning?

Learning activities
How are they learning?

Teacher role
How is the teacher facilitating their learning?

Materials and resources
With what are they learning?

Grouping
With whom are they learning?

Location
Where are they learning?

Time
When are they learning?

Assessment
How is their learning assessed?

Rationale
Why are they learning?

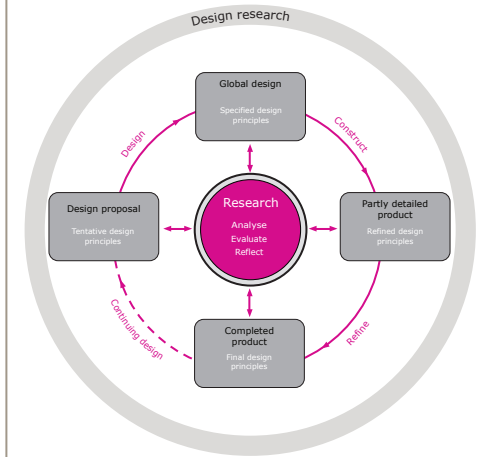## 4 Evaluation method

○ **Screening**
Members of the design research team check the design with a checklist containing required characteristics of the product.

○ **Focus group**
A group of respondents reacts on a prototype of the product.

○ **Walkthrough**
The design research team and representatives of the target group simulate the use of the product.

○ **Micro-evaluation**
A small group of target users use parts of the product outside its normal user setting.

○ **Try-out**
The target group uses the product in practice.

5 Activities

○ **Using a checklist**
Using a checklist with required characteristics of the product.

○ **Interviewing**
Asking respondents questions verbally.

○ **Observing**
Noticing what happens in practice and how respondents act.

○ **Administering a questionnaire**
Respondents answer questions on a paper-based or digital questionnaire.

○ **Testing or requesting a report**
Respondents make a test or draw up a learning report.

○ **Requesting logbooks**
Respondents write down their actions and reflections during a certain period.

Design research

Design research

Design — Construct — Refine — Continuing design

Global design
Specified design principles

Partly detailed product
Refined design principles

Completed product
Final design principles

Design proposal
Tentative design principles

Research
Analyse
Evaluate
Reflect

'Evaluation matchboard'

① Stage of development				④ Evaluation method	⑤ Activities	② Quality aspect					
Design proposal	Global design	Partly detailed product	Completed product		▼ Recommendation ▼	Relevancy	Consistency	Expected practicality	Expected effectiveness	Actual practicality	Actual effectiveness
				Screening ✓							
				Focus group							
				Walkthrough							
				Micro-evaluation							
				Try-out							
				▼ Remaining possibilities ▼							
				Screening ✓							
				Focus group							
				Walkthrough							
				Micro-evaluation							

Explanation: On one horizontal row, combine a stage of development (1) with a quality aspect (2) and find an evaluation method (4) with relevant activities (5)

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