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Preparing pre-service teachers to integrate technology into inquiry-based science education: Three case studies in The Netherlands

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Summary. — Integration of technology (*e.g.* measuring with sensors, video measurement, and modeling) into secondary-school science teaching is a need globally recognized. A central issue of incorporating these technologies in teaching is how to turn manipulations of equipment and software into manipulations of ideas. Therefore, preparation for pre-service teachers to apply ICT tools should be combined with the issues of minds-on inquiring and meaning-making. From this perspective, we developed a course within the post-graduate teacher-education program in the Netherlands. During the course, pre-service teachers learnt not only to master ICT skills but also to design, teach, and evaluate an inquiry-based lesson in which the ICT tool was integrated. Besides three life sessions, teachers' learning scenario also consisted of individual tasks which teachers could carry out mostly in the school or at home with support materials and online assistance. We taught three iterations of the course within a design-research framework in 2013, 2014 and collected data on the teacher learning processes and outcomes. The analyses of these data from observation, interviews, questionnaires, and documents were to evaluate implementation of the course, then suggest for revisions of the course set-up, which was executed and then assessed again in a subsequent case study. Main outcomes of the three case studies can be summarized as follows: within a limited time (3 life sessions spread over 2–3 months), the heterogeneous groups of pre-service teachers achieved a reasonable level of competence regarding the use of ICT tools in inquiry-based lessons. The blended set-up with support materials, especially the Coach activities and the lesson-plan form for an ICT-integrated inquiry-based lesson, contributed to this result under the condition that the course participants really spent considerable time outside the life sessions. There was a need for more time for hands-on, in-group activities in life sessions and more detailed feedback on individual reports of pre-service teachers. The majority of the pre-service teachers were able to design a lesson plan aimed at a certain inquiry level with integration of ICT, but just a few could implement it faithfully in the classroom. There was still a considerable difference between intended inquiry activities and actual realized inquiry which parallels results from the literature for experienced teachers. The participants had to struggle with science —ICT conceptual issues as well as getting their students to focus on inquiry and concept learning in the classroom. Each evaluation guided iteration of the course resulted in better learning outcomes.

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1. – Introduction

1·1. *Background and context.* – Since the beginning of 1980s, the international community has widely recognized possibilities of Information and Communications Technology (ICT) to stimulate inquiry-based teaching and learning of science. Firstly, tools for gathering data with sensors became available, and also environments for dynamical modeling. Later on, the multimedia power of computers enabled video measurement and simulations. These technology applications enable teachers to motivate and support secondary-school students to construct understandings of scientific concepts. Although these tools have been available for thirty years in teacher education and training, it is still questionable how far teachers are with respect to good practices of these ICT tools in the "normal" teaching of science. Actually proper use of these potentials of technology in science education is rather far away.

Abrahams and Millar (2008) observed 25 "typical" laboratory lessons in English secondary schools and concluded that "*Practical work was generally effective in getting students to do what is intended with physical objects, but much less effective in getting them to use the intended scientific ideas to guide their actions and reflect upon the data they collect*" (p. 1945). Teachers sometimes tried to apply innovative ICT tools in the classroom, but mostly in traditional ways in which they provided a cook-book list of tasks for students to follow ritualistically. Meanwhile, students knew in advance from the text-book what would come out from the laboratory. This was concluded by Hofstein and Lunetta (2004, p. 47) in a review of decades of research on laboratory use in science education. On the one hand, high-tech tools such as data logging, video measurement, and modeling are powerful in many cases in which traditional laboratory instruments or secondary-mathematics prior-knowledge cannot help students to investigate real-life phenomena. On the other hand, students always need a lot of instruction and time to handle these ICT tools. Direct instruction like "do this, then do that" might be the fastest and most convenient method, but it does not promote student's minds-on inquiring and meaning making. The challenge to teachers in applying ICT as laboratory instruments, therefore, is how to turn manipulations of equipment (*e.g.* experiment apparatus, sensors, and software) into manipulations of ideas (*e.g.* ideas, theories, and hypotheses) (Berg, 2013, p. 75).

Shulman (1986) developed the idea of Pedagogical Content Knowledge (PCK) to describe knowledge on how to teach a specific content (*e.g.* a science concept), which has become a widely-accepted conceptual basis for subject-focused pedagogy. Koehler and Mishra (2005) built on Shulman's formulation of PCK and added technology (*e.g.* laboratory instruments, educational software) as a key component to the framework. They proposed the concept of Technological Pedagogical Content Knowledge (TPCK), which is knowledge about using technology to teach specific contents.

1·2. *Development of a teacher-education course on integration of technology into science education.* – Our project aims at developing a course for pre-service teachers in which preparation for teachers to integrate technology in science education should be combined with the issues of inquiry-based teaching. Based on the TPCK framework, the content goals of our course could be stated as:

- TCK (Technological Content Knowledge): Teachers' learning to use ICT tools in the science laboratory

- TPCK: Teachers' learning to apply these tools to teach an inquiry-based lesson in the classroom

The TCK concerned three ICT tools: data logging, video measurement, and modeling which are integrated in an authoring and learning environment, called Coach. Coach is present in almost all Dutch secondary-schools. In Europe, Coach is used in many countries, available in many languages (`http://www.cma-science.nl/`). It offers tools with flexible authoring facilities which enable inquiry-based approaches with more realistic contexts for science lessons (Heck *et al.*, 2009, p. 153).

The central design issue is how to develop a time-effective course in which pre-service teachers with heterogeneous backgrounds (see Sect. **2**·2) within a limited time learn to apply the ICT tool in such a way there must be inquiry components in laboratory activities. The theoretical exploration in this research and development domain (Tran *et al.*, 2014) suggested us three main requirements which the participating teachers should fulfill during the course:

1) Becoming aware of possibilities of ICT tools and learning in depth only one tool by choice,

2) Carrying out a complete cycle of designing, implementing, and evaluating an ICT-integrated inquiry-based lesson in the classroom,

3) Learning on their own most of the time through life sessions and individual tasks with support materials and online assistance.

These requirements are the three principles underlying our course design. To optimize the course, we taught, evaluated, and revised it through the iteration of the three case studies in the Netherlands.

1·3. *Research questions and design-based research approach.* – Development, evaluation, and optimization of the course have been driven by the following research questions:

1) To what extent was the course implemented as intended? To what extent did the course have effects as expected?

2) What were technological and pedagogical problems of teachers in learning to use and apply the ICT tools in an inquiry-based lesson?

3) What suggestions for revision of the course came out of course evaluation (driven by questions 1 and 2), aiming at teachers' more-effective learning? And did the revision work out in the subsequent iteration of the course?

We utilized a design-based research framework which consists of two successive stages: the explorative phase and the cyclic phase (fig. 1). This paper presents research findings from the cyclic phase with three case studies in the Netherlands; in each of which we executed the course and simultaneously collected data on teachers' learning process (formative assessment) and teachers' learning outcomes (summative assessment). Analysis of the collected data helped us to evaluate faithful implementation and effectiveness of the course (Question 1) as well as to identify problems of the pre-service teachers in learning to use and apply the ICT tools in an inquiry-based lesson (Question 2). Based on the course evaluation after each case study, we revised, and then executed and evaluated the course again in the subsequent iteration. Assessment on whether revisions worked out in the next round was also taken into account (Question 3).

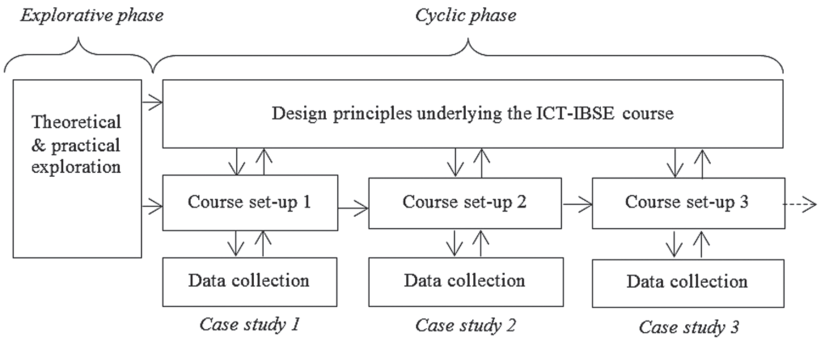

Fig. 1. – Research design— optimization of the course through three case studies (adjusted from Knippels, 2002, p. 15).

TABLE I. – *Three case studies (CS) in the context of a teacher-education one-EC course in the Netherlands.*

Case study	Duration	Time for 3 life sessions	Time anticipated for individual tasks	Teachers in total	First-year teaching	Partly paid/ internship
CS1	5 weeks, 28/1 – 4/3/2013	3 hours each	19 hours	12	9	5
CS2	7 weeks, 6/5 – 24/6/2013	3 hours each	19 hours	12	10	5
CS3	11 weeks, 17/2 – 16/5/2014	Session 1: 6 hours Sessions 2, 3: 3 hours each	16 hours	9	8	2

2. – Method

2˙1. *Participants and boundary conditions of the course.* – The course was offered jointly by Dutch universities (*i.e.* VU, UU, UvA, and TU Delft) within the second semester of the one-year, post-graduate, teacher-education program. A total of 33 pre-service teachers (more physics teachers than chemistry) took part in one of the three iterations of the course (table I). The teachers were willing to cooperate with us to gather data from their learning as well as teaching in the classroom.

For more information about the context of science-teacher education in the Netherlands and about the boundary conditions in the course, we refer to Tran *et al.* (2014). Here we summarize briefly:

- Time intended for the course was very limited (only one EC equivalent to 28 learning hours) in regard to extensive activities (*e.g.* demonstrations, hands-on, discussions, reports, etc.) in life sessions and intensive individual tasks of practicing the new ICT tool and trying out the lesson plan in the classroom. Meanwhile, most of the participating teachers were experiencing pressures of a first year teacher, and many of them already had a teacher appointment rather than only a guided internship (table I). Therefore, they had to struggle with management of time and energy for university-course assignments, preparation for regular lessons, and extra school-tasks. In short, the time for teachers to carry out individual tasks was really limited.

- All of the teachers had at least a Bachelor of Science and one-year master studies in their subjects. However, their backgrounds were very heterogeneous in terms of age (from 24 to 50 years old); mastery of subject area knowledge (from just graduated to a PhD or even years of research experience in physics or chemistry); experience with the ICT tools (many participants knew very little about video measurement or modeling; some were quite familiar with data logging; some had no experience with Coach, but with another platform). Their teaching conditions (*e.g.* levels of students, the school's experience with ICT applications in science, and infrastructure like software, sensors, interfaces, and computers) were very different as well.

2·2. *Teachers' learning scenario, support materials, and assessment instruments.* – From the design principles, we elaborated the course set-up, which interacted with the boundary conditions, including three components: teachers' learning scenario, support materials, and assessment instruments. Initially the three life sessions in the course were spread over 5 weeks, later this was extended to 7 and finally 11 weeks in order to allow more time for the classroom try-out of teachers' lesson plans (table I). In between life sessions were two teachers' successive individual tasks (fig. 2) which were coupled with the two content goals (TCK & TPCK). In Session 1 teachers were taught about possibilities of the three tools, and then they were suggested to specialize in one tool by choice (fig. 3(a)). Task 1 required teachers to continue mastering the tool they chose by practicing the given Coach activities. In Session 2, the teachers designed an inquiry-based lesson plan with ICT activities which utilized the chosen Coach tool. Task 2 required teachers to try out their lesson plans in the classroom (figs. 3(b), (c)). Lastly, in Session 3 the teachers reported and evaluated their try-outs (fig. 3(d)). In a nutshell, we motivated and supported the teachers to follow a flexible scenario in which they started from a broad perspective about possibilities of using three ICT tools in science education (Session 1), and then they went deeply and narrowly (fig. 2) to the core of learning to use one tool (Task 1) to teach one lesson to one class at a certain level of inquiry in a

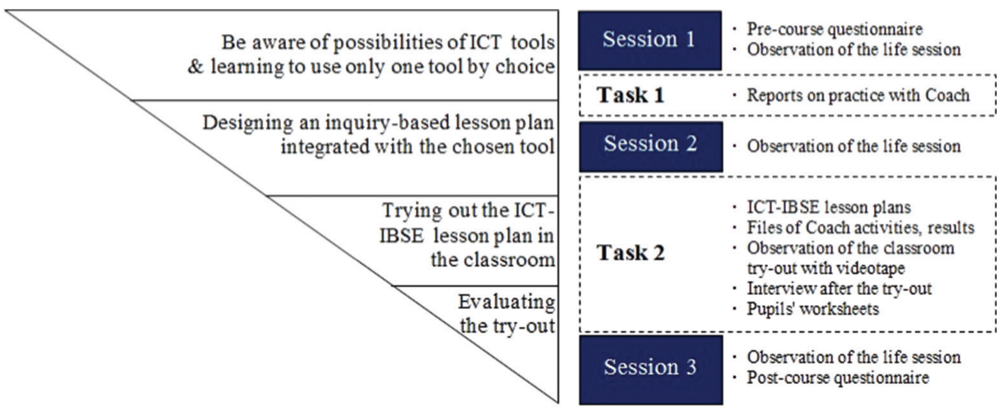

Fig. 2. – The course's scenario for teachers' learning and data collection.

(a) (b) (c) (d)

Fig. 3. – Teachers' activities in chronological order of the teachers' learning scenario.

particular context (Session 2, Task 2), so that they could reflect (Session 3) and really appreciate the integration of ICT into Inquiry-Based Science Education (IBSE).

Tran *et al.* (2014) described the support materials which were used for Case study 1, and those did not change much for Case studies 2 and 3. For the TCK domain, the Coach activities were for teachers to master their chosen tool mostly on their own. For the TPCK domain, we designed a form for an ICT-IBSE lesson plan for teachers. It was like a scaffold with five phases (*i.e.* orientation, design of experiment, execution, interpretation, and what did we learn) for teachers to construct their own plan of applying the ICT tool in an inquiry-based lesson. There are additional questions/requirements in the form such as "What will you do to make sure the lesson is minds-on?", "Prepare examples of teacher questions when going around to stimulate minds-on". A list of inquiry skills is given at the end of the form, and teachers had to indicate which skills they incorporated in their lesson. The teachers could browse these support materials on the course's online environment. We also provided teachers online assistance (via emails, forums) whenever they encountered any difficulties in carrying out the individual tasks.

Regarding evaluations of teachers' professional development, Guskey (2002) introduced five critical levels: level 1: teachers' reactions, level 2: teachers' learning, level 3: organization support and change, level 4: teachers' use of new knowledge and skills, level 5: students' learning outcomes. The assessment of teachers' learning during our course (fig. 2) only focused on levels 1, 2, and 4. We utilized multiple data-collection methods such as pre- and post-questionnaires, observation (fig. 3), interviews, and documents. Therefore, a finding from one source can be compared and contrasted with that from another to ensure internal validity of data analysis. For example, we asked teachers to submit their lesson plans in advance (documents), and then commented on it. Next, we came to their schools to observe their classroom try-outs with videos taped (Observation). After that, we carried out a semi-structured interview with voice recorded (Interview) to get their self-evaluations of the try-outs.

TABLE II. – *Numbers of teachers, who tried out the lesson plan (before or after Session 3) or not at all.*

	N	Before Session 3	After Session 3	Not try out at all
CS1	12	2 (16.7%)	9	1
CS2	12	7 (58.3%)	2	3
CS3	9	7 (77.8%)	2	0
Total	33	16	13	4

3. – Results

Outcomes of the three case studies are presented in the following three sections which are coupled with the three research questions. To some particular aspects, we clarify results of each case study so that the reader might judge the development process of the course throughout the three iterations. The data collected from various resources were consistent with each other. Data about individual teachers vary, reflecting heterogeneity of their backgrounds and teaching conditions, but all of these data indicate improvement of their knowledge and skills to some extent in regard to the use of ICT for IBSE.

3˙1. *Faithful implementation and effectiveness of the course.*

3˙1.1. Faithful implementation of the course – assessment of teachers' learning process. All activities (*i.e.* lectures, demonstrations, hands-on practice, and group-discussions) intended for life sessions were covered and executed quite smoothly. Twenty-nine pre-service teachers (out of 33) fulfilled the complete cycle of designing, implementing, and evaluating an ICT-IBSE lesson in the classroom (table II). Through teachers' self-reports, we estimated that they invested 14.5 hours on average outside the life sessions, and this number did not deviate much from what we had anticipated (table I). The largest proportion of this time was for preparing the lesson plan with the related Coach activity (5.3 hours, SD = 3.0), followed by 3.9 hours (SD = 2.0) for practicing the Coach activities, 3.0 hours (SD = 1.6) for arranging, executing, and evaluating the classroom try-out.

a) What did not go as intended

The most remarkable deviation was that 17 teachers (incl. 10 in CS1, 5 in CS2, 2 in CS3) (table II) could not try out their lesson plans before Session 3 which was intended for them to share their classroom experience. Accordingly, the intended activities for Session 3 had to be adjusted to suit teachers at different stages of the learning scenario. In addition, we had to spend weeks after the course to follow teachers' try-outs. Eventually, 13 teachers (out of 17) managed to implement their lesson plans, but they did not have an opportunity to get feedback on the try-out from fellow teachers and teacher-educators.

11 teachers (incl. 5 in CS1, 4 in CS2, 2 in CS3) did not follow the suggestion of specializing in only one tool, which was emphasized in both the course documents and Session 1. In Session 1, many teachers were eager to learn new tools (*e.g.* modeling or video measurement). Unexpectedly, conditions (*e.g.* students' familiarity with the tool, room in the curriculum) for application of modeling or video measurement were inconvenient to some teachers. Therefore, they had to apply another tool (*e.g.* data logging) in order to prepare a lesson plan which was feasible for the classroom try-out. However, most of these teachers could not reach advanced skills with Coach.

The teachers did not utilize the online environment as much as we expected. We designed the forum (within Moodle for CS1, CS2 or Google for CS3) for teachers to discuss with peers or teacher educators about their difficulties to individual tasks, but they did not post any questions on the forum at all. Additionally, most of teachers struggled a lot with technical details of the Moodle platform (CS1 and CS2) whereas they only used it as a resource of support materials. Consequently, for Case study 3 we just designed and offered a static, simple webpage with the course's description and support materials. In fact, some teachers asked via email about ICT problems. Other teachers asked their Coach-experienced colleagues in the school, and some others left the questions for life sessions. It turned out to be rather difficult and took time for teachers to explain an ICT problem, and then discuss back and forth in text via the Internet. Even with us as Coach-experienced users, we had to spend much time to understand teachers' questions, and then prepare descriptive texts with screen-shoots or video clips for effective online communication. On the other hand, discussions via the Internet about the inquiry-based lesson plan went quite well. Therefore, in later iterations of the course we increased practice time with the tools during life sessions, so any trouble shooting could be done quickly with assistance of peers and the teacher educators rather than with much frustration at home.

b) Obstacles to teachers' ICT-IBSE tryouts

Pre-service teachers' workload was high and demanding. Here was one of many teachers' complaints, "*I'm afraid I haven't got very far with my Coach work. My SPD* (teacher mentor) *has been absent all week, and I haven't had any guidance or support on the course of action to take regarding the Coach project to implement at school... I'm overworked and overstressed as I've been pretty much thrown in the deep end at school with very little guidance or supervision due in part to the unfortunate timing of developments related to my SPD and events at school... I find it very frustrating to see how much can be done with a tool such as Coach, but how little in practice I can achieve given the circumstances (lack of means, guidance and momentum at school)*". Some teachers (mostly in CS1 and CS2) completed the lesson plan in hurry, so they could not send it to the course's teacher educator in advance for suggestions and improvement. Consequently, they did not really review the entire plan carefully or practice it before the classroom try-out.

Possibilities for teachers' classroom try-outs between Session 2 and Session 3 turned out to be influenced by many factors. First, room in the school physics or chemistry curricula for integration of certain ICT tools was limited. For instance, a teacher could not find any opportunity to integrate modeling activities in the chapter of direct current circuits which she was teaching in this duration. Second, dependent on progress of the curriculum, the try-out schedule of some teachers (CS1) could not be arranged before Session 3. Third, the school's agendas affected the try-out plan remarkably. For example, the intended time was at the end of the school year (CS2). The teachers rushed to complete all the lessons or prepare students for the final exam, so they hardly searched for room for the try-out.

About half of the teachers reported good support of the school for the incorporation of ICT in teaching practice. Here was an example, "*We have Coach Lab II + and Coach lab mobile with specific science laptops with Coach software installed. The science department encourages the use of Coach software and my mentor was very positive about the use and continued use of the program and sensors*". The other half complained about inconvenient conditions for ICT-IBSE try-outs in their schools. These schools lacked Windows PCs, Coach interface, and sensors; the teacher mentor did not have experience with the ICT tools. This was a circumstance shared by a teacher, "*For next year, the chemistry department is trying to get computers or tablets for in class, but at this point ICT in the classroom is about non-existent.*"

c) How the blended set-up and support materials were useful to teachers' learning

In the post-questionnaire, we asked the teachers, "We applied a setting of 3 sessions spread over several weeks and major tasks in between the meetings instead of an intensive training in 3 consecutive days without tasks outside the course. - Which setting do you prefer?". Twenty-eight teachers (out of 33) reacted to this questions, and 20 of them preferred the blended set-up with life sessions and individual tasks in between. Following was a teacher's feedback, "*I prefer spread out sessions with tasks in-between. That gives me more time and occasions to practise the tool in a more realistic setting (that means doing what I really want to do with it without constant guidance). I get more time to think about what I really want to do and what kind of problems I really have and why. Then I can ask for appropriate help. With intensive training I always feel I'm doing what I'm told to do instead of what I will in actual fact want or need to do. The likelihood that I will afterwards actually use it is then much lower*". In the blended set-up, teachers could learn in their own time and pace with preferred styles (*e.g.* following text/video instructions or trying and then fixing errors). There were 6 teachers who had no preference one way or another and 2 teachers who preferred the other set-up. A disadvantage of our blended set-up was pointed out by a teacher as follows: "*A longer period is the problem to keep your focus on course.*" Moreover, activities intended for Sessions 2 and 3 are based on accomplishments of the individual tasks. Therefore, the teachers admitted that emails sent at certain moments during the course somehow to remind them about the tasks were very useful.

There were 7 teachers (4 in CS1, 3 in CS2) who were absent from Session 1 of the course, and 6 of them had a meeting with us for about an hour to catch up. We instructed them how to work with support materials. After that all of these teachers could follow the course and accomplished their classroom try-outs. Especially a teacher, who was absent from both Sessions 1 and 2, worked with us for 3 hours to practice with Coach video measurement, and then we introduced the form for the ICT-IBSE lesson plan. Eventually, she could manage to design and teach the lesson in which the given Coach video-measurement activity (*i.e.* falling of a shuttlecock) was applied as an interactive-demonstration. She completed the course requirements, although at a level which was lower than the others. These cases indicated that the support materials, especially the Coach activities and the form for the ICT-IBSE lesson plan, were very helpful for teachers' learning on their own. This result was in line with teachers' responses to the post-course questionnaire.

3·1.2. Effectiveness of the course – assessment of teachers' learning outcome.

a) Level of awareness and motivation

The teachers pointed out different aspects of benefits of ICT tools for science education through the post-course questionnaire or life discussions. Here was a teacher's reflection, "*Using computers in general is a motivating factor for the lesson; the students enjoy the lesson more, and that increases their output of learning. Data logging is a very handy saving a lot of handwork to create graphs. Student get a nice graph after relatively little work, such positive experiences are stimulating. Video measurement is a lovely tool to answer every day question, e.g. how hard did Zlatan kick that ball? Modeling is more complex, but yields the biggest rewards as well. Once the students can understand most*

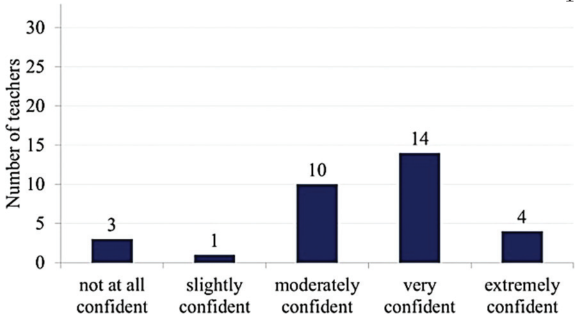

Fig. 4. – Teachers' confidence in learning ICT tools which they did not choose to learn in depth during the course.

models, then concepts can become thoroughly fortified into their brains after modeling with them".

Becoming aware of the potential of ICT, teachers were soon motivated to learn further during and after the course. Teachers' eagerness of learning Coach in hands-on activities in Sessions 1 and 2 were clearly observable. Here is an example.

> A teacher was inspired by a demonstration about Coach in Session 1 so that she asked us for a Coach activity of height measurement under control of a button, which could be used in her school's open day. We instructed her via email how to develop the activity which required many advanced skills, so it did not run well the first time. We continued to discuss back and forth via email. In time, she could manage to execute the experiment with students and parents. In Session 2, she confidently presented the standalone setup: how to calibrate the ultrasound sensor, how to trigger via the light sensor, and how to analyze hundreds of data by histogram. She looked proud to share the satisfaction of parents and students' interest about her measurement. It was not difficult for her to answer questions from a fellow teacher. We did not require teachers to apply the tool as soon as she did in Session 2. In this instance, the teacher was motivated to learn, and she got quite advanced skills with the tool which she chose in such a short time.

Many teachers shared their willingness to learn and apply ICT tools after the course. Here was a teacher's thought, "*Actively wanting to learn to use Coach, since most teachers I've met (if not all) seemed to be so negative about it. I wanted to learn how to give students the opportunity to practical work beyond the (often very boring, uninteresting and far removed from their daily life and experience) classical lab practical and experiments that have been done through the years and that mostly populate the text books, physics websites and experiments' databases.*" Moreover, we asked teachers the following question via the post-course questionnaire, "In the course, you focused on learning to use and apply only one of the Coach tools (*i.e.* data logging, video measurement, or modeling) in IBSE. How confident are you in learning by yourself and applying the other tool(s)?" The gathered data (fig. 4) indicate that most of the teachers were confident to learn further and apply ICT tools in which they did not specialize during the course.

b) Level of technical mastery of the tools

The teachers reported about their familiarity with each of the three ICT tools before and after the course through a 5-point, rating-scale question: 1 = not familiar at all, 5 = extremely familiar. These data enable us to estimate changes in familiarity (with a

TABLE III. – *Familiarity of teachers with the tool they specialized in before and after the course and results of the Wilcoxon signed rank test and effect sizes.*

Groups of teachers who learnt the same ICT tool	Pre-course mean (SD)	Post-course mean (SD)	Statistic Z	Effect size		p
				Cohen's d	Pearson r	
Data logging ($N = 18$)	2.5 (1.15)	3.44 (.70)	2.804	0.99	0.47	0.005
Video measurement ($N = 21$)	2.05 (.92)	3.05 (.86)	3.084	1.12	0.48	0.002
Modeling ($N = 17$)	2.59 (.87)	3.65 (.86)	2.846	1.23	.49	0.004

certain tool) of teachers who chose to specialize in that tool further during the course. We categorized the data into three groups of teachers (considering three case studies together) who learnt the same particular tool: Data-logging (18 teachers), video-measurement (21 teachers), and modeling (17 teachers). The sum of numbers of teachers in these groups exceeds the number of participating teachers (33) in the three case studies because there were many teachers who studied more than one tool during the course. We applied the Wilcoxon signed-rank test to assess whether the familiarity of teachers (on average) to a particular tool (which they learnt) differ statistically before and after the course. The result was that the familiarity of teachers to the tool (they chose to learn) after the course was statistically significantly higher than that before the course as p values are all much smaller than 0.05, and the effect size is considered large: Pearson r values ~ 0.5 and Cohen's d values > 0.8 (table III). These increases in teachers' familiarity with ICT tools were also observed in their Coach activities as well as in their work with Coach in life sessions and in the classroom.

To prepare the Coach activity for the ICT-IBSE try-out, the teachers had options of using one of the Coach subject activities (which we gave them as support materials) or modifying it to be more suitable for an inquiry-based lesson. These options suited teachers with just basic Coach skills. Furthermore, teachers were also encouraged to develop a new Coach activity with a strong inquiry component. However, developing a new Coach activity demanded from teachers not only a good idea and a feasible design of the activity but also advanced Coach skills and some experience with trouble shooting. Throughout the three case studies, 8 teachers (incl. 2 in CS1, 1 in CS2, and 5 in CS3) could develop their own, new Coach activities (table IV) with little or no support from the teacher educator.

c) Level of application of ICT in IBSE

Before the course, the teachers had good knowledge about inquiry-based teaching, but little classroom experience. Eventually, 30 teachers (out of 33) could design an inquiry-based lesson plan which was integrated with a Coach activity. The lesson plans reflected teachers' understanding of inquiry-based teaching with clear descriptions about the lesson topic, students' prior knowledge, and objectives of knowledge and skills as well as details about what teachers and students would do in each inquiry phase. Coach activities were used at the relevant point of the learning process, supporting certain levels of students' investigations (*e.g.* open inquiry, guided inquiry, and interactive discussion with demonstration).

Twenty-nine teachers implemented their lesson plans in the classroom. All lessons were videotaped, and most were observed by the first author. The try-outs were in a

TABLE IV. – *List of teachers' newly developed Coach activities.*

Case study	Topics of newly-developed activities	Tools
CS1	1. Chemistry - Chemical equilibrium	Modeling
	2. Physics - Determining the shape of an object (using-ultra sound sensor)	Data logging
CS2	3. Physics - Temperature dependence of a resistance (using voltage and current sensors)	Data logging
CS3	4. Chemistry - pH calculation after dissolving HCl	Modeling
	5. Physics - Horizontally-launched projectile (using high-speed video)	Video measurement
	6. Physics - Resonance of a wine glass (using a sound sensor) (fig. 5)	Data logging
	7. Chemistry - Carbon cycle	Modeling
	8. Physics - Felix Baumgartner's supersonic fall from space	Modeling with real data

regular lesson with a whole class, a school project for a few weeks, or an extracurricular lesson with a small group of student volunteers. Teachers looked confident in teaching the lessons, and most of them did not meet any problems in manipulating with Coach. In the interview after the lesson or in the self-evaluation report, teachers could point out what went as intended and what were deviations in the implementation. Most of deviations were caused by the lack of teaching experience (*e.g.* time management, interaction with students). Some lesson plans turned out to be too ambitious as some content could not be covered, or students did not achieve some objectives. Many lesson plans were not implemented at the intended inquiry-level faithfully. However, most of the teachers were quite content with what they had done with the try-out because that was the first time they taught such an ICT-IBSE lesson. They were motivated to teach the lesson again with some revisions. One teacher was so inspired by effects of the course that she published her learning experience of designing and teaching an inquiry-based lesson with Coach modeling in the Dutch science-education journal, NVOX.

3˙2. *Technological and pedagogical problems of teachers in learning ICT for IBSE.*

3˙2.1. Technological-science problems of teachers in using the ICT tool. In Session 1, we observed teachers' how-to issues in learning to use a certain Coach tool. They had to get over initial hurdles in learning a new tool, regarding new concepts (*e.g.* video measurement: frame, scale, time calibration, point tracking) and hands-on manipulations (*e.g.* modeling: connecting variables and constants). Many teachers could achieve basic technical mastery of the tool after a certain time by practicing Coach tutorial activities. However, to understand or develop a complete Coach activity for students, teachers faced additional challenges such us proper understanding of concepts and mechanisms by which the tool measures, processes, or represents the related quantities. Following are three examples of teachers' technological-content problems, which corresponded to three different Coach tools and occurred at different moments in teachers' learning scenario.

A teacher designed an experiment (fig. 5) about resonance of a glass. He tried out the same set-up with two different measurement devices (incl. Coach), but got two different results for the resonance frequency. The Coach result looked incorrect. He struggled in

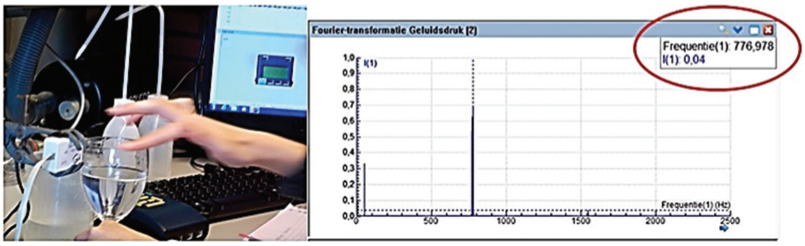

Fig. 5. – A Coach activity for measuring the frequency of resonance of a glass.

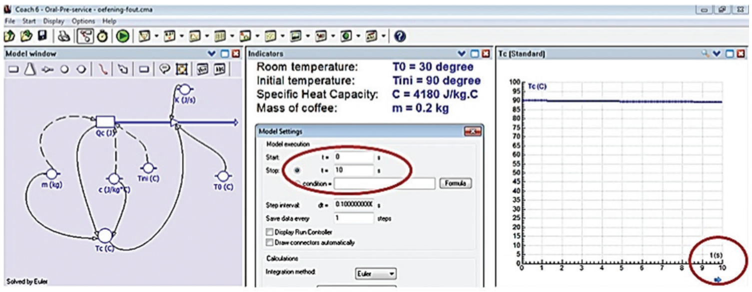

Fig. 6. – A Coach activity for modeling cooling of a cup of coffee.

checking the set-up, redoing several times, but still getting the wrong result. Eventually he asked us about this problem in Session 2. The resonance frequency was expected to be about 800 Hz whereas the sampling frequency in his measurement setting was only 50 Hz (default). We suggested him to increase the sampling frequency to 5000 Hz. Consequently, the Fourier transform of the sound signal yielded an acceptable value of the resonance frequency. In this case, the teacher managed to develop a new Coach activity, but he needed some experience of trouble shooting which requires the understanding of how Coach samples measurements.

A teacher wanted to apply the given Coach model of cooling down a cup of coffee for her classroom try-out. However, she was uncertain if she could react properly to students' questions about Coach modeling, so she tried to recreate a model from a blank modeling window. When running the model, she got the unexpected graph in which temperature seemed to remain constant over time (fig. 6). She checked constants, variables, and connections carefully again to ensure that they were exactly the same as those in the given model. Executing the model again, she still got the "strange" graph, so she lost her confidence and emailed for help. In the given model, the execution time was set to one hour, so it produced a nice curve of temperature *vs.* time, decreasing from initial temperature to room temperature, then remaining constant. What she did not notice when reconstructing the model was the execution time, only 10 s (default). Therefore, the change of temperature was not visible in the graph. We suggested her to change the execution time, and then she could deal with the problem easily. The challenges to her were not only about getting familiar with technical details of the modeling tool, but also about learning to model a phenomenon, considering various issues such as concepts, laws of science, actual parameters. She had to learn both aspects. Through the close supervision via email, we helped her to overcome obstacles, and then she did progress further.

In Session 1, a teacher practiced the tutorial activity about measuring coordinates

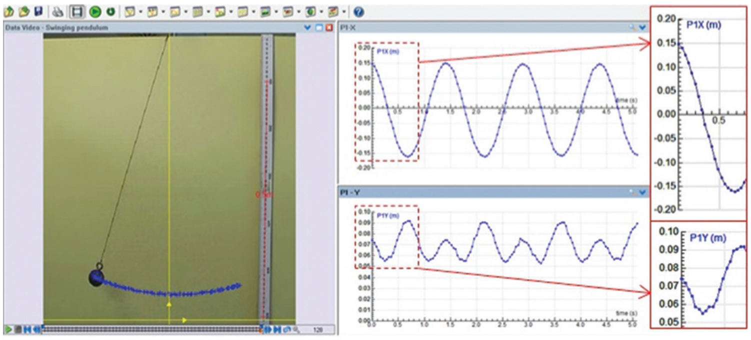

Fig. 7. – A Coach activity for measuring on a video of a pendulum with x *vs.* t above and y *vs.* t below.

of a pendulum bob over time, and then plotting the graph of horizontal coordinate (x) *vs.* time. He predicted from theory that the y-t graph would also have the sine shape as the x-t graph, so he plotted the y-t graph as well. However, the y-t graph actually did not look as expected (fig. 7) whereas the x-t graph resembled a theoretical sine shape. He repeated the measurement, clicking on the central of the bob as precisely as he could, but the result did not change. He struggled with this problem for almost the entire hands-on time. Eventually, he asked for help. Errors in the measurement of x, y coordinates could not be avoided due to the actual set-up and manipulations such as spatial perspective, scaling, clicking on the central manually. Change of x (about 30 cm) was much larger than the error (about 1 cm), so the error was not seen clearly on the x-t graph. Meanwhile, change of y was only about 4 cm, so the error was not neglectable, and it was shown obviously in the y-t graph. The problem to the teacher was not the actual measurement, but the physics issue of how to interpret the data.

3·2.2. Pedagogical-science problems of teachers in teaching with the tool. In the Bachelor of Science and Master of Science programs, all teachers completed several university-laboratory courses and thesis work which required inquiry and laboratory skills. Moreover, in Sessions 1, 2 of our course the teachers studied the theory of inquiry-based teaching and how to develop an ICT-IBSE lesson. Teachers' knowledge about application of ICT into IBSE, therefore, was reflected in the lesson plans to some extent. However, pre-service teachers lacked practical knowledge and experience which they had to invent for themselves in their teaching situations. Thus, the demand of teaching a lesson integrated with ICT and IBSE components really stressed additional cognitive load on the teachers. To reduce complication of the task, we left ample options for the teachers to select which ICT tool was used to teach, what topic, at which level of inquiry. It was even possible for teachers to arrange just a part of the lesson with inquiry teaching, and other parts with direct instruction. However, the teachers still encountered didactical problems. Through classroom observations and videos, we found out that there was a big gap between intended inquiry activities in the lesson plan and actual realized inquiry in the classroom. Following are two examples.

Example 1:

> In a regular lesson, a teacher provided ultra-sound sensors to groups of students and asked them to design an experiment to determine shapes of some hidden objects. However, he did not realize the implications of the fact that students were not really

familiar with the sensor and the Coach software. The students did not come up with the idea of the experiment. Therefore, the teacher had to come to groups and explain the investigation problem, then raise detailed questions to involve students in the inquiry process. Consequently, although the plan was bounded inquiry, the implementation really was an interactive demonstration, not with a whole class as usual, but with each group of students. With more practical knowledge and experience he would have posed the investigation problem differently or would have been able to respond better to the implementation problems.

Example 2:

In a school project, a teacher assigned her students to design an experiment measuring capacitance through discharge of a capacitor. However, no matter the student accomplished the design or not, the teacher gave all students the same cookbook instruction to execute the experiment (with voltage, current sensors and circuit components). In fact, many students had not completed the experiment design when already receiving these instructions. To these students, the project was a cook-book laboratory. Because of the desire that all students would complete the project with good reports, the teacher implemented her guided-inquiry lesson plan with much less inquiry than intended.

3·3. *Revisions of the course set-up after each case study.*

Revisions after Case study 1. In life sessions of Case studies 2 and 3, we allocated more time for teachers' practice with Coach and mind-on tasks about inquiry teaching; and less time for plenary demonstration about Coach and lectures about IBSE. Teachers shared and discussed their individual work with small groups (CS2, CS3) instead of with the whole-class, so that every teacher could get detailed-feedback on her/ his tasks. The framework of inquiry-based teaching was introduced right from Session 1 (CS2, CS3) instead of Session 2 (CS1). Hence, the teachers could start thinking about the inquiry-based lesson earlier and start discussing this lesson plan and possibilities for its try-out in the school.

Revisions after Case study 2. About the time frame, Session 1 took place in a whole day (CS3) instead of a half day (CS1, CS2), and the time between Session 2 and Session 3 was extended considerably, 9 weeks instead of 3 weeks (CS1) or 4 weeks (CS2) to enable the teachers:

- To practice Coach with direct support from peers and trainers in Session 1. Hence, they could get over initial difficulties with the tool and progress much faster than practicing Coach alone at home.
- To arrange and execute their lesson plans before Session 3

About individual tasks, teachers were requested to read PPT slides about Coach and explore conditions for the classroom try-out in advance so that right in Session 1, they could already choose their tool for specialization. Moreover, the teachers had to complete a first draft of the lesson plan before Session 2, so in this session, they could complete it (CS3) with direct supervision from the teacher educator instead of just starting with finding some ideas (CS1, CS2).

Did the revisions work out? From Case study 1 to Case study 3, the number of teachers who did not follow the suggestion of learning only one tool during the course decreased (*i.e.* 5 for CS1, 4 for CS2, 2 for CS3). There were fewer and fewer teachers who could not try out before Session 3 (*i.e.* 10 in CS1, 5 in CS2, 2 in CS3) (table II). In Case study 3, the teachers were quite satisfied with time distribution for each type of activities in life sessions. In addition, teachers in Case study 3 invested more time (17.1 hours) outside life sessions than those in Case studies 1 and 2. There were more teachers who developed new Coach activities for the ICT-IBSE lesson in Case study 3 (*i.e.* 5 compared to 2 in CS1 and 1 in CS2). The classroom try-outs in Case study 3 were implemented more faithfully than those in Case studies 1 and 2. In conclusion, the revisions of the course after each case study worked out as intended.

4. – Conclusions and discussions

4˙1. *Conclusions*. – The teachers' learning scenario (incl. life sessions and individual tasks) was implemented quite faithfully. The activities intended for life sessions were covered and executed fairly smoothly. There were obstacles to teachers in designing and teaching an ICT-integrated inquiry-based lesson such as their demanding workload, limited room in the curricula, dependence on the school agenda, or lack of needed ICT infrastructure. Therefore, many teachers could not try out their lesson plans before Session 3 as intended. The teachers spent a reasonable amount of time outside life sessions for individual tasks, using support materials and online assistance. Eventually, most of the teachers (29 out of 33) fulfilled the complete cycle of designing, implementing, and evaluating an ICT-IBSE lesson in the classroom. The Coach activities for practicing ICT skills and the lesson-plan form for preparing an ICT-IBSE lesson were essential and useful for teachers' learning during the course.

Within a limited time, three heterogeneous groups of pre-service teachers achieved a reasonable level of competence regarding the application of ICT tools in inquiry-based lessons. Being aware of potential benefits of ICT tools and of carrying out individual tasks, the teachers were soon motivated to learn further during and after the course. After the course, teachers' familiarity with the tool which they chose to specialize in was significantly higher than that before the course. Most of the teachers did not meet any difficulties in manipulating the ICT activity in the classroom try-outs. Some teachers (8 out of 33) could develop their own, new ICT activities which required new ideas and advanced skills with the tool. Teachers' lesson plans reflected their knowledge of incorporating ICT into IBSE, but some were too ambitious, so just part of learning goals were achieved in the classroom. Teachers' efforts to implement the lesson plan indicated different possible contexts for application of ICT into IBSE such as a regular lesson with a whole class, a school project for a few weeks, or an extracurricular lesson with a small group of student volunteers. Although most of the teachers were confident in executing the lesson plan, there was still a considerable gap between intended inquiry activities and actual realized inquiry. However, the teachers were able to evaluate the lesson after the tryout, and most of them felt confident to learn other ICT tools (which they did not specialize in during the course) on their own after the course and apply these tools in the inquiry-based lesson.

In addition to objective difficulties from external factors (*e.g.* time constraints, teaching conditions), the teachers struggled with problems regarding their conceptual understanding and experience about ICT, inquiry-based teaching, and science. First, many teachers had to get over initial hurdles in learning an unfamiliar tool (*e.g.* video measurement or modeling) such as new ICT concepts and how-to issues of particular manipulations. Considering the tool in the whole laboratory activity, the teachers faced further challenges which required proper understanding of the phenomenon (*i.e.* concepts, laws, and events) as well as knowledge of how the tool collects (or models) information (about the phenomenon) and of how it then processes and represents these data. They also needed trouble-shooting experience to deal with these types of problems. Second, many teachers came across problems in executing the ICT-IBSE lesson plan in the real classroom environment. In addition to the lack of practical knowledge (*e.g.* time management, interaction with students), the teachers needed experience of getting students to focus on inquiry and concept learning in the classroom, which is a typical problem of beginning (and experienced) teachers (Abrahams and Millar, 2008).

In the learning scenario, Sessions 1 and 2 were to prepare the teachers to be able to master technical skills (Task 1) and to teach an inquiry-based lesson with the ICT tool (Task 2). Meanwhile, activities on Sessions 2 and 3 were based on accomplishments of the two successive tasks. Many teachers got frustrated with technical problems in manipulating the ICT tool at home. In addition, arranging and teaching an inquiry-based lesson with the ICT tool turned out to be very demanding and time-consuming. Therefore, main revisions of the course throughout the three case studies were to adjust activities in life sessions and the time frame in order to make teachers' individual tasks more feasible and endurable. For example, we allocated more time for hands-on, in-group activities and less time for theory, plenary activities in life sessions so that the teachers could earlier specialize in their individual issues (*i.e.* practicing ICT skills, preparing the lesson plan) and consequently, progress faster because of in-time, direct support/feedback from the teacher educator. Spending a whole day for Session 1 (instead of a half day), the teacher could get basic skills with the ICT tool which would enable them to troubleshoot their difficulties (in working with the tool) themselves. Moreover, the IBSE framework was introduced right from Session 1, so the teachers could start to design and complete the first version of the lesson plan before Session 2 (shifting the first part of Task 2 forward). The duration for Task 2 was extended considerably, so the teachers could find room for arranging and executing their lesson plans before Session 3. These revisions worked out as the course was implemented more faithfully and effectively in Case study 3.

4˙2. *Discussion.* – Integration of technology into science education is a need globally recognized, and the teacher is the key factor for the practical technology-incorporation in the classroom. This study, therefore, aimed at development of a course on this TPCK domain which can be integrated in the teacher-education program. From the theoretical exploration, we defined the three principles (Sect. **1**˙2) underlying the course design, following which teachers are encouraged to become aware of possibilities of all three ICT tools, but then specialize in one tool by choice (*depth first*) through a complete cycle of designing, teaching, and evaluating an inquiry-based ICT-integrated lesson in the classroom. The classroom application of what teachers learn in life sessions might enable them to experience and appreciate various aspects of integration of ICT into IBSE (passing over threshold). This also requires a blended set-up for the course, including life sessions (as in a traditional course) and individual tasks outside life sessions in which the teacher work with sufficient support materials and online assistance. Success in an in-depth complete cycle with one ICT tool might bring teachers' expertise and inspiration to learn others on their own (*breadth later*). Outcomes of the three case studies proved that these three principles are suitable to the Dutch boundary conditions in which the time for pre-service teachers' learning is very limited, and their backgrounds and teaching conditions are very heterogeneous.

The design-based research framework (fig. 1) proved to be suitable to the development of the course. This approach guided us to elaborate design principles (defined from theoretical exploration) for the teachers' learning scenario taking into account the boundary conditions. The three iterations of (re)constructing, executing, and evaluating the course helped to optimize the faithful implementation and effectiveness of the course in the Dutch context. We recommend the course's learning scenario with the support materials and developed assessment instruments to teacher educators who are going to prepare their pre-service teachers to apply technology into science education in the Netherlands. For a broader perspective, we have been investigating applicability of the design principles and support materials in other countries (*i.e.* Slovakia and Vietnam) with adaptations geared to a different local, educational, cultural context. The outcomes of the additional case studies at the international level may reveal some limitations of the course in the Netherlands and also provide recommendations for adaptations to other contexts and countries. The conclusions and discussion above were based on data from teachers' learning with the Coach platform, but easily transferrable and valid for other platforms.

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