Engineers in the Physics Classroom

Helping engineers become physics teachers

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INTRODUCTION

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With shortages of physics teachers in many countries the option to attract engineers for a teaching career has been identified as a potential solution. To ensure in-depth physics teaching, subject knowledge enhancement courses can be offered [1]. We report on the design and implementation of the Dutch subject knowledge enhancement project Natk4all which has been running since 2015 [2]. The project is a joint effort of all physics departments and university teacher training programs of nine Dutch universities. Each year sixty engineers take physics courses taught by subject matter specialists of all universities involved. Quantum physics and Particle physics are typical topics that engineers usually have not encountered during their studies. Students appreciate the more conceptual approach as compared to mathematical approaches in the standard university physics curriculum. The blended learning format offers both online components and contact hours in which theory is clarified and exercises are worked on together. This format suits those combining their studies with a teaching job at a school. The chosen conceptual approach is highlighted via examples.

1 BACKGROUND AND CONTEXT

In many countries shortages of physics teachers urge policy makers and academics to find solutions [3]. In the Netherlands the numbers of graduating physics teachers are also not meeting the replacement needs of schools, with a reported 7.4% of the physics lessons taught by non-qualified teachers in 2015 and - with unchanged policies - an estimated gap of 10.5% in 2027 on a total of 1881 fulltime physics teacher equivalents [4]. Science Faculties at universities are also concerned to see the level of teaching go down at secondary schools as this is an essential cornerstone of a strong science tradition with substantial economic impact [5]. Therefore the Dutch Ministry of Education supported the Natk4all project that would help engineers and non-physics scientists become physics teachers [6].

Before the arrival of Natk4all, engineers were already allowed to enter physics teacher training programs at nine different universities after successfully completing a number of physics courses together with Bachelor physics students. For a substantial number of engineers this was no option due to the strong mathematical nature of these research oriented physics courses, often lacking more conceptual approaches which would fit the needs of physics teachers. Also rosters did not fit with job obligations thus excluding engineers who wanted to switch jobs or were already committed to teaching at schools. The yearly turnout of the nine university programs is 40-50 graduating physics teachers [7] of whom approximately two-thirds actually choose to become a physics teacher. In view of these numbers, clearly none of the nine university teacher training programs was having the economy of scale to design their own tailored subject knowledge enhancement courses for small numbers of students with an engineering background. A consultation study showed great willingness to engage in a joint effort to help engineers and non-physics science students become a physics teacher [6].

Governing design research questions of how the Natk4all project was designed and carried out:

(Q-1) What physics subject knowledge needs to be taught and at which level?

(Q-2) How to synchronize intake procedures of all nine universities?

(Q-3) What characteristics of these courses fit best with the target group needs?

(Q-4) How to embed a conceptual approach in the courses?

2 METHODS

With respect to the physics subject knowledge topics to be covered (Q-1) there are national and international listings of subdomains available for physics teacher education [8, 9]. An analysis of the Dutch national exam program syllabus further clarifies which topics should be mastered. Also prior intake data were available that could help set intake and matching standards (Q2). Semi-structured interviews with representatives of the Physics department and the Teacher training program were held at each of the nine universities addressing all four design research questions listed above (Q1-4). To ensure ownership of the project the final text sent to the Ministry of Education was agreed upon by all parties with signatures of all deans involved. Also a project contract was agreed upon and a steering committee was initiated with nine representatives which could decide on project policies and which could also act on local issues if needed (Q-2). For the characteristics of the courses such as home-study support and online features an analysis of the target group was made focusing on those already at work (Q3). The teachers assigned to each course by the university partners were gathered to discuss the options to embed a conceptual approach in their courses. Also consecutive teacher meetings were used to share best practices (Q-4). The Results section will discuss both the resulting design and what has been achieved in the period since 2015 when the subject knowledge courses were put in action.

3 RESULTS

3.1 Subject knowledge enhancement course contents

With respect to the physics topics (Q-1) it was clear that most engineers lack expertise in modern physics areas such as quantum physics, nuclear and particle physics and special relativity theory. Mechanical engineers do not need further courses on classical mechanics. Likewise electrical engineers already have in-depth expertise of electromagnetism. As the Dutch physics curriculum allows for electives such as biophysics and geophysics, these were also offered as courses and certified teachers lacking in-depth knowledge of these subjects were targeted. Finally, a course into the history and philosophy of physics was found to be helpful for aspiring physics teachers. With respect to the level of the courses all universities agreed that graduated engineers had already shown master level and they should not be rebuilt into research physicists. So, the first bachelor course in each subdomain would be the required level. Depending on the emphasis of the topic in the examination program courses were categorised to have either 3 or 6EC size (1EC=28 hrs). Based on 2015-2018 course enrollments Table 1 lists the courses according to enrolment. The exam levels of the courses were achievable by most students with an average success rate of 82% at the first attempt. On average students enrolled in 2.5 (SD=1.8) courses, with some finishing them in one academic year and others taking two years to complete their physics courses. Despite serious advertising, master classes at teacher conferences and other communications we did not manage to engage many certified teachers into our course offerings with respect to the electives biophysics and geophysics (right column, Table 1).

Table 1. Subject knowledge enhancement courses taken by engineering students as part of their preparation to become a physics teacher.

Natk4all courses (% of students taking certain courses)		
50-100%	20-50%	0-20%
Quantum physics (6EC)	History & philosophy of physics (6EC)	Experimental physics (3EC)
Particle physics (3EC)	Mechanics (3EC)	Biophysics (3EC)
Special relativity theory (3EC)	Astronomy (3EC)	Geophysics (3EC)
Electromagnetism (6EC)	Thermodynamics (3EC)	

3.2 Intake of engineers for physics teacher training programs

All universities agreed to use the Natk4all course listing for their intake and matching (Q-2). This consensus was prepared at the Natk4all steering committee and then agreed upon at the national level by all university teacher training departments. This alignment resulted in a matrix for most common engineering programs versus physics courses (Table 2). As not all engineering programs are identical and students may take different electives, some tailoring was allowed for, based on the engineering course list that each student could produce. Some universities prefer their students to handle the subject knowledge enhancement courses first of all whereas other universities allow engaging in both physics and educational courses. A positive by-effect of the matrix was that some engineering students with teaching in mind now take Natk4all physics courses as electives in their engineering programs.

Table 2. Intake matrix (partly) mapping of engineering diplomas on physics courses. Elective courses Astronomy, Biophysics and Geophysics are not in this table.

Natk4all physics courses >> vv **Engineering diploma**	Mechanics	Quantum physics	Electromagnetism	Special relativity theory	Thermodynamics	Particle physics	Experimental physics	History & philosophy of physics	TOTAL (EC)
Mechanical engineering			6	3	3	3	3		24
Electrical engineering	3	6		3	3	3			18
Biomedical engineering		6	6	3	3	3			21
Architecture & building engineering		6	6	3	3	3	3	6	30
Industrial design		6	6	3	3	3	3	6	30
Civil engineering		6	6	3	3	3	3		24
Chemical engineering	3	6	6	3		3			21

3.3 Course design based on user requirements

The initial survey study and a needs analysis with respect to our target group led to a series of design decisions (Q-3):

Scheduling - Students should be able to combine physics and education courses with job obligations. We therefore choose to schedule all courses on Fridays. Students who already have a regular teaching job were asked to arrange with their schools to block this day for them. Also teacher training programs were not using Fridays for their courses.

Central location - Students live all over the country. We therefore selected a suitable and central location for course meetings, a school building in Utrecht in the middle of the Netherlands, next to the railway station.

Blended learning - Balancing home-study and contact hours is important. Relying too much on home-study would lower success rates and would introduce procrastination due to time pressure of school job deadlines. A number of contact meetings is required for peer interaction and teacher support. A blend was arranged of home-study tasks and scheduled meetings every fortnight. Home-study was supported by online knowledge clips and diagnostic tests, simulations and homework assignments. Theory introduction of meetings were recorded for those not being able to attend sessions and for reviewing purposes.

Overview - To give students good overview each course is supported with a Moodle course site connecting with all resources, assignments and results. After the first year the set-up of these Moodle sites was synchronised to support easy navigation for students across.

Explaining and understanding - Students are preparing for teaching physics. They should therefore have conceptual understanding as just making quantitative exercises is not sufficient [10, 11]. This also relates to the fact that Dutch national physics exams contain numerous questions that require reasoning and explaining. See also paragraph 3.4 for examples.

Math support - In the first year we found out that some students were in need of support on their mathematical skills. The scheduled meetings were immediately extended with an extra optional math hour for those in need of refreshing their mathematical skills. Also online mathematics resources were presented for home-study purposes [12].

Quality assurance – University programs need assurance with respect to the level and quality of courses and exams as they are supervised by accreditation bodies. A committee of three physics experts was asked to check the course and exam quality. Comments were shared with teachers both individually and during teacher meetings on shared issues. The final report was then shared with the universities via the steering committee. Also student questionnaires were used for evaluation purposes. Course appreciation scores are high with an average 7.8 (SD= 0.5) on a 10 point scale (1=very bad; 10=excellent). In particular the course meetings were appreciated for high quality teachers and for peer interaction.

3.4 Conceptual approach

With respect to the conceptual approach that we advocated (Q-4) the survey responses indicate that mastering basic content comes first. Also the teacher training programs indicated that they would include subject specific conceptual understanding issues in their courses [13]. Nevertheless many colleagues were interested to see if we would succeed to combine basic physics coverage with improved conceptual understanding. Students at both secondary and university level should be able to handle questions that require understanding and reasoning, sometimes even without calculations. With respect to the implementation in the courses a number of conceptual exam questions are shown in Table 3. Another example from quantum physics is the assignment in which students present how they educate certain quantum concepts which are new in the school curriculum.

Table 3. Examples of explaining and reasoning questions, taken from different exams.

Course (teachers)	**Sample concept question**
Mechanics (Mudde & Dekkers)	If a solid box slides down a slope and a solid cylinder with the same mass rolls down the same slope (no friction, no slipping), which one will be at the bottom first?
Quantum physics (Vonk, Schoutens & van Wezel)	Close to absolute zero temperature a cloud of fermions will have lower density when compared to a cloud of bosons. Assume same weight for bosons and fermions. Explain.
Particle physics (de Jong & Kleiss)	How do we know that a neutron weighs more than a proton?
Biophysics (Opstal & Oostendorp)	Explain pressure differences in blood vessel branches.
Astronomy (Barthel & Lamers)	How do we know that there should be dark matter in the Milky Way?

4 SUMMARY AND DISCUSSION

The Natk4all program is a well appreciated set of physics courses for engineers preparing for physics teaching. The blended learning format suits the students who combine a teaching job and teacher training program. The setup and execution of the Natk4all program has received continuous support from all universities involved. As a by-product intake procedures for new physics teachers were synchronised. The conceptual approach aimed for was implemented by the teachers embedding this within a foundation approach covering the content and procedures of relevant physics subdomains at an academic level well above the secondary school exam level.

With 40-50 graduating physics teachers per year the numbers of engineering students engaging in Natk4all courses indicate that numbers will go up if they finish their studies. However the shortage of physics teachers has not been resolved yet. This emphasizes the importance of an integral approach of which this Natk4all program is just one stepping stone. Universities are now looking into ways to allow students to embed teacher training components in their bachelor and master program as an alternative to the capstone trajectory that most have to follow right now. With study loans for students instead of bursaries, 5+1 year trajectories are too long for many. Visibility of teacher tracks is also an issue. Engaging students in outreach activities appears to be a successful way of having students start considering a teaching career.

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