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Teaching Quantum Mechanics Using qCraft

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Preface

The Generic Model

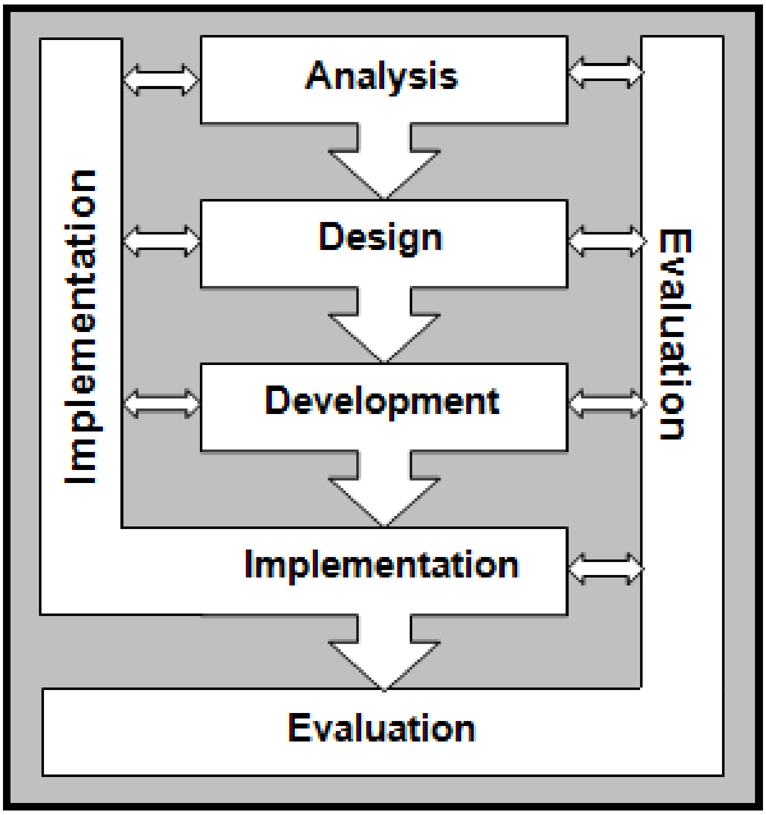

Figure 1: The generic model by Plomp et al. (1992)

Analyses

The first step of the Generic Model by Plomp et al. (1992) (see figure 1 on page 4) is Analysis. Smith and Ragan (2005) give an elaborated description of how to perform these analyses for instructional design. They distinguish three different kinds of analysis: analyzing the learner context, analyzing the learner and analyzing the learning task. The analysis of the learning context can provide the instructional needs and a description of the different factors influencing the instruction. The purpose of the learner analysis is the characterization of the end user of the instruction, which is in this case the middle school students. In the task analysis the test specifications are written, with which the content of the instruction can be established.These three analyses are executed in the following three chapters.

Context Analysis

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 (Smith & Ragan, 2005). 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.

Needs Assessment

The first goal of the need assessment is to investigate whether there exists a need for the instruction. Without a need, it would be a waste of resources to develop the instruction (Smith & Ragan, 2005). Next to this, it is conducted to better specify the need for the instruction. In the context of instruction, the assessment often results in a learning goal, which is the main goal of the instruction. This main goal is needed to continue the rest of the analyses, because all other analyses are conducted in respect to this goal. The goal can also be used to construct the summative evaluation, because when this goal is achieved, the instruction has proved to be successful.

Smith and Ragan (2005) identify three different models for the needs assessment, namely the problem model, the innovation model and the discrepancy model (see figure 2). The problem model is used when there exists a problem in the current system which has to be solved. As can be seen in figure 2, this model is to be used as a prerequisite for the other two models for assessment. With this model, it is determined whether there really is a problem, whether the cause of the problem is related to emloyees' performance or learners' achievement, whether the solution to the problem is learning and whether instruction for these learning goals is currently offered. After the problem model, the needs assessment splits into the two other models. The innovation model is used when there is a new learning goal that the learners should achieve, and the discrepancy model is used when the already available instruction is not adequate to achieve the learning goal. The designer should choose one of these models for his needs assessment.

In the case of the instruction which will be constructed for this assignment, at first the problem model will be used to investigate the problem, and which of the two follow-up models should be used for the needs assessment.

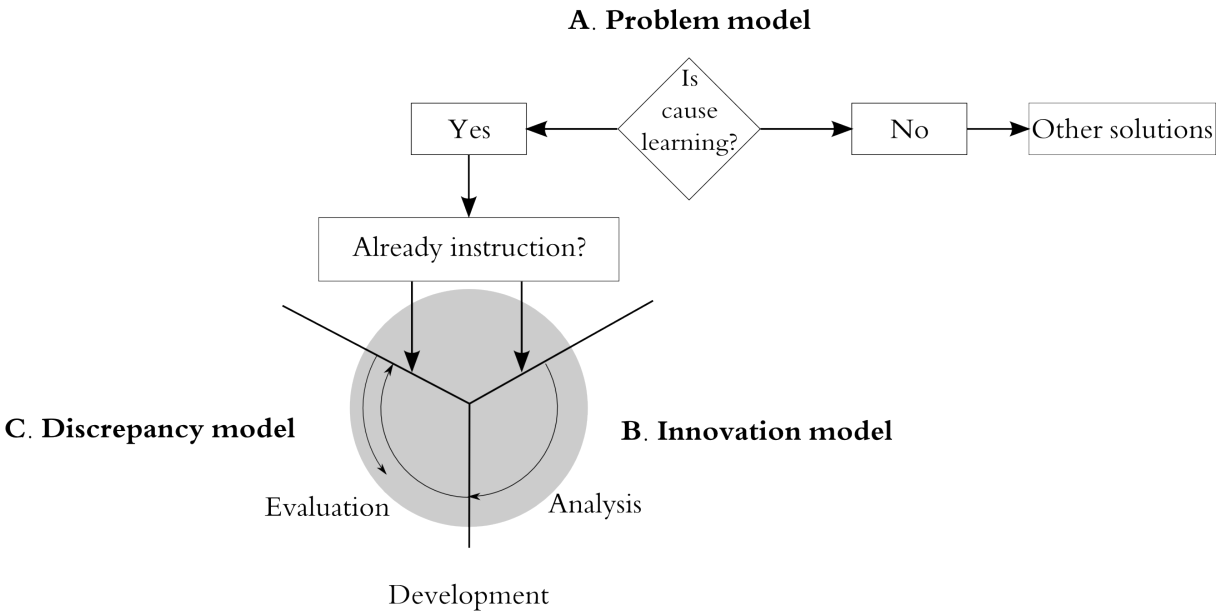

Figure 2: The three sides of needs assessment (Smith & Ragan, 2005)

The problem

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 (Laan, 2013). However, one of the changes in the Centraal Eindexamen of 2016 was the addition of domain F1, which is called Quantum world (Groenen et al., 2014). 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. This is an example of extrinsic motivation. However, is there also intrinsic motivation to teach quantum mechanics on high schools? First of all, there is no article which claimed that quantum mechanics should not be taught on high schools. On the other hand there are but a few authors who did have some arguments in favour of teaching. Müller and Wiesner (2002) and Henriksen et al. (2014) state that quantum mechanics shapes our world view and that educated citizens should therefore become acquainted with the topic. It is also regarded as fundamental and should therefore be taught (Henriksen et al., 2014; Hobson, 2012). Finally, Erduran (2005) states that the teaching of philosophical themes in science education has been advocated for several decades, and quantum mechanics is one of these themes.

Because it involves new instruction, the innovation model will be used for the second part of this needs assessment.

The innovation

The nature of the innovation lies within the change of the Centraal Eindexamen of 2016 in respect to the Centraal Eindexamen of 2015. The new additions within the domain Kwantumwereld outline the new goals of physics education in the Netherlands, and will be the ultimate goals for the students to achieve, and therefore be the ultimate learning goals for the students to achieve. This results in the following learning goals (Groenen et al., 2014):

The candidate can:

- describe quantum phenomena in terms of the enclosure of a particle:
  - estimate whether quantum phenomena are to expected by comparing the debroglie-wavelength with the order of largeness of the enclosure of the particle;
  - apply the uncertainty principle of Heisenberg;
  - describe the quantum model of the hydrogen atom and calculate the possible energies of the hydrogen atom;
  - describe the quantum model of a particle in a one-dimensional energy well and calculate the possible energies of the particle;
  - Bohr radius, zero-point energy.
- describe the quantum-tunnel effect with a simple model and indicate how the chance of tunneling depends on the mass of the particle and the height and width of the energy-barrier,
  - minimal in the contexts of: Scanning Tunneling Microscope, alpha-decay.

These goals confirm what the literature describes about the current appliance of quantum mechanics teaching within secondary, namely that often quantum mechanics is introduced with great emphasis on learning and practising algorithmic skills (Papaphotis & Tsaparlis, 2008a, 2008b). However, it is also found that students show higher interest in the conceptual aspects than the algorithmic aspects (Papaphotis & Tsaparlis, 2008a, 2008b; Levrini & Fantini, 2013). When focusing on the conceptual aspects, it engages students (Henriksen et al., 2014) and students start asking fundamental questions (McKagan et al., 2008). Furthermore, mathematical oriented approaches might be more common, however, quantum mechanics is regarded to be mathematically challenging (Gianino, 2008; McKagan et al., 2008), and most high school students lack proper background in mathematics at the required level (Dori, Dangur, Avargil, & Peskin, 2014). Because the usual focus on the algorithmic aspects, students often do not learn what instructors want them to learn (Asikainen & Hirvonen, 2014; McKagan et al., 2008), and improved student learning is possible by shifting the focus to conceptual understanding (McKagan et al., 2008). Therefore, the aim of this instruction is to focus on a conceptual approach instead of a mathematical approach. Then, after the students have a sufficiently conceptual understanding of the material, the concurrent instructions in the curriculum can emphasise the goals stated by the Centraal Eindexamen of 2016, which adds the mathematical layer on top of the conceptual layer and can deepen the understanding of quantum mechanics.

Learning Environment

The learning environment description is the other major component of the learning context analysis (Smith & Ragan, 2005). The description contains information of all the external factors influencing the instruction. These are the mediators of the instruction, the already existing curricula which takes place in the environment, the available equipment available on the location of the instruction, the characteristics of the facilities at the location of the instruction, the characteristics of the organization in which the instruction will take place, and the philosophies and taboos of the larger community in which this organization exists.

For most teachers, quantum mechanics is a new subject to teach. However, a first degree teacher training (*Cursussen Leraar Natuurkunde (Professional Master) Tilburg — Fontys*, 2015) does encompass quantum mechanics, so the teachers should be familiar to the domain. Whether the teachers are familiar to the three principles is unclear at this moment, and would be an important aspect of implementation of this innovation. It should be investigated whether teachers already have sufficient knowledge on the topic, or need further instruction to use the innovation.

When implementing the instruction, the placing within the already existing curriculum is also important, because the instruction depends on prerequisites from other elements of the curriculum. The main prerequisite is knowledge of Bohr his atom model, because the different particles within this model are the particles on which quantum mechanics apply. This knowledge is teached in Domain E from the centraal eindexamen (Groenen et al., 2014), and because of the prerequisite, it is of upmost importance that this instruction is placed after Domain E in the exisiting curriculum.

Another important aspect is the method of delivery (Smith & Ragan, 2005). If the instruction is delivered by traditional methods like books, teachers are already used to it and don't need further instruction. If the instruction is delivered otherwise however, it should be a part of the implementation to instruct the teachers how to use the technology. Another key element would be the available technology. If computers or tablets are used for the instruction, it should be investigated whether the available technology on the school is sufficient.

Finally, it is important to investigate whether the instruction fits in with the mission and vision of the school, and also the philosophies and taboos that the teachers hold. Therefore, it is advized to find these discrepancies by the means of interviews, in which the school board is asked about their mission and vision, and the teachers about their personal believes in regard to quantum mechanics.

In any case, this assignment does not look into the implementation of the instruction yet, so these factors have to be looked closer at when embedding the instruction in the context of a specific school.

Learner Analysis

The second analysis is that of the learners (Smith & Ragan, 2005). 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. Smith and Ragan (2005) provide a list of factors which play a role in designing the instruction. They catagorize these factors with a 2×2 matrix (see table 1), creating the catagories stable similarities, stable differences, changing similarities, and changing differences.

	Similarities	**Differences**
Stable	Stable similarities	Stable differences
Changing	Changing similarities	Changing differences

Table 1: The four catagories of Learner Characteristics (Smith & Ragan, 2005)

Stable Similarities

The stable similarities are the similarities between the members of the target audience which do not change. Smith and Ragan (2005) mention three types of stable similarities, namely the sensory capabilities, the information processing, and the types and conditions of learning.

Because of the young age of the target audience (17-18 years), the sensory capabilities are still high. It would make sense to stimulate the students by using both visual and auditory cues. On the other hand, according to information processing theories like Cognitive Load Theory (Smith & Ragan, 2005), it is important to also work with the constrains of the working memory. Therefore, it would be important to use the visual and auditory cues in a constructive way, without it being distractive from the learning content. Smith and Ragan (2005) mention a couple of strategies to decrease the cognitive load, for example off-loading, segmenting and weeding.

Which specific types and conditions of learning exist for the target demographic within the context of quantum mechanics will be researched during the literature research.

Stable Differences

There are also aspects of the members from the target audience which will not change which vary among these members. Smith and Ragan (2005) state them to be aptitudes, styles, traits and group membership factors.

The first of these aspects, aptitude, refers to the readiness or facility to learn or achieve. It is true that humans chosen by random sampling will probably differ among themselves in aptitude, also depending on the task or topic which they are assessed on. However, in the context of this assignment, only 6 vwo students which have chosen physics as an exam subject have to be considered. Because the group is so specific, their aptitude towards the subject of quantum mechanics can already be predicted to be relatively high. Another feature of this group is that they can be predicted to score high on assessments measuring logical/mathematical intelligence (Gardner, 1993), which is the type of intelligence required most in the context of learning quantum mechanics.

This analysis won't go into the different cognitive styles, psychosocial traits, or gender, ethnicity and racial groups. First of all, these are dependent on the place of implementation and the specific target audience. Next to this, the group membership factors are not relevant for this topic, for they are all personal aspects and do not relate to the field of quantum mechanics.

Changing Similarities

Intellectual development processes

Language development processes

Psychosocial development processes

Moral development processes

Other development processes

Changing Differences

Intellectual development state

Other development state

General prior learning

Specific prior learning

Task Analysis

The final step is analyzing the learning task (Smith & Ragan, 2005). 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. Zeilinger (2005) 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 (Smith & Ragan, 2005). Every learning objective will fall into a category of Bloom his taxonomy of learning objectives (Bloom, Englehart, Furst, Hill, & Hrathwohl, 1956), 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.

Learning goal

Types of learning

Information-processing analysis

Prerequisite analysis

Learning objectives

Test specifications

Theoretic Framework

Design

Development

Formative Evaluation

References

Asikainen, M. A., & Hirvonen, P. E. (2014). Probing pre-and in-service physics teachers' knowledge using the double-slit thought experiment. *Science & Education*, *23*(9), 1811 - 1833. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ1040923&site=ehost-live

Bloom, B. S., Englehart, M. D., Furst, E. J., Hill, W. H., & Hrathwohl, D. R. (1956). *Taxonomy of educational objectives: Handbook i, cognitive domain*. New York: McKay.

Cursussen leraar natuurkunde (professional master) tilburg — fontys. (2015). Retrieved from \allowbreakhttp://fontys.nl/Werk-en-studie/Opleidingen-en-cursussen/Leraar-Natuurkunde-Master/Studiekosten-59/Inhoud-opleiding/Cursussen.htm

Dori, Y. J., Dangur, V., Avargil, S., & Peskin, U. (2014). Assessing advanced high school and undergraduate students' thinking skills: The chemistry–from the nanoscale to microelectronics module. *Journal of Chemical Education*, *91*(9), 1306 - 1317. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ1040100&site=ehost-live

Erduran, S. (2005). Applying the philosophical concept of reduction to the chemistry of water: Implications for chemical education. *Science & Education*, *14*(2), 161 - 171. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ925087&site=ehost-live

Gardner, H. (1993). *Frames of mind: the theory of multiple intelligences.* New York: Basic Books.

Gianino, C. (2008). Energy levels and the de broglie relationship for high school students. *Physics Education*, *43*(4), 429 - 432. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ802501&site=ehost-live

Groenen, E., Michels, B., Smeets, P., de Leeuw, A., van de Poppe, D., Bouwens, R., … Meek, H. (2014, April). *Syllabus natuurkunde vwo centraal examen 2016, nader vastgesteld.* Utrecht.

Henriksen, E. K., Bungum, B., Angell, C., Tellefsen, C. W., Frågåt, T., & Bœ, M. V. (2014). Relativity, quantum physics and philosophy in the upper secondary curriculum: Challenges, opportunities and proposed approaches. *Physics Education*, *49*(6), 678 - 684. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ1044233&site=ehost-live

Hobson, A. (2012). Teaching quantum nonlocality. *Physics Teacher*, *50*(5), 270 - 273. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ984073&site=ehost-live

Laan, H. W. (2013, April). *Syllabus natuurkunde vwo centraal examen 2015.* Utrecht.

Levrini, O., & Fantini, P. (2013). Encountering productive forms of complexity in learning modern physics. *Science & Education*, *22*(8), 1895 - 1910. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ1039645&site=ehost-live

McKagan, S. B., Perkins, K. K., Dubson, M., Malley, C., Reid, S., LeMaster, R., & Wieman, C. E. (2008). Developing and researching phet simulations for teaching quantum mechanics. *American Journal of Physics*, *76*(4), 406-417. Retrieved from `http://scitation.aip.org/content/aapt/journal/ajp/76/4/10.1119/1.2885199` doi: http://dx.doi.org/10.1119/1.2885199

Müller, R., & Wiesner, H. (2002). Teaching quantum mechanics on an introductory level. *American Journal of physics*, *70*(3), 200-209. doi: 10.1119/1.1435346

Papaphotis, G., & Tsaparlis, G. (2008a). Conceptual versus algorithmic learning in high school chemistry: The case of basic quantum chemical concepts–part 1. statistical analysis of a quantitative study. *Chemistry Education Research and Practice*, *9*(4), 323 - 331. Retrieved from `http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ888350&site=ehost-live`

Papaphotis, G., & Tsaparlis, G. (2008b). Conceptual versus algorithmic learning in high school chemistry: The case of basic quantum chemical concepts–part 2. students' common errors, misconceptions and difficulties in understanding. *Chemistry Education Research and Practice*, *9*(4), 332 - 340. Retrieved from `http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ888351&site=ehost-live`

Plomp, T., Feteris, A., & Pieters, J. (1992). *Ontwerpen van onderwijs en trainingen* (W. Toic, Ed.). Utrecht: LEMMA.

Smith, P. L., & Ragan, T. J. (2005). *Instructional design*. Oklahoma: John Wiley & Sons, Inc.

Zeilinger, A. (2005). *Einsteins spuk. teleportation und weitere mysterien der quantenphysik*. München: C. Bertelsman Verlag.