Development of a course on integrating ICT into inquiry-based science education

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Summary

Background and research questions

Information and Communication Technology (ICT) and Inquiry-Based Science Education (IBSE) with innovative features have been available for more than thirty years and have been included in formal science curriculum documents. The science education community mostly agrees about relevance of *integration of ICT in IBSE* for pupils exercising inquiry practices, acquiring inquiry skills, and understanding scientific inquiry. However, ICT in IBSE is still very much under-used and applied at a relatively small scale in most countries. When it is used, the use often lacks the basic characteristics of inquiry. Factors involved are amongst others: a) limited curriculum time and limited teacher preparation time; b) mismatches of the IBSE goals with commonly used lesson materials; teaching methods; and assessment and examination (e.g. prescriptive nature of materials and methods, predominance of content over inquiry goals), and c) insufficient teacher preparation and training on integrating ICT into IBSE. All of these factors need to be changed consistently and in concert to realise proper incorporation of ICT and IBSE into a classroom where manipulation of equipment and software is turned to manipulation of ideas and concepts for knowledge generation and validation.

Within our PhD project, we focussed on preparation and training of science teachers on ICT in IBSE teaching and developed an effective and relatively short course for student teachers and teachers with diverse teaching experience. The present research confined the ICT in IBSE teaching to a) three constructional tools: data logging with sensors, video measurement, and dynamical modelling and b) the use of these tools to support inquiry by pupils. In an ICT in IBSE activity, the pupils should have some role not only in executing the experiment/model but also to some extent in formulating research questions, designing the experiment/model, and interpreting the results. We developed a short course so that it can be accommodated within typical overloaded teacher education programmes or adopted as an in-service course. Furthermore, educational theories and products, such as our ICT in IBSE course, do not always travel well as educational and cultural contexts in different schools and countries can be very different. That is why the present research included three case studies in The Netherlands, Slovakia, and Vietnam and in pre- and in-service teacher education. That way we could test the transferability of our course design and the generalizability of the pedagogical principles at the basis of this design.

The aim of the present research was twofold. First, the objective was to design a short course, which – with some adaptations - will be effective in widely different educational settings. Second, this research was to investigate *the validity of pedagogical principles*, which were used to guide a) the design, implementation, evaluation, and optimisation of the course and b) the extent to which the course can be adjusted to the different settings in the Netherlands, Slovakia, and Vietnam. The pedagogical principles are at a higher level of abstraction and intended to be generalizable across educational and cultural contexts. The design research approach was applied as it can provide guidelines and scientific reasoning for such a research and design process, which was guided by the two research questions. First, *what are characteristics of an effective, short course for Dutch student teachers to learn to*

apply the ICT tools in IBSE? Second, *to what extent is the course applicable in different educational and cultural contexts of pre- and in-service teacher education in different countries (i.e. the Netherlands, Slovakia, and Vietnam)?*

Course design and research design

The general aim of the course was elaborated into the four objectives as follows:

1. *Awareness objective*: participants become aware of educational benefits of the ICT tools in science education.
2. *ICT mastery objective*: participants master skills to operate the ICT tool.
3. *ICT in IBSE objective*: participants can design, implement, and evaluate an ICT in IBSE lesson.
4. *Motivation objective*: participants are motivated to continue studying the ICT tools and trying out ICT in IBSE lessons with pupils.

The ICT in IBSE objective (3) was considered as the *main objective of the course*. In order to reach this objective, participants had to achieve a certain minimum level of mastery of the ICT tools (2). The awareness objective (1) and motivation objective (4) were aimed at the course's long-term effects on participants' teaching practice. The Coach platform for data logging, video measurement, and modelling was used together with available support materials (i.e. Coach introductory, tutorial, and exemplary activities) and materials that we developed (i.e. forms for designing and self-evaluating the ICT in IBSE lesson).

The literature on design research and on professional development of teachers led us to the following pedagogical principles (see Chapter 2) as the basis for (re)designing, evaluating, and optimising the ICT in IBSE course:

1. *One theory-practice cycle*: participants are required to go through at least one complete cycle of designing, implementing, and evaluating an ICT in IBSE lesson within the course. Participants will apply the IBSE theory in a design for an ICT in IBSE lesson, which they will also try out in the classroom, self-evaluate, and report in the final session of the course.
2. *Distributed learning*: participants study in live sessions and carry out individual assignments in between the sessions with the support materials and in consultation with the course instructor. Learning time is distributed between live sessions and individual assignments, but is also carefully distributed over a longer period to provide opportunities for a well-planned try-out in a real classroom.
3. *Depth first*: participants are introduced to the possibilities of the three tools after which they specialise in only one ICT tool. Learning time is prioritised for an in-depth study and application of one tool (one-tool specialisation) rather than broad study of all three tools at a more superficial level, so depth first - breadth later.
4. *Ownership of learning*: participants have freedom to select what to learn and how to learn it, using the course scenario and support materials in order to achieve the course objectives. The individual participants pursue their self-tailored learning process in which they make their own choices regarding the tool, the grade level, topic, and activity for their ICT in IBSE try-out with pupils.

The four objectives, four pedagogical principles, and support materials together form the general design of the ICT in IBSE course.

To examine the effectiveness of the ICT in IBSE course; validity and generalizability of the pedagogical principle; and transferability of the course design in different education contexts, we conducted the Dutch, Slovak, and Vietnamese case studies. These three case studies were related; the Dutch case study was the earliest and most extensive, followed by the Slovak case study, and then the Vietnamese case study. All three case studies a) concerned the same questions about implementation of the pedagogical principles and course design, usefulness of the support materials, and attainment of the course objectives, b) applied the same evaluation framework, and c) used the same instruments for data collection and analysis. The course evaluation was guided by two main questions:

A. To what extent were the four pedagogical principles implemented as intended?
B. To what extent did the ICT in IBSE course achieve its four objectives?

Question B involves the evaluation of the effects of the course on participants, which resulted from actual implementation of the pedagogical principles, the course design, and the support materials. The evaluation of this actual implementation was guided by Question A and based on a comparison between a) the intended course programme and b) the actual activities of participants during the course. To evaluate attainment of the course objectives, we first operationalised performance levels for each objective. The definition of these levels was based on theoretical considerations and aligned with time-constraint conditions of the course. After that, we collected data, compared the data-analysis outcomes with the pre-defined levels of the course objectives, and concluded which level(s) of each objective the participants achieved. Chapter 3 presents this evaluation framework in detail with related instruments for data collection and analysis (i.e. pre-course, post-course, and follow-up questionnaires; observations and video recording of live sessions and classroom try-outs; participants' ICT in IBSE lesson plans and self-evaluation reports of the classroom try-outs; computer performance test for each tool; the inquiry-analysis inventory; and the communication records). With these instruments, data were collected from a variety of sources and by different data collectors (i.e. the researcher, the course instructor, course participants). Accordingly, we could record both intended and possibly unintended outcomes as the course was implemented. Most outcomes were evaluated by more than one instrument thus allowing for data triangulation.

In the Dutch case study, we further operationalised the pedagogical principles in the initial scenario of the ICT in IBSE course. With "scenario", we mean the programme of the course and all instructor and participant activities and assignments (see Chapter 3). After that, we implemented and evaluated the course with 40 physics/chemistry student teachers spread over four sequential cycles. Among these four cycles, Cycles 1 and 2 were for fine-tuning of the course scenario. The *course evaluation* (Questions A and B) and *experiences with the course* in Cycle 1 (incl. what did work, what did not work, and why) suggested revisions of the initial scenario. These revisions were aimed at more faithful implementation of the course in Cycle 2 and with respect to many factors such as diversity of participants' background and ability; school schedules; and curriculum time for ICT in IBSE try-outs. Likewise, the Cycle 2 evaluation was guided by the objectives and pedagogical principles and resulted in further optimisation of the course scenario. We achieved the faithful implementation of the four principles in Cycle 3. Consequently, in this cycle, the summative effects of the Dutch version of the ICT in IBSE course were evaluated, and only minor suggestions were made for further

optimisation. The robustness of the course design and the ecological validity of the pedagogical principles were tested in Cycle 4 under routine implementation conditions without the extra support of the researcher.

The new understanding of how the course was developed and why it was effective (Dutch context) together with the basic course design (incl. course objectives, pedagogical principles, and support materials) enabled the tailoring of local versions of the ICT in IBSE course in different contexts. The ICT in IBSE course was adapted and tested in a) two cycles with 66 physics/biology/chemistry teachers with diverse teaching experience (1 to 33 years of teaching) in Slovakia (see Chapter 5). The two cycles of the Slovak course were already in routine implementation conditions without the direct participation of the researcher. The ICT in IBSE course was adapted and tested in one cycle in Vietnam with 22 master students in physics education, who either had taught for 2 to 9 years or came straight from a Bachelor teacher-education programme (see Chapter 6). Evaluations of the three local versions of the course enabled us to draw conclusions about a) the extent to which the four objectives can be attained, b) the validity and generalizability of pedagogical principles, c) the transferability of the course design, and d) the practical relevance of the course. These evaluations led us to new understanding of the extent to which the pedagogical principles can guide the fine-tuning of the basic design of the ICT in IBSE course to varying boundary conditions (see Chapter 7).

Findings, discussion, and conclusions

Chapter 4 presents the Dutch case study, which resulted in an improved and successful course scenario in which the Dutch participants achieved the course objectives also when the course was taught under routine conditions (Cycle 4). The iterative evaluation and refinements of the Dutch course confirmed the validity of the pedagogical principles in the Dutch context. The support materials proved necessary and useful for the sufficient implementation of the pedagogical principles and the satisfactory attainment of the course objectives. To conclude, *the four course objectives, the four pedagogical principles, and the optimised scenario with the support materials establish the core characteristics and basic design of an effective short ICT in IBSE course* for Dutch student teachers. Findings from the iterative refinement of the course show that *fine-tuning the distribution of time and individual assignments* is crucial as far as distributed learning is concerned. *Direct, personalised support* (in live meetings and/or via emails) and *sense of direction* (via explicit support framework plus assignment tracking and stimulation) are crucial factors to ensure effectiveness of independent learning, especially the quality of the ICT in IBSE lesson plan. These factors create a balance between *much freedom of choice and appropriate guidance*, which is essential to establish *ownership of learning*.

The Dutch, Slovak, and Vietnamese contexts for the ICT in IBSE course were different in many aspects (e.g. scheduling requirements, school conditions, and characteristics of participants). First, the Dutch course was limited to 12 contact hours out of 28 hours of total study time, but it was spread over 11 weeks. The Vietnamese course was compressed in 5 weeks, but 30 hours out of total 60 study hours were scheduled for live activities. The Slovak case had the least constraints, regarding both contact hours (25 out of total 40 study hours) and "spread" of the course (15 weeks). Second, the Dutch school conditions (e.g. curriculum time, teacher preparation time, national examinations, pupils' experience with ICT

and IBSE, availability of equipment and software) were not excellent but sufficient. Meanwhile, the Slovak school conditions were insufficient, and the Vietnamese conditions were very poor. Third, the Vietnamese and Slovak participants were experienced teachers, but their ICT mastery entrance level was low. The Dutch participants had more experience with the ICT tools and felt more free to decide their own lesson objectives and teaching methods. However, they lacked teaching experience, especially classroom management skills. Vietnamese teachers work in an education system with a strong hierarchical culture and much less autonomy than in the Dutch system. Lessons are teacher-centred and there is no tradition of open learner investigations in secondary school and teacher education. All three groups of participants lacked practical experience with inquiry teaching with or without ICT, so ICT in IBSE teaching was challenging for them. For all three versions of the course, diversity of participants and time constraints were challenging contextual factors.

Across the three case studies (Chapters 4, 5, and 6), the *awareness* and *motivation objectives* of the ICT in IBSE course were achieved as expected. The participants could enumerate relevant benefits of the ICT tools. They devised plans and actually continued studying the ICT tools and teaching ICT in IBSE lessons after the course. About the *ICT-mastery objective*, all three groups of participants were able to operate the Coach tool fluently after the course. Compared with the Dutch participants, the Vietnamese participants attained a higher mastery level for the chosen tool, and the Slovak participants achieved a similar ICT mastery but with all three ICT tools. This shows effectiveness of the many more contact hours with direct, personalised support scheduled for the ICT-mastery objective to compensate for the low ICT entrance of the Slovak and Vietnamese participants.

About the *ICT in IBSE objective*, all three groups of participants were able to design and realise acceptable ICT in IBSE lessons considering their teaching conditions and their inexperience with inquiry teaching with ICT. The Dutch participants could design and realise better ICT in IBSE lessons than the Slovak and Vietnamese participants. Many Dutch participants were able to engage pupils in designing experiments or models and predicting and interpreting results as expected. Meanwhile, the Slovak and Vietnamese participants focused too much on pupils' execution of experiments or models (manipulation of equipment and software) and did not sufficiently involve pupils in moving back and forth between the physical and theoretical worlds (manipulation of ideas and concepts). Most Slovak and Vietnamese participants intended to take control over the entire classroom activity through plenary systematic explanations and/or prescriptive worksheets for the group work. In contrast, in half of the Dutch ICT in IBSE lesson plans, pupils were required to take a larger role in conception, planning, and interpretation of the experiment/model in more-open inquiry patterns. This shows a clear difference in teacher/pupil centeredness and education culture among the three countries.

Although familiar with theory of IBSE, all three groups of participants had trouble to operationalise real inquiry in lesson plans and even more so in the classroom. There were many deviations between intended and actual ICT in IBSE lessons, and these resulted from reasons such as shortcut of intended inquiry opportunities; tasks that were too demanding; over ambitious timing; and ineffective communication with pupils. However, Dutch, Slovak, and Vietnamese participants were able to identify the shortcomings in their ICT in IBSE

lessons and suggest relevant revisions of their lesson plans for future use. To conclude, the basic design of the ICT in IBSE course was *effective, practical, and transferable* in the different educational and cultural contexts of pre- and in-service teacher education in different countries. The course can cater to diverse groups of teachers and teacher-education programmes, and it fits into time-constraint conditions. For all three cases, the ICT in IBSE course achieved its objectives to the pre-determined acceptable level, except that for the ICT in IBSE part there was still much room for improvement.

Considering the issue of teachers learning to teach by inquiry, we prepared and expected our course participants to get their first experience with inquiry teaching with ICT. The theory-practice cycle was valuable to make them *more aware* of what IBSE involves, of what are differences between guided versus open inquiry, and of how to involve pupils in planning and interpretation of an experiment. It was concluded that the educational and cultural system influences teachers' perception and implementation of inquiry-based teaching with ICT. This results in different typical patterns of ICT in IBSE in different countries. The analysis of the lesson plans and classroom try-outs using the inquiry-analysis inventory revealed considerable *inconsistency between inquiry objectives and activity specifications* and noticeable *deviations between intended and actual IBSE lessons*. These are persistent problems, which have been reported worldwide (Abrahams & Millar, 2008; Abrahams & Reiss, 2012; Tamir & Lunetta, 1981). Many teachers do have problems to operationalise inquiry in the classroom, even in countries like The UK and The U.S. where inquiry has been emphasized in the curriculum for a long time. Research findings from the Vietnamese case study shed light on challenges of and potential solutions to the application of IBSE in a hierarchical education culture (Chapter 6). Obviously, the ICT in IBSE course under the time constraints does not push its participants far enough yet in the direction of inquiry teaching with ICT. Participants' achievement through the course is a starting point; more theory-practice cycles are needed to bring them further in such ICT in IBSE direction.

In the present research, the pedagogical principles are valid in providing not only *the framework* for implementing, evaluating, and optimising the course in a specific context but also *guidelines for effective adaptation* of the course to varying boundary conditions. When adapting the course to a different context, the "*one theory-practice cycle*" principle should not be changed. Instead, the "*depth first*" and "*distributed learning*" principles can be adjusted by the course instructor to some extent to the specific context, considering the entrance level and other characteristics of the participants and the scheduling requirements. The "*ownership of learning*" principle has to be enabled to provide a dial for participants to self-tune the course to their own interest and ability. The adjustment with distributed learning and depth-first makes the first flexible phase: *ICT mastery*, which can be lengthened (Slovak case) and compressed (Vietnamese case) in order to compensate for the low ICT entrance, accommodate diversity of the participants, and align their activities, assignments, and efforts with the intended attainment of the ICT mastery objective. Such ICT mastery attainment is necessary for the participants to be able a) to design and teach the ICT in IBSE lesson and b) to continue studying and using the ICT tools after the course. Among the four course objectives, the ICT-mastery objective can be achieved in a compressed course with sufficient contact hours, whereas the learning with respect to the ICT in IBSE objective needs to be distributed sufficiently to allow for a well-planned and mature lesson plan and curriculum

time for classroom try-out. The support materials proved necessary, useful, and robust in different contexts. This finding suggests that it is not always necessary to develop materials locally to have effective educational innovations. Instead, with certain adaptations, one can use existing materials.

Reflections on the findings and methods

Based on our positive experiences with one theory-practice cycle, we think that this principle should be wider applied in teacher education. Would it be possible to identify a small number of core practices and have student teachers go through one theory-practice cycle for each? For example, the study of formative assessment could be followed by classroom practice with embedded formative assessment and feedback. Regarding the depth-first principle, deeper understanding of one ICT tool has surplus value compared to partial understanding of all three tools, and it leads to better transfer to the whole ICT environment (breadth-later). This further suggests the application of the depth-first principle as part of a solution for content overload in teacher-education programmes. Regarding the learning of ICT skills, collective practice of ICT skills in small groups is more effective than either individual practice at home or the practice under plenary step-by-step instructions to the whole class. Personalised, direct support from the course instructor and peers is essential for participants to get over initial hurdles of learning a new tool and to troubleshoot TCK problems. To troubleshoot TCK problems independently, participants need to understand how the ICT system works and to be confident and committed in searching and trying out solutions. Taking the computer performance test can be a first step to learn such troubleshooting skills.

At the beginning of the present research, we defined the unique objectives of the course to be developed and a clear view about design criteria. Based on these objectives and criteria, we chose the design research approach to develop, evaluate, and optimise the course as an educational product through research, and this approach worked well. We started this research and design project with the pedagogical principles and concluded it with these principles as the core of the basic design of the ICT in IBSE course. These principles can be considered as independent, validated educational products, which teacher educators can "buy into" and use for broader aims than only ICT in IBSE integration. Pedagogical principles establish the theoretical model underlying the course design, provide guidelines and structure to the (re)design, implementation, evaluation, and optimisation process, and help to communicate the design research to others. The role of pedagogical principles in design research is indeed essential. Moreover, in our design research, we incorporated a) a "*robustness test*" step to try out the course under routine conditions and b) a "*generalizability and transferability testing*" step to try out the course in different programmes or even countries. We achieved successful outcomes with these steps. Consequently, we strongly recommend robustness and generalizability/transferability tests as part of design research.

Main limitations of the present research were that it only measured the quality of one theory-practice cycle, that it did not have an opportunity to measure the further development of participants in later ICT in IBSE activities in their classrooms, and that it did not measure pupil results. Learning to teach the IBSE way takes a longer trajectory than this course, and so our measurements only show the start of the participants' development. For the same reason,

there was no point in measuring pupil achievement, as improvement of their inquiry skills would only become visible after a series of lessons rather than one lesson.

It is common practice that each teacher education programme invents its own wheels. Our research outcomes through the development/adaptation, implementation, and evaluation of the ICT in IBSE course in the Netherlands, Slovakia, and Vietnam indicate that with careful design and well-chosen pedagogical principles, courses and other educational products could be fine-tuned and shared. The fourth and fifth Dutch course and the second Vietnamese course were implemented by the local course instructors without any involvement of the researcher. The third Slovak course is planned within a new large-scale national project, which is aimed at implementation of ICT tools across science subjects in Slovakia. The Dutch ICT in IBSE course (implemented with five batches already) is unique, since it is the only teacher-education course offered by several Dutch universities together, as far as we know. The Vietnamese ICT in IBSE course is unique as it is the only Master course of which design and materials were entirely developed outside the university. These institutionalisations do not happen often for general educational projects. These show not only the *practical relevance of the basic design* of the ICT in IBSE course for different educational and cultural contexts of pre- and in-service teacher education, but also suggest the possibility to have *more-productive standardisation* among teacher education courses.