Chapter 12
Stem, Inquiry Practices and Technology in Physics Education

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Abstract How to make Physics Education more challenging, relevant and attractive for our school students? How to stimulate the development of creative thinking, problem solving, and other higher cognitive skills? What are the realistic conditions that must be fulfilled so that teachers can realise this kind of quality Physics Education? Governments in many countries stimulate science and technology in schools; the more recent Alphabet Soup acronyms are IBSE, STEM (or STEAM), and MINT (Germany). What is meant with that, and what are the main expectations? And, can technology applied in physics education bring us closer to the desired goals?

Clearly it has been demonstrated that technology can help to make physics education more relevant, more linked to real life and more authentic. And can increase the opportunities for own investigations by the students. So really has an added value, and not just provides another way of teaching the same. This is known for decades but still applied at a relatively small scale.

A major challenge is the preparation of teachers for using technology in this direction. The authors recently investigated the development of an effective and relatively short course for teachers to prepare them for the use of ICT/Technology in IBSE lessons. The final course setup is based on several rounds of tryouts and improvements, and has been applied in the Netherlands, Slovak Republic and Vietnam. The course will be presented, some attention will be given to the differences in application in different settings (pre-service and in-service, different

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cultures) and the learning effects on the participants. Interesting and important conclusion is that such a high-quality course design can be applied broadly.

12.1 Introduction

The knowledge society requires innovative products and services, and so workforce must be able to apply knowledge in innovative ways. It is challenging, because many students entering technical universities are not able to cope with open tasks; they are not trained in divergent thinking. About secondary school students, there has been a decline in interest for science (OECD 2006); many school students do not see science and technology attractive, relevant, and related to jobs. Therefore, the overall challenge in physics education today is probably attracting more students for Science and Technology; this results in driving questions in physics education: *How to make physics more challenging, relevant, and attractive for students? How to stimulate their development of creative thinking, problem solving, and other higher cognitive skills?*

In many countries, governments have been innovating the science curriculum, considering these questions. For example, to let students experience physics as a relevant topic for them, students' authentic projects is included in the school agenda, and the teacher is stimulated to link regular physics lessons to real life. To show students that physics itself is still very much alive, modern topics (e.g. quantum physics, elementary particles), and applied physics (medical imaging, biophysics) are introduced. More connections between schools and universities, research institutes, companies, outreach are established, and more facilities for improvements of school labs are provided. To prepare students also for higher cognitive skills, the curriculum includes students' own investigations (with minds-on) and design tasks (divergent thinking).

Since the 1980s, advances in technology and physics education research have stimulated intensive development of Information Communication Technology (ICT) for data logging with sensors, video measurement, and dynamical modelling. These tools resemble those of scientists and engineers but are designed for educational purposes and primarily aimed at classroom use. Can the technology applied in physics education bring us closer to the desired goals? Clearly it has been demonstrated that technology can help to make physics education more relevant, more linked to real life, and more authentic. And can increase the opportunities for own investigations by the students. So it really has an added value, and not just provides another way of teaching the same. Many initiatives such as STEM or STEAM (USA), MINT (Germany), ICT in IBSE (EC) are the more recent Alphabet Soup acronyms. In this chapter, we present the main contributions of technology: *showing students how physicists work today* (e.g. beats plus signal analysis, numerical model for cooling down); *enabling authentic projects by powerful tools for doing investigations* (e.g. reentry of a capsule in atmosphere, bungee jumping, bouncing balls);

and *facilitating a better link to real-life phenomena* (e.g. high jumping, parachute jump).

Educational benefits of these ICT tools are known for decades, but they are still applied in physics education at a relatively small scale. Factors involved are among others:

– Limited curriculum time and limited teacher preparation time.
– Lack of equipment, resources and technical support.
– Mismatch between assessment, examinations and curriculum objectives (e.g. inquiry).
– Pupil problems (e.g. high cognitive load of inquiry learning).
– Teacher problems (e.g. prescriptive instruction with ICT) and lack of continuous teacher education.

Needed are systemic changes in these factors and concerted, simultaneous actions of all stakeholders, especially teachers who should be well-prepared, be professionals and be treated like that! Such changes take time and there needs the right actions.

In our recent study, we focus on teacher preparation and training, which are driving forces for change in classroom practices regarding ICT incorporation. We investigated the development of an effective and relatively short course for pre- and in-service teachers to prepare them for the use of ICT in Inquiry-Based Science Education (IBSE). Several pedagogical principles, like the depth-first and one theory-practice cycle, were applied to (re)design, implement, evaluate and optimise this ICT in IBSE course. The course was aimed not only at learning ICT skills, but also at awareness of benefits and motivation. The final course setup is based on several rounds of tryouts and improvements, and has been applied in the Netherlands, Slovak Republic and Vietnam. The course is presented in this chapter as well; some attentions are given to the differences in application in different settings (pre-service and in-service, different educational systems, and different cultures) and the learning effects on the participants.

12.2 Inquiry Practices in Physics Education

Science educators have been aware of the potential benefits of an inquiry-based approach in science teaching and learning at both primary and secondary levels, and the term "Inquiry-Based Science Education"—IBSE has been popular for a long time. In an article published in 1910, Dewey (1910) remarked that science is not only a body of knowledge to be acquired, but it also includes inquiry methodologies to generate and validate knowledge. In this chapter, we consider inquiry as a process of generating and validating knowledge through moving back and forth between the theoretical world (ideas, concepts, relationships, theories and models) and the physical world (objects, phenomena, observations, measurements and experiments). According to Van den Berg (2013), ideally, IBSE will engage pupils in thinking

back and forth between these two worlds like scientists; and "the phenomena and experiments serve as a source for validating ideas and theories and as a playground for generating new ideas and theories in a complex mix of inductive and deductive mind play" (p.75).

Inquiry as process of generating and validating knowledge fits into a view on learning as knowledge creation, discussed by Paavola et al. (2004). Inquiry, under the knowledge-creation perspective, is the process whereby new knowledge and understandings are (re)constructed. From the knowledge-creation perspective, knowledge is not always objectively true. Knowledge is not always given by teachers and scientists or in other knowledge containers (e.g. journal articles, textbooks). Knowledge and its representations (e.g. ideas, concepts, relationships, theories and models) can also be created, elaborated and restructured by learners and researchers. This is in line with Duschl et al. (2007) that the brain is filled with preconceptions from early life experiences; some of these preconceptions match with science, others do not. Therefore, much learning involves reconstruction of prior ideas, which are already in the learner's brain. In addition to the knowledge-creation model, Paavola et al. (2004) discussed two other metaphors of learning: acquisition and participation. The knowledge-acquisition metaphor focuses on learning within individuals' minds, whereas the participation metaphor emphasises learning as a process of participation in various practices and activities. The knowledge creation perspective encompasses both acquisition and participation.

In the book: "The scientist in the crib", Gopnik et al. (1999) implied that from young ages, children can create new knowledge by inquiry, and scientists make the most of this capacity, which lets "children learn so much so quickly" (p.9). Consequently, we indeed concur with Duschl et al. (2007, p.83) that pupils can "engage in and profit from instruction that incorporates relatively complex scientific practices from the very beginning of their schooling".

The science-education community has suggested making authentic inquiry of science more accessible to pupils (e.g. Gaskell 1992; Edelson 1998; Braund and Reiss 2006). Authenticity of inquiry in the school can be interpreted as resemblance of pupil activities to experimentation/modelling activities of practicing scientists in constructing new knowledge, considering the three following aspects (Heck 2009):

– A real-life context for learning that provides pupils with opportunities to investigate realistic science problems in history or present-day research and so pupils will appreciate the relevance of scientific knowledge in everyday life.
– Tools and techniques that enable pupils to carry out experiments/modelling and to analyse and process high-quality data in much the same way scientists do.
– Scientific attitudes of learning that stimulate pupils' pursuit of unanswered questions, commitment to challenging tasks, and social interactions (e.g. cooperation, argumentation).

Authentic inquiry is close to real science, so makes school science more attractive and relevant. Moreover, considering the "learning as participation" metaphor (Paavola et al. 2004), pupils can appreciate inquiry as a scientific method of

generating and validating knowledge through being engaged in practices similar to those of scientists.

IBSE is an integral component of the intended science curricula in many countries (Jeskova et al. 2015). In such school science curricula, "inquiry" refers to learning goals (i.e. understanding of the methods of scientific inquiry and the ability to carry out scientific inquiry). "Inquiry" also refers to teaching strategies that stimulate and support pupils to exercise inquiry practices, including hands-on activities, minds-on discussions and meaning making (Hodson 2009; Minner et al. 2010; NRC 2012).

12.3 Technology for Inquiry Practices in Physics Education

12.3.1 An Open Computer Learning Environment

As known for a long time, ICT can enable physics education in a direction that brings students in a similar position as researchers in physics (Heck and Ellermeijer 2014). The development of ICT tools for physics education should be driven by a combination of educational research, curriculum development and innovative technology. We envisioned a scenario of teachers and students using a set of tools for inquiry-based study of natural and mathematical phenomena. This set of tools is integrated in one open environment designed for a broad educational setting. Openness means that it is:

– A flexible, customisable, multipurpose system.
– An environment for solving open problems that need definition, setup, exploration, data processing and analysis, mathematical modelling, and so on; that is primarily a cognitive tool.
– As much as possible free of didactic context or principles; that is less considered as a pedagogical tool, but more as a tool for doing physics.

This computer learning environment does not only exist in the minds of software designers, but it has already been realised to a large extent in the Coach learning and authoring environment, which is the result of three decades of sustained research and development work at CMA, Amsterdam, the Netherlands to improve STEM education. "Coach" refers to coaching and support of learning.

A one-sentence description of Coach is as follows: Coach is a single, activity-based, open computer learning environment that is designed for the educational setting and that offers a versatile set of integrated tools for the study of Science, Technology, Engineering, and Math (STEM) (Heck 2009). For more detail about the latest version of Coach, please visit http://cma-science.nl/coach-7-overview.

Coach activities are mostly based on the powerful tools for *data logging with sensors*, advanced *video measurement* up to *dynamical modelling*. Teachers can use readymade activities or author new activities to structure the lesson materials (i.e. experiments, models). Such activities may contain:

– Texts with activity explanations or instructions.
– Pictures illustrating experiments, equipment, and/or context situations.
– Video clips or digital images to illustrate phenomena or to use for measurement.
– Measurement data presented as graphs, tables, meters, or digital values.
– Models (textual, equations based, or graphical) to describe and simulate phenomena.
– Programmes to control devices and to make mathematical computations links to Internet sites and other external resources for students.

Coach activities are presented below, but please note that all kinds of activities are supported in a single computer environment and not in a suite of separate programmes. Having a single environment instead of a bunch of special purpose software packages brings many benefits. First, students and teachers only need to familiarise themselves with one environment, in which components are geared with each other. They can grow into their roles of skilled users of the system during their learning and teaching. A learn-once-use-often philosophy of educational tools is realisable. Additionally, students may experience the connections between different school subjects using a single environment instead of a grab bag of disconnected tools. Another advantage of a single environment compared to a software suite is the possibility to easily combine different tools in one activity.

12.3.2   Coach Tool for Data Logging with Sensors

12.3.2.1   Characteristics

The Coach tool for data logging with sensors enables students' experimentation activities in which the sensor, connected to an interface, measures a quantity (e.g. temperature, voltage, pH) in the physical world and transforms this quantity into a voltage or other signal(s), which is then read by the interface. The interface converts the signal into digital data that are transferred to, then interpreted and processed by the connected computer or other devices with dedicated software (Fig. 12.1). A computer equipped with an interface and ample sensors becomes a universal measuring instrument, which has a wide range of sampling frequencies from very low to very high (e.g. 10,000 samples per second). This computer-based instrument certainly can take the place of instruments such as thermometers, voltmeters and pH meters, used in conventional practical work. It enables automatic, accurate, conditional measurements and includes ample ways of storing, displaying and analysing data. During the measurement, real-time data can be represented in graphs, tables or displayed as digital values.

Fig. 12.1 Diagram of the tool for data logging with sensors (including sensor, interface and computer with dedicated software)

12.4   Challenges of Technology in Teaching Physics

Among different software packages, Coach has common measurement methods:

– Time-based measurement in which data are automatically gathered at regular time intervals according to the sampling frequency; with this setting, it is possible to specify a signal condition from which the computer automatically starts a measurement (i.e. triggering). For example, Fig. 12.1 shows time-based measurements of interfered sound and the obtained graph displays the sound signal.
– Event-based measurement in which measurements are taken each time a pulse (i.e. an event) is received on an interface input. For example, in an experiment with stroboscopic light, each light flash generates a pulse via a light sensor, and then a measurement is taken.
– Manually triggered measurement in which a single measurement is taken every time the user presses a button; this setting also allows to type in data (e.g. observational data, standards, given values) via the keyboard. For example, in the Boyle's law experiment, pressure of air, which is trapped inside a cylinder fitted with a piston, is measured by a pressure sensor each time a value of gas volume read by naked eyes is manually entered in the software.

Data logging with sensors is a generic experimental tool for physics, chemistry and biology.

12.4.1   Examples of Coach Data-Logging Activities

Figure 12.2 shows a screen shot of the measurement and signal analysis of the voice sound "eeh" recorded with the €Sense interface, which is mostly used at primary school or by beginners. The diagrams show that the sound signal is well described by a sinusoidal signal that consists of four frequencies. A visual representation of the €Sense interface with the built-in microphone is also present in the activity screen to make the experimental setup clear to students. A text window is used for explanation and description of tasks.
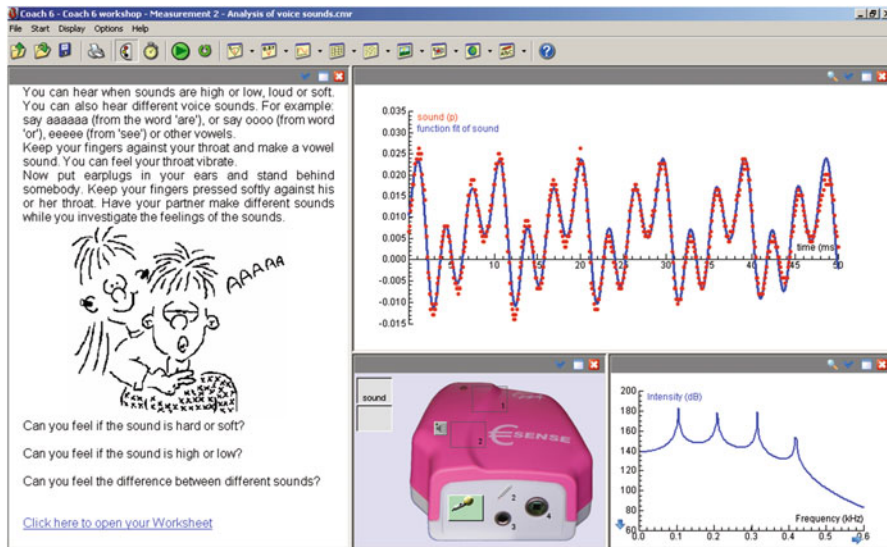
Fig. 12.2 Measurement and signal analysis of voice sounds with the €Sense interface

12.4.1.1 Educational Benefits

The tool for data logging with sensors has many educational benefits if it is properly integrated in the science lessons. First, this tool enhances new possibilities and contexts for physics experiments that might not be otherwise possible due to time constraints and technical difficulties (Barton 2004; Newton and Rogers 2001). This increases access to real-life phenomena, facilitates new classroom experiments, and allows measurements in the field. Second, the tool enables collecting, recording and representing of many data and even repeating this process several times in short time (physical world). Consequently, pupils will have time in the classroom to design the experiment, interpret data and/or explain relationships (theoretical world).

Third, the "real-time graphing" feature of the data-logging tool stimulates pupils to move back and forth between the physical world and the theoretical world. For example, a pupil walks in front of a motion sensor, and immediately the software shows in the graph her or his position and/or velocity in real time. By observing the pupil walking and the graph showing up at almost the same time, other pupils in the class can easily realise the connection between the motion of their classmate and the kinematics concepts. According to Brasell (1987), this immediacy between the phenomenon and real-time graphing of data stimulates pupils' conceptual understanding, and this feature is critical for both understanding and motivation. Sokoloff et al. (2007) showed research evidence that the use of the tool for data logging with sensors in a laboratory curriculum (i.e. RealTime Physics Mechanics) improved pupils' understanding of dynamics concepts, and the retention of the concepts by those pupils was excellent.

Finally, the incorporation of the data-logging tool enables pupils to participate in aspects of scientists' experimental inquiry, considering that the data-logging tool is

like those used by scientists. According to Ellermeijer et al. (1996), once pupils get used to the data-logging tool, they can decide and reflect at any time about what to measure, how to calibrate and what readings should be taken. This shows that such participation in authentic inquiry with the data-logging tool will stimulate pupils to comprehend scientific inquiry.

12.4.2   Coach Tool for Video Measurement

12.4.2.1   Characteristics

The Coach tool for video measurement enables pupils to conduct experiments in which, for instance, position and time data of a moving object, registered in a digital video, are collected in the successive video frames by mouse clicking. Among different software, Coach includes common steps to gather real-life data from a video. First, the user must define the video scale, time calibration and coordinate system. The video clip is scaled by specifying which distance on the video screen corresponds to which actual distance (e.g. 1 m viewed in the video frame in Fig. 12.3). A video is a collection of rapidly displayed pictures called video frames. The time interval between two successive frames shown in the software is calibrated by entering the actual frame rate of the video (i.e. how many video frames were taken in a second as the video was recorded). Next, the user moves the cursor over the video screen to locate the point(s) of interest (e.g. a baseball) and then click to store the first video point (i.e. first coordinate and time data). The video clip automatically advances to the next frame, and then the user continues clicking on the reference
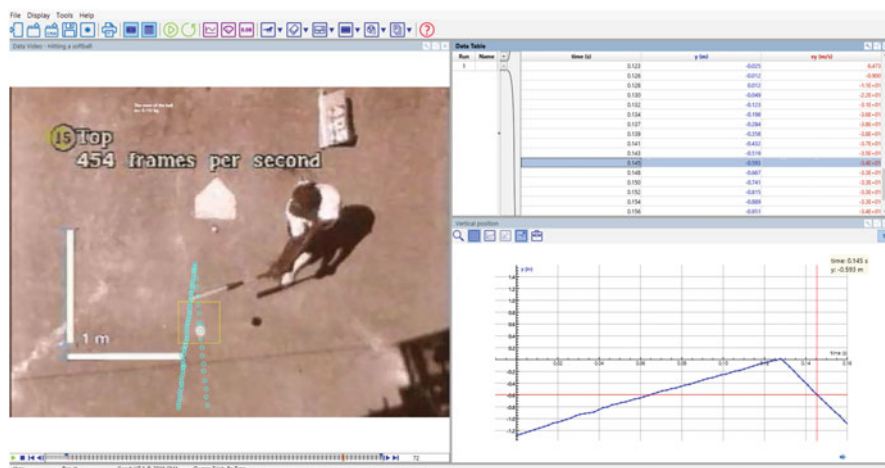

Fig. 12.3 Screenshot of an experimentation activity facilitated by video-measurement tool

point. This procedure with the software is repeated until the user obtains a desired number of data points.

Coach allows automated tracking of the movement of objects and enables collection of different video points in a single video frame. Like the data logging with sensors, during the manual measurement and automated tracking from a video, the collected data are simultaneously displayed in a diagram or table (real-time graphing) (Fig. 12.3). Other dynamics quantities such as velocity, acceleration, momentum, kinetic energy, force can be numerically computed based on the collected data. Finally, collected and computed data are analysed and processed further by the software. Video measurement is mostly limited to movement, so it is mostly used in physics.

12.4.2.2 Examples of Coach Video-Measurement Activities

Figure 12.3 illustrates an experimentation activity facilitated by the video-measurement tool. In this activity, position and time of a baseball is collected from a high-speed video and displayed in the graph and table by the software. The dotted cross in the graph indicates that the scan feature of the software is activated. In this illustration, the data point (− 0.593 m, 0.145 s) on the graph and the table is scanned, and the video advances to Frame 72, which shows the corresponding position of the baseball.

Another example is the video measurement of the motion of a self-made yoyo, which is winding up and down (Fig. 12.4). In this case, the position of the point near the rim of the disk and marked by a sticker (P1) is measured in a slightly moving coordinate frame whose origin is at the hand of the person holding the end of the
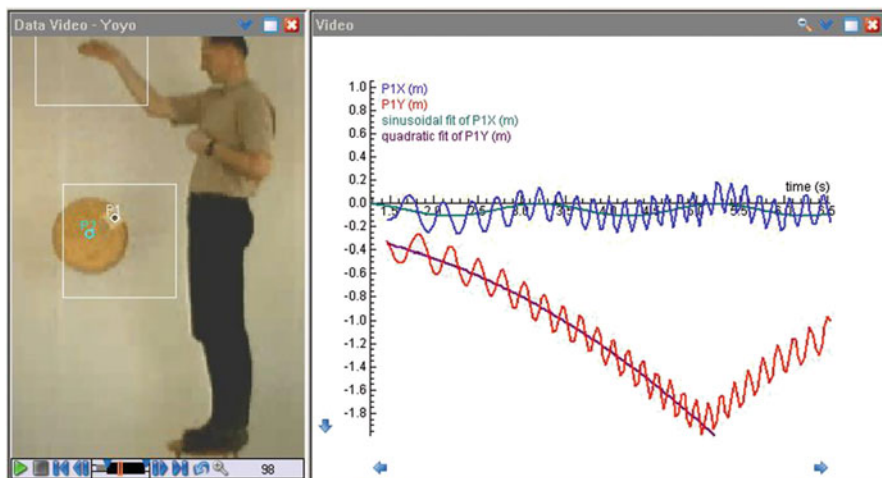

Fig. 12.4 Screen shot of a video analysis activity about the motion of yoyo

cord of the yoyo. But point-tracking makes the measurement at hand easier and less time-consuming: in the starting frame, the positions of the hand and of the sticker are specified and the shapes of the search areas (white boxes) are set, and then the coordinates of these points are automatically recorded in subsequent frames.

In the diagram to the right, the horizontal position and the vertical position of P1 are plotted against time. This is combined in the diagram with a sinusoidal fit of the horizontal displacement of the yoyo, due to an unintentional pendulum motion of the yoyo, and a quadratic function fit of the vertical position during the first phase in which the yoyo unwinds. These trend curves can be used as coordinate functions of a computed point that is displayed in the video clip (P2): It turns out to be close to the position of the axle during the unwinding phase of the yoyo. Please refer to Heck and Uylings (2005) for detailed modelling of the yoyo motion.

12.4.2.3   Educational Benefits

The Coach tool for video measurement has much added value if it is incorporated appropriately in school science. First, like the data-logging tool, video measurement creates new possibilities and contexts for experimentation activities. With the video-measurement tool, the teacher can bring real-life, attractive scenes of motion into classroom activities that show pupils the relevance of science concepts and theory in everyday life (Heck 2009; Zollman and Fuller 1994). Such realistic scenes of motion can be quite ordinary (e.g. basketball shots, amusement-park rides, dancing) or unusual (e.g. car crashes, jumps on the Moon, rocket launch). With high-speed videos (i.e. up to 1200 frames/s), the teacher and pupils can quantitatively explore many more situations of realistic motions (e.g. multidimensional collisions between billiard balls, gun recoil) that would be mostly impossible to investigate with traditional instruments and even with sensors for school science. Additionally, the video-measurement tool can serve as a cost and time effective instrument for the school laboratory, which might replace rulers, timers, photogates and motion sensors in motion-related experiments.

Second, the tool enables the collection and representation of many video data from different realistic situations in a short time (physical world). Consequently, pupils will have time in the classroom to interpret data and/or explain relationships (theoretical world). Third, the "real-time graphing" and "scan" features of the video-measurement tool stimulate pupils to think back and forth between the physical and theoretical worlds. This becomes more likely as images of these two worlds are shown in the same software interface (Fig. 12.3). When pupils scan a data point in one of the graphs, the corresponding video frame, where the data were collected, displays simultaneously. This feature enables pupils to identify events during the realistic situation (physical world) and connect them to abstract representations in the graph (theoretical world). This results in pupils' deeper understanding of the motion and related kinematic concepts (Beichner 1996; Gröber et al. 2014).

Finally, the incorporation of the video-measurement tool makes it possible for pupils to exercise experimental inquiry practices like those of biomechanics and

movement-science scientists (Heck 2009; Kearney and Treagust 2001; Laws and Pfister 1998). Pupils can participate in many aspects of experimental inquiry using video measurement. For example, formulating problems; designing the scenario and setup for appropriate video recording by a webcam, a smartphone or a video camera; calibrating time and scale of the video; defining from which frames to get data and with which techniques to collect data; and processing and interpreting the collected video data.

12.4.3 Coach Tool for Dynamical Modelling

12.4.3.1 Characteristics

Modelling has different meanings for different communities, depending upon the context in which it is discussed. The term "modelling" will refer to computational, dynamical modelling that is a tool used by scientists in many different fields (e.g. science, technology, economics, sociology) to describe, explain and predict complex dynamical systems. It helps to understand a system's structure, the interaction between its objects, and the behaviour it can produce. Many of such systems can be built as models on the computer, which can carry out many more simultaneous calculations than human mental models and which can enable solution of differential equations. These differential equations cannot be solved with secondary school mathematics.

The Coach tool for dynamical modelling provides the teacher and pupils with possibilities to be engaged in the modelling process in science: "analyse a situation in a realistic context and reduce it to a manageable problem, translate this into a model, generate outcomes, interpret these outcomes, and test and evaluate the model" (van Buuren et al. 2010, p.112). First, a realistic context (e.g. a tennis ball bouncing on the floor) is analysed and simplified to be manageable by ignoring realistic effects or situational factors (e.g. the ball moving vertically without rotation, air resistance and aerodynamics effects); the stripped-down, mental model is then translated into a computational model. Next, the computational model is constructed by graphical elements: state variables (e.g. height, velocity); in- and out-flows of state variables (i.e. rates of change); auxiliary variables; constants (e.g. acceleration due to gravity); events (e.g. bounce) that provoke discrete, instantaneous changes of state variables; and relations that are visualised by connectors between variables, constants, events (Fig. 12.5) and are specified by simple mathematical formulas.

As the model is executed, differential equations behind the model are automatically solved by numerical iteration methods and so result in values of variables as a function of time. To interpret these modelling data, the modeller needs to choose relevant representations of the resulting values of variables such as (a) graphs that show more explicit, comprehensible relationship between variables; (b) animations that visualise behaviours of modelled objects. To validate the model (i.e. evaluating its descriptive, predictive and explanatory quality), the modeller compares modelling
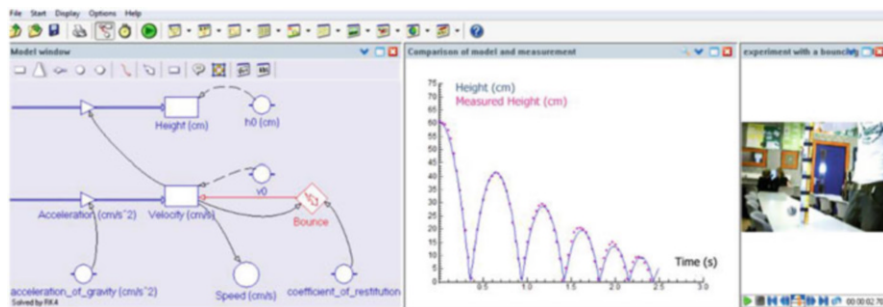
Fig. 12.5 Screenshot of a modelling activity facilitated by the modelling tool

outcomes with their counterparts in the physical world (i.e. standards, measured data, empirical graphs).

There are different ways to represent variables and relationships behind a dynamical model in Coach, including (a) the stock and flow mode (graphical representation) and (b) text-based modes, using equations or a textual representation. In this chapter, we confined ourselves to graphical modelling with a stock and flow representation of variables and relationships among these variables. This was because the stock and flow representations stimulate pupils to focus on qualitative relationships (theoretical world) and connections of these to the realistic situation (physical world) rather than mathematical equations or programming syntaxes.

12.4.3.2 Examples of Coach Modelling Activities

Figure 12.5 illustrates a modelling activity facilitated by the modelling tool. In this activity, bouncing of a solid, rubber ball is modelled, and the modelling result is compared with data obtained from video measurement of the bouncing ball. The graph shows the modelling result (solid curve) and the measurement (dots) for height versus time. Another example is a graphical model of the main span of Golden Gate bridge (Fig. 12.6), which is based on the approximation of the suspension cable by k_{max} straight line segments with horizontally equidistant joint.

Coach is in fact a hybrid system that combines a traditional system dynamics approach with event-based modelling. The left window of Fig. 12.7 shows a graphical model of a ball hanging on a vertical spring attached to the ceiling and that can also bounce against the ceiling; a special event-icon (with the thunderbolt symbol) is used to specify what should happen when the ball bounces. The window in the middle is an animation window that displays the simulation results as animations where model variables are presented as animated graphics objects. A student can interact with the animation through a slider bar, that is, select the value of the spring coefficient before the start of the simulation or change it while the simulation runs. Animation allows students to first concentrate on understanding a phenomenon with the help of simulations before going into the details of how the simulations have been implemented by means of computer models.
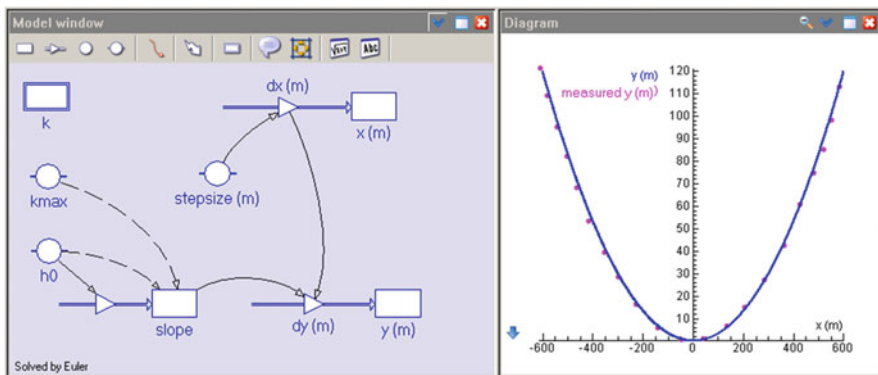
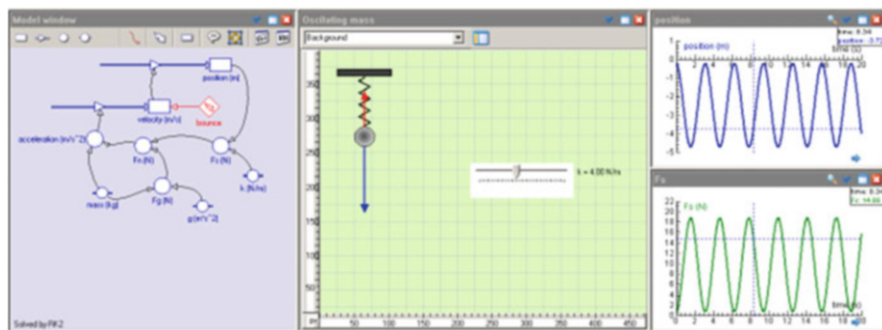**Fig. 12.6** A graphical model of the shape of the Golden Gate Bridge

Fig. 12.7 A model of the harmonic motion of an oscillating ball hanging on a spring and an animation of the motion

12.4.3.3 Educational Benefits

First, the modelling tool holds the potential to enlarge possibilities for pupils' theoretical inquiry of realistic, dynamic phenomena (e.g. motion with air resistance, charging and discharging capacitors, combustion of carbon monoxide, and chemical equilibrium). These phenomena are difficult to describe with school mathematics but relatively easy to model with software (Heck 2009; Velanova et al. 2014). There are different patterns in which pupils can move back and forth between the theoretical and physical worlds and so learn with the modelling tool. For example, pupils run a given model (e.g. a parachute jump with air resistance) to understand a phenomenon and/or explore its structure to gain insight into interactions between the model elements. Based upon their understanding, pupils can also make a small change to a given model, try out various modelling ideas, and then evaluate if the revised model describes the phenomenon better. For example, "unfortunately, the parachute does not open right away. Therefore, there is first free fall for two minutes and then fall with air resistance while the parachute already opens". With a certain mastery of

the modelling tool, pupils may construct a new model from their mental model of the realistic phenomenon and validate the model by comparing modelling outcomes with experimental results. Patterns for teachers to prepare a lesson, using the modelling tool are similar; the teacher might use a ready model, modify it a bit or develop a new model.

Second, the software allows importing measured data and graphs to the modelling activity. This enables simultaneous observations of the modelling graph (i.e. an outcome from the theoretical world) and the experimental graph (i.e. an outcome from the physical world) in the same diagram (Fig. 12.5). It is convenient for pupils to compare these outcomes of the two worlds. If the modelling result does not fit the real data, then pupils can adjust the model (e.g. changing parameters, adding variables, correcting relationships), execute it again, and compare new modelling results with the real data. The modelling tool enhances opportunities for many rounds of thinking back and forth between the theoretical and physical worlds.

Last but not least, the incorporation of the modelling tool enables pupils to (a) get used to modelling as a scientific tool in computational science (doing science with computer), (b) appreciate what modelling is as a way of thinking, (c) understand how important it is in science, and (d) develop a critical attitude by working with several models for one and the same phenomenon (i.e. modelling cycle). In their article, submitted in November 2008, Heck and Ellermeijer (2009) used Coach video measurements and models of runners to predict the possible time: 9.6 s for 100 m of Usain Bolt based on his Olympic run in Beijing 2008. This model accurately predicted or apparently affirmed his world record at the 2009 World Championships in Athletics in Berlin (9.58 s). This instance illustrates the power of the Coach tools in explaining and predicting real-world phenomena like sprinter's run. Additionally, Heck and colleagues showcased students' research projects (i.e. yoyos, alcohol metabolism, beer foam, bouncing balls) in which pupils could build models from simple to more complex (i.e. progressive modelling approach) by incorporating more factors aimed at better matching between the model and reality (Heck 2007, 2009; Heck et al. 2009a).

12.4.4 Data Processing and Analysis in Coach: Generic Components of the Coach Tools

Generated from the model or collected from the experiment or the video, numerical data can be then quickly transformed into more comprehensible, graphical representations: graphs, tables and animations. If such representation forms are arranged in advance, then pupils can see, for example, how empirical graphs appear (i.e. real-time graphing) or how animated objects move during the measurement or generation of data.

Additionally, just requiring simple manipulations, the software provides pupils with many possibilities for elementary analysis such as scan, slope, area and further

processing such as (a) fitting or modelling the data with analytic functions (e.g. function fit); (b) integrating, differentiating data; and (c) displaying Fourier transforms of the data (Sokoloff et al. 2007; Heck et al. 2009b). Moreover, swift analysis and processing with three tools save time on labour intensive, repetitive tasks (e.g. drawing graphs) and so allow pupils to focus on inquiry skills like interpreting data, inferring relationships, and testing different assumptions, which are otherwise impossible due to time constraints. These features of data processing and analysis crucially add to specific characteristics of the three Coach tools mentioned above. This makes each of the ICT tools an authentic platform where pupils can easily move back and forth between the physical and theoretical worlds within the classroom time to generate or validate knowledge of science.

12.4.5 An Example of ICT in a Student Project: A Surprising Result

#### 12.4.5.1 The Student Project with ICT: "Physics of Bungee Jumping"

The Dutch curricula require pupils to gain exposure to research projects in physics and other subjects where they must make their own choices with respect to topic, questions, and experiments/models; collect and analyse data; and compare outcomes with literature. A final investigation project is intended for 80 h outside of regular lessons and spread over a whole school year (about 2 h a week). In 2003, two Dutch students teamed up to investigate the physics of bungee jumping. In the first phase of bungee jumping, the bungee jumper falls, and the bungee rope is still slack. In instructional material, this phase is often considered a free fall. Considering the mass of the bungee rope, the students formulated the research question: *How large is the acceleration at a bungee jump and to what degree is this acceleration influenced by the relative mass of the rope and the jumper?*

The students collected position-time data through Coach video measurements on a dropped scale model (an Action Man toy figure) and on dropped wooden blocks of various weights attached to ropes of various stiffness. The velocity and acceleration of the dropped object were computed by numerical differentiation. Soon the students realised that the mass ratio between rope and objects was too low to see an outstanding result and they repeated the experiment with objects of larger mass ratio. The graph of the acceleration at the moment that the block has fallen a distance equal to the rest length of the elastic as a function of the mass ratio of elastic and block is shown in Fig. 12.8, together with the graph of the following theoretical result:

$$a = g\left(1 + \frac{\mu(4+\mu)}{8}\right) \tag{12.1}$$

Fig. 12.8 Graphical display of experimental results (below) and computed values (above)
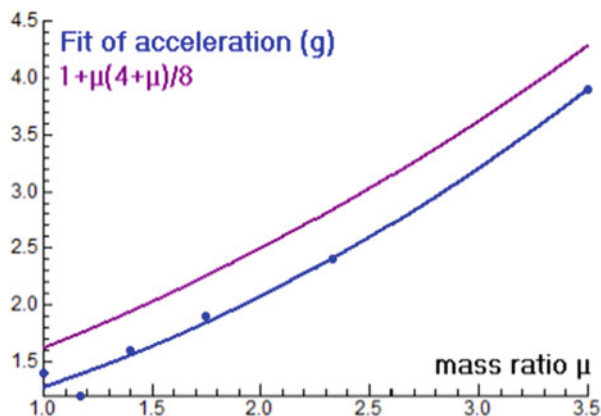
where μ is the mass ratio of the elastic and the wooden block. The students noted that the graphs obtained by measurement and theory are alike, with the theoretical values just a bit higher. They attributed the difference mainly to the development of heat during the motion.

12.4.5.2 The Surprising Result

Not knowing that a Dutch physics teacher had published around the same time about an experimental verification of the physics of bungee jumping, the students wrote an article about their work that was published in the journal of the Dutch Physics Society. The students' article claimed the result for acceleration during first phase "free fall" up to $a = 3.9\ g$ for mass ratio $m/M = 3.5$. It triggered quite several reactions in the journal and for almost a year on Internet. It seemed that a major part of the physics community, at all levels of education, was suddenly playing with ropes, chains, elastics, and so on. The result of the student project is contrary to the usual experience with free falling objects and therefore hard to believe by many a person, even by an experienced physicist.

It was a starting point for heated discussions about the quality of the experiments and the physics knowledge of the experimentalist, and it even prompted complaints about the quality of current physics education in the Netherlands. However, experiments did reveal the truth, and students could do this supported by ICT tools. Two theoretical physicists agreed with the findings of the students, and they explained that physics intuition is easily fooled, as everyone is taught the Galilean paradigm of the motion of constant masses, according to which acceleration must be produced by a force. A launched rocket and a falling chain or slinky are important counterexamples to this line of thought. As can be seen in the theoretical section, believing the statement $a > g$ means giving up or generalising the law $F = ma$. For other bungee-jumping experiments, which investigate the phenomenon further and make more use Coach, we refer to Heck et al. (2010).

12.4.6 Integration of the ICT Tools in Recent Physics Curricula

Already for a long time, physics curricula have included laboratory activities. Together with a widespread integration of ICT in schools, there have been more and more school curricula that incorporate data logging with sensors in the science laboratory. Furthermore, in recent years, learning about modelling and learning to model have become explicit goals of science curricula in many countries (e.g. the Netherlands, the United States, Germany, and the United Kingdom). The current framework for science education in the United States (NRC 2012), for example, stated that

> Curricula will need to stress the role of models explicitly and provide students with modelling tools so that students come to value this core practice and develop a level of facility in constructing and applying appropriate models (p.59).

Modelling is now included in the Dutch Physics curriculum (and in Chemistry and Biology) for the pre-university track in secondary schools. Recently, a learning path to achieve modelling skills has been developed for the Dutch lower secondary physics curriculum. This learning path is completely integrated into the curriculum and has been tested in school practice (van Buuren 2014).

Looking back at thirty years of research on the use of ICT in education, curriculum development, and software/hardware development, it is fair to say that a lot has been achieved. Hardware and software development, including the development of the working environment—Coach, has been able up to now to meet more or less the requirements of trends in STEM education such as the change towards context-rich education, emphasis on scientific approaches, better preparation for higher education through a stronger focus on competencies, and emphasis on individual learning and provision of students' autonomy over the process of knowledge and skills acquisition. This work will undoubtedly continue, due to the very nature of technology and education, and new demands from society.

12.4.7 Conclusions About Technology for Inquiry Practices in Physics Education

It has been demonstrated that the Coach tools for data logging, video measurement, and modelling can stimulate inquiry by pupils. The proper use of these tools enhances opportunities and time for pupils' generation and validation of knowledge in the classroom. These meaningful opportunities and enough time enable pupils to move back and forth between the physical and theoretical world within the inquiry process. Students can work directly with high-quality, real-time data in much the same way professionals do. Physics learning with the ICT tools resembles practice in contact with current research work. With these ICT tools, investigations are

characterised as being challenging, complex, and open-ended, cross-disciplinary, and requiring strong commitment and broad range of skills.

12.5 Integration of Technology into Inquiry: Challenges

12.5.1 Integration of ICT into IBSE in Teaching Practice

12.5.1.1 ICT and IBSE in Teaching Practice

ICT, IBSE and ICT in IBSE are still not implemented sufficiently and properly in the classrooms in most countries. Abrahams and Millar (2008) summarised results of observations in 25 typical laboratory lessons in the United Kingdom as follows:

> 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 try to apply ICT tools (e.g. data logging with sensors) in the classroom, but mostly in traditional ways in which they provide a prescriptive list of tasks for pupils to follow ritualistically. Meanwhile, pupils know in advance from the textbook what the results of the practical work should be (Hofstein and Lunetta 2004). Prescriptive instruction enables pupils to operate the ICT tool on their own (manipulation of equipment), but such instruction limits inquiry opportunities for pupils (manipulation of ideas).

International ICT projects (e.g. KLiC and ICT for IST) highlighted possibilities and good practices of ICT tools for IBSE but were not of the scale needed to bring about the substantial impact on classroom implementation. At the national level, in many countries (e.g. Greece, Russia and Ireland), governmental education-reform projects have invested in ICT apparatus and software, delivered it to schools nationwide, and provided teachers with short training. Meanwhile, knowledge-oriented curriculum objectives and paper-and-pencil assessments were not reformed. Eventually, sufficient and proper implementation of the ICT tools was not realised. In this situation, projects with a huge funding failed to make the intended change in the classroom due to lack of consistent and concerted efforts to design, align, and implement curriculum innovation regarding ICT integration.

12.5.2 Integration of ICT in IBSE: Challenges to Pupils

Pupils' authentic inquiry in the classroom should be similar to, but cannot be the same as those of scientists, because interests, background knowledge and motivations of pupils are enormously different from those of scientists (Edelson 1998). "Real" authentic inquiry is open-ended and requires a solid discipline-knowledge

base. As Ogborn (2014) claimed, real inquiry takes some years and requires scientists "full critical attention", whereas "replicated" inquiry in the classroom is often intended for very limited time (i.e. half an hour) and relies on pupils' "intuitive responses". These responses "will most often be wrong or misguided, yet seem good to them, and be difficult to counter" (p.42). Reviewing several studies that empirically examined the inquiry learning process, de Jong and van Joolingen (1998) identified "intrinsic problems" of pupils in inquiry learning. These problems are related to hypothesis generation, design of investigations, interpretation of data, and regulation of learning. Consequently, IBSE might generate a heavy cognitive load for pupils (Kirschner et al. 2006).

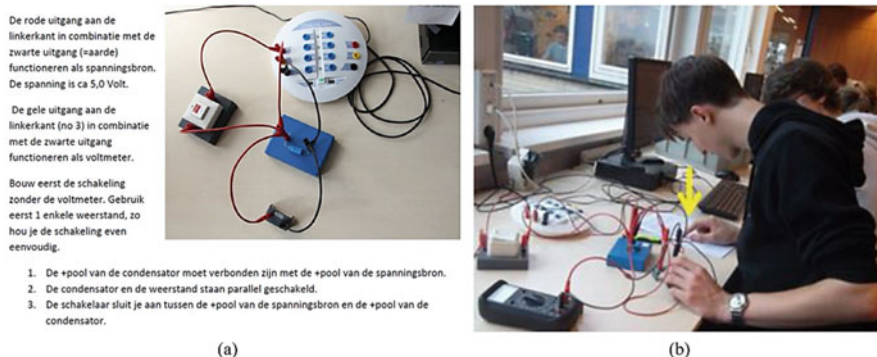### 12.5.3 Integration of ICT in IBSE: Challenges to Teachers

Even without ICT integration, proper implementation of IBSE activities is still a problem for teachers. A number of studies have reported that teachers often find it difficult to elicit pupils' ideas about the research questions, to guide pupils in planning, executing investigations and analysing, interpreting data, and to manage pupils' independent learning at different paces (Davis et al. 2006; Hofstein and Lunetta 2004). ICT provides innovative tools for IBSE, but the use of these tools will "further complicate the complex web of overlapping factors, which characterise pedagogical thinking involved in planning and executing lessons" (Rogers and Twidle 2013, p. 229).

Effective ICT integration assumes that teachers have to learn possibilities of the ICT tools for their subject, acquire skills to operate the software and hardware, and get used to troubleshooting technical problems. More importantly, teachers need to adapt and improve their pedagogical knowledge to be able to design suitable ICT in IBSE activities and engage pupils in implementation of such activities in the classroom.

12.5.3.1 Inquiry Teaching Versus Prescriptive Instruction with ICT

Pupils need sufficient instruction and practice time in order to handle laboratory equipment in the classroom. Recipes like "do this, then do that" might be the fastest and most convenient way in helping pupils to get over hurdles in manipulating equipment within a limited time, but it hinders pupils' minds-on inquiring and meaning making. Research on practical work often uses the "cookbook" metaphor to describe this prescriptive instruction (Fig. 12.9).

Considering the ICT integration, extra instructions needed to handle the necessary software might further reinforce the prescriptive nature of ICT-enhanced experimentation/modelling activities. These instructions can unintendedly come to dominate the activity, although there are practical ways to get around this. For example, after a cookbook phase for learning to manipulate the tools should come

De rode uitgang aan de linkerkant in combinatie met de zwarte uitgang (=aarde) functioneren als spanningsbron. De spanning is ca 5,0 Volt.

De gele uitgang aan de linkerkant (no 3) in combinatie met de zwarte uitgang functioneren als voltmeter.

Bouw eerst de schakeling zonder de voltmeter. Gebruik eerst 1 enkele weerstand, zo hou je de schakeling even eenvoudig.

1. De +pool van de condensator moet verbonden zijn met de +pool van de spanningsbron.
2. De condensator en de weerstand staan parallel geschakeld.
3. De schakelaar sluit je aan tussen de +pool van de spanningsbron en de +pool van de condensator.

(a)

(b)

Fig. 12.9 In the photograph (**b**), a pupil was following a cookbook instruction (**a**) to set up the experiment using sensors and the computer

an inquiry phase in which pupils themselves have to make decisions on how to use the new tools in their investigations.

12.5.3.2 Limited Preparation Time and Limited Curriculum Time

In many countries including Slovakia and Vietnam, teachers are pressed to teach all the content standards within a tightly structured, explicitly expressed syllabus (Woolnough 2001). In the Netherlands, the school science curricula are rather overloaded with standardised requirements, too; except that the way to attain these requirements is mostly left open to the teacher. In such constrained circumstances, teachers tend to get through the content (Bencze and Hodson 1999) rather than engaging pupils in investigations with the ICT tools. This is because these investigations require ample time and aim at not only conceptual learning but also other goals. Incorporating the ICT tools in school science might add extra problems to time-constraint situations, considering that teachers need extra time, effort, and/or training to learn to handle the ICT tools and to practice their use. Logistics of organising the use of hardware and software cause extra preparation time for teachers. The constraints on preparation time and curriculum time can be a factor explaining for the fact that: although the ICT tools have many innovative features that stimulate pupils' authentic inquiry practices, really authentic inquiry learning is limited to a few special projects, for example in Dutch schools, once in junior secondary and once in senior secondary.

12.5.4   Conclusions About Challenges of Technology Integration in Inquiry Practices

The science education community mostly agrees about the relevance of using ICT, IBSE, and their integration: 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.

Although integration of ICT into IBSE is relevant, it is cognitively and practically challenging for both students and teachers. ICT-enhanced inquiry-based strategies have proved their potential, but not their general efficacy in the hands of average teachers. Science teachers need effective training and practical guidelines to handle the complexity of the ICT-enhanced, inquiry-based activity without reducing it to simple "cookbook recipes". Furthermore, integration of ICT into IBSE needs sufficient time to be faithfully implemented. An actual impact of ICT in IBSE teaching on pupils needs both a longer period and consistent incorporation of ICT in IBSE in regular teaching.

12.6   Development of a Short and Effective Course for Teachers on Technology in Inquiry-Based Teaching of Physics

12.6.1   Aim and Research Questions

Factors involved in the under use of ICT and IBSE in teaching practice are among 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 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 recent research project (Tran 2016), 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 Coach 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 generalisability 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 generalisable 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)?*

12.6.2   Course Design and Research Design

12.6.2.1   Objectives of the ICT in IBSE Course

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).

12.6.2.2 Pedagogical Principles Underlying the ICT in IBSE Course

The literature on design research and on professional development of teachers led us to the following pedagogical principles 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 tryout 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 tryout with pupils.

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

12.6.2.3 Evaluation of the ICT in IBSE Course Through Three Case Studies

To examine the effectiveness of the ICT in IBSE course; validity and generalisability of the pedagogical principle; and transferability of the course design in different education contexts, we conducted the Dutch, Slovak and Vietnamese case studies (Fig. 12.10). 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
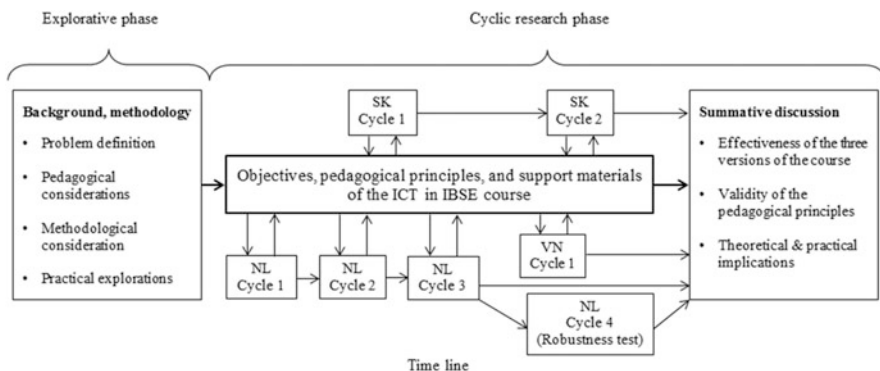
Fig. 12.10 Design and research process including an explorative phase and a cyclic-research phase with three case studies in the Netherlands (NL), Slovakia (SK) and Vietnam (VN)

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.

This evaluation framework includes 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 tryouts; participants' ICT in IBSE lesson plans and self-evaluation reports of the classroom tryouts; 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. 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 tryouts. Likewise, the Cycle 2 evaluation was guided by the objectives and pedagogical principles and resulted in further optimisation of the course scenario. We achieved 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 (including 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 (1–33 years of teaching) in Slovakia. 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 2–9 years or came straight from a Bachelor teacher-education programme. 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 generalisability 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.

12.6.3 Findings, Discussion and Conclusions

The Dutch case study 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). A typical reaction of one of the participants was:
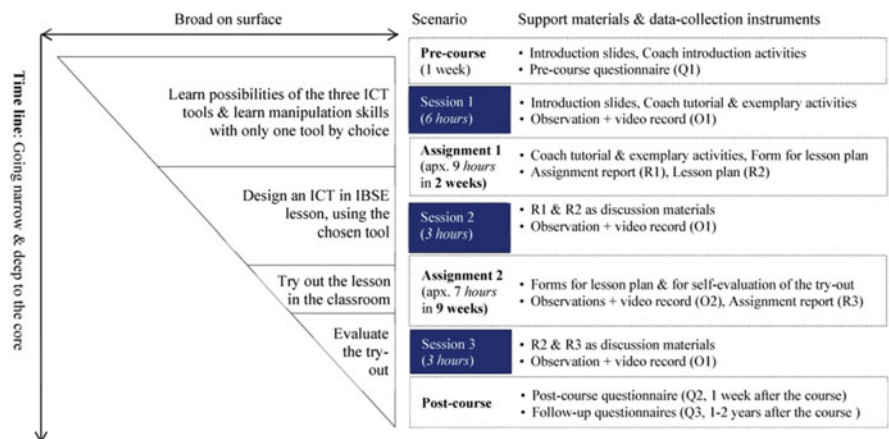
Fig. 12.11   The optimised scenario of the ICT in IBSE course in the Dutch context

Very relevant, I am happy that the course was offered and that I took it. In the teacher-education programme, we learn a lot of theory but for the implementation of it, I feel rather on my own, with very little guidance. The ICT in IBSE course was very hands-on (though the theory was also presented), gave me the opportunity to learn with and from others (knowledgeable, friendly experts and other (beginning) teachers). I got the guidance I needed to develop an activity and implement it, and the feedback after completion. The duration was fine. I strongly advise the training to other student teachers

Figure 12.11 visualises the optimised scenario, illustrates the specific operationalisation of the pedagogical principles in the Dutch context, and describes the time distribution for the three live sessions and two assignments and the plan on when to use which support materials and data-collection instruments. For more detail about the programme for the live sessions, the requirements for the individual assignments, and the support materials, see Tran (2016).

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.

Table 12.1 Differences among Dutch, Slovak and Vietnamese contexts for the course

	Dutch context	Slovak context	Vietnamese context
Participants			
• Number	40 student teachers	66 experienced teachers	22 master students
• Background and age	Mix of fresh-master and second career graduates; physics & chemistry Age: 23–55	Mix of physics, chemistry, biology and geography teachers Age: 23–55	Mix of fresh graduates and experienced teachers, Physics Age: 23–31
• Teaching experience	1–5 years 83% at first-year teaching	1–33 years 19 years on average	0–9 years 23% with no teaching
• Entrance level of ICT skills	Moderate	Low	Low
Scheduling requirements			
• Programme	Postgraduate teacher education	Accredited professional development	Master in physics education
• Total study time of the course	28 h	40 h	60 h
• "Spread" of the course	11 weeks	15 weeks	5 weeks
Teaching conditions			
• Availability of the ICT tools	Sufficient *Available in most schools*	Limited	None
• Pupil experience with ICT	Sufficient *Pupils have ever used Coach/ similar software*	Insufficient *ICT is starting to be introduced*	None
• Pupil experience with IBSE	Insufficient *Certain experience with laboratory but less with IBSE*	Poor *A little experience with laboratory but very limited with IBSE*	None
• IBSE in curriculum	Explicit and required	Starting to be required	In new 2016 curriculum
• Teacher autonomy	High	Moderate	Low

   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) (Table 12.1). First, the Dutch course was limited to 12 contact hours out of 28 h of total study time, but it was spread over 11 weeks. The Vietnamese course was compressed in 5 weeks, but 30 h 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 freer 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, 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 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 tryouts 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 and Millar 2008; Abrahams and Reiss 2012; Tamir and Lunetta 1981). Many teachers do have problems to operationalise inquiry in the classroom, even in countries like the UK and the US where inquiry has been emphasised 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. 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 applied pedagogical principles proved to be 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 tryout. 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.

12.6.4   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 "Technological Content Knowledge" (TCK) problems. Beyond the basic manipulation skills, TCK problems involve:

– Advanced features of the ICT tool (e.g. how to add the empirical graph to the modelling activity and compare it with the modelling graph; how to make control bars to change constants and initial values of variables of the model).
– Participants' understanding of the phenomenon (i.e. concepts, laws and events) to be experimented or modelled with the ICT tool and general experimentation/modelling skills.
– Participants' knowledge of mental model behind the digital tool that enables (a) collection and modelling of information about the phenomenon (sampling, digitalisation, numerical iteration) and (b) representation, analysis, and processing of the collected/modelled data.

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 tryout the course in different programmes or even countries. We achieved successful outcomes with these steps. Consequently, we strongly recommend robustness and generalisability/ 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. Education should be less political-driven and more expert-driven!

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