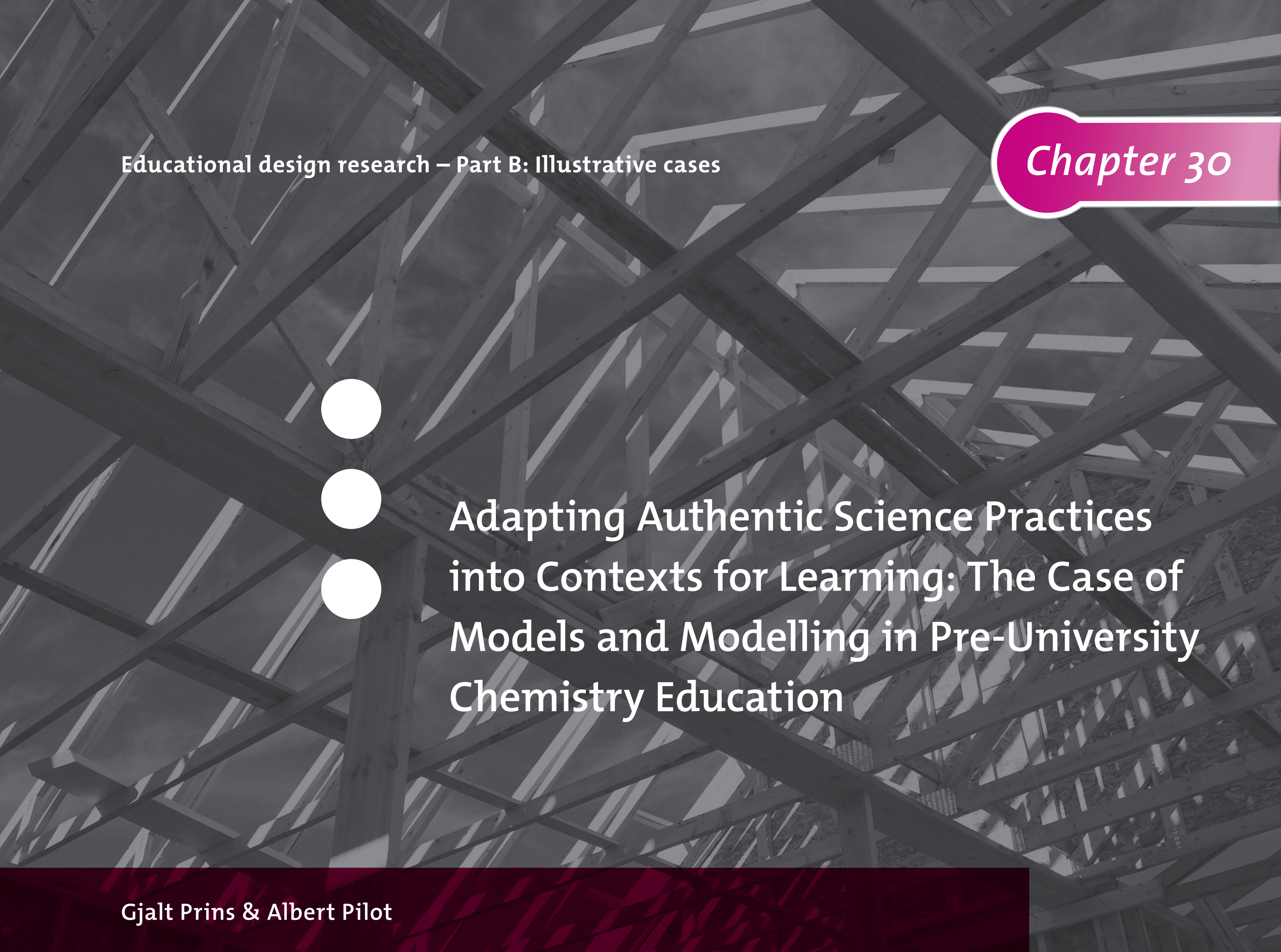

Chapter 30

Adapting Authentic Science Practices into Contexts for Learning: The Case of Models and Modelling in Pre-University Chemistry Education

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30. Adapting authentic science practices into contexts for learning: The case of models and modelling in pre-university chemistry education

Gjalt Prins & Albert Pilot

Abstract

This research study explores the potential benefits of using authentic modelling practices as contexts for learning in chemistry education. An authentic modelling practice is characterized as professionals sharing common purposes, working to a similar type of modelling procedure, while applying relevant issue knowledge. The educational challenge is to adapt these practices to suit students' abilities and lead to desired learning outcomes. This study employs an educational design research approach for the construction of an intervention aimed at enhancing students' epistemological notions regarding models and modelling. The design knowledge is captured in design principles, a synthesis of strategy components and pedagogic effects underpinned by theoretical notions, empirical experiences and/or practical considerations. These design principles provide heuristic guidelines that support practitioners and educational designers in constructing authentic practice-based interventions for science education.

1. Introduction

In this chapter we describe the adaptation of an authentic chemical modelling practice into a context for learning for use in pre-university chemistry education, students in grade 10/11 (age 16/17) in the Netherlands. The learning of models and modelling is regarded as an integral part of scientific literacy (Clement, 2000; Gilbert, 2004). However, many studies have revealed that students do not effectively learn about models and modelling (Grosslight, Unger, Jay, & Smith, 1991; Harrison & Treagust, 1996). There is substantial evidence that the traditional chemistry curriculum does not fully support students' learning of models and modelling (Erduran & Duschl, 2004). A current belief is that - rather than teaching students about models constructed by others - students should become actively involved in modelling processes in which they develop understanding of their models including the evaluation and testing (Penner, Lehrer, & Schauble, 1998; Raghavan & Glaser, 1995). It has been claimed that this aspiration might be realized by designing a learning environment which accurately reflects an authentic science practice that employs models (Edelson, 1998; Roth, 1998; Sadler, 2007).

In broader perspective, making science learning more resemble authentic scientific practices has been a goal among educational reformers for several decades (Edelson, 1998). The potential benefits are that students become active learners acquiring scientific knowledge and developing skills and attitude in a meaningful context. Using authentic practices as contexts for learning in science education stems from and relates to the Activity theory in education rooted in sociocultural view on learning (Vygotsky, 1981; Leont'ev, 1978). Activity theory describes society in terms of connected social practices as manifestations of activity. The unit 'activity' is considered the foundation of knowledge. Activity theory considers the zone of proximal development as a core concept, in which development involves cognitive, affective and volitional aspects.

An authentic modelling practice is characterised by professionals with common motives and purposes for model construction (feature I), working according a similar modelling procedure (feature II) and applying relevant knowledge (feature III) in the area they are working in. When using authentic practices as contexts for learning, one needs to acknowledge significant differences between the population of students and that of experts. An authentic practice-based curriculum unit needs to be designed such that it leads to desired learning outcomes within the constraints of the classroom (Lijnse, 1995). This study employs an educational design research approach, on the one hand to tackle the design challenges to achieve the benefits of authenticity in classroom, on the other hand to generalize the scientific yield in empirically validated design principles. Design principles are defined as tools providing heuristic guidelines for strategy components for realising pedagogic effects in classroom (Van den Akker, Gravemeijer, McKenny, & Nieveen, 2006). Design principles inform practitioners and educational designers about the construction of interventions. The central research question addressed is:

What are the characteristics of a teaching-learning process using an authentic modelling practice as context for learning in pre-university chemistry education?

In the following we will first clarify the design stages, the respective quality criteria and evaluation methods used in this study. Secondly, we describe the analysis and selection of suitable authentic modelling practices for use as context for learning. Thirdly, we describe the construction phase consisting of iterative stages of development of the intervention, empirical testing and evaluation thereof. Finally, we describe the outcomes in terms of design principles, a synthesis of strategy components and intended pedagogic effects underpinned by theoretical notions, empirical experiences and/or practical considerations. We end this paper with a reflection on the use of authentic practices as context for learning in chemistry (or science) education.

2. Overview of development stages and their quality criteria

In Table 1 an overview is presented of the consecutive development stages, respective quality criteria and evaluation methods employed in this Educational Design Research (EDR) study, building on earlier research (Nieveen, 1999, 2009). The relevance (content validity) concerns the need for the intervention based on 1) a literature analysis of the students' learning difficulties related to models and modelling, 2) strategies described in literature to overcome the reported learning difficulties, and 3) a complete and detailed description of the authentic modelling practice to be used as context for learning. The consistency (construct validity) concerns the design of the intervention, e.g. the embedding of the essential elements of the authentic modelling practice in the intervention and the construction of a meaningful sequence of teaching and learning activities. The practicality denotes the feasibility of the intervention in the settings for which it has been designed and developed, on the level of 'expected', e.g. argued predictions about the functioning of the intervention, and 'actual', e.g. empirical data on the realised enactment of the intervention. The effectiveness is focused on students' learning outcomes, also both on the level of 'expected' and 'actual'.

Table 1: Overview of consecutive design stages, respective quality criteria and evaluation methods in this EDR study

Design stages / Quality criteria		Analysis of authentic modelling practices		Development and empirical testing of the intervention		
		Design specifications	Outline of the design	Partly detailed intervention	Complete intervention	Implemented intervention
Relevance		• Document and literature analysis • Expert appraisal	• Screening			
Consistency			• Screening • Expert appraisal	• Screening	• Screening • Expert appraisal	
Practicality	expected		• Screening	• Screening • Walkthrough	• Expert appraisal	
	actual			• Micro-evaluation	• Try-out	
Effectiveness	expected		• Screening			• Expert appraisal
	actual					• Case study

In each design stage a prototype of the intervention is evaluated with use of appropriate formative evaluation methods that fits the evolutionary stage. The first design stage started with a literature search to reveal students' learning difficulties related to models and modelling, as well as to gain an overview of proposed teaching strategies to overcome the reported learning difficulties. In addition, authentic modelling practices were searched for, analysed and selected, based on thorough elaboration of the practices (document analysis) and a series of interviews with representative experts (expert appraisal). The findings informed the design specifications and provided input for the second design stage: the outline of the design. The outline described the selected modelling issue for students to work on, embedded in the selected practice, and the planned sequence of teaching and learning activities. The outline was screened by members of the design team. The screening focussed on identifying critical components and activities in the practice to incorporate in the educational design in order to maintain coherency and authenticity from students' perspective. In addition, the screening was focussed on identification of the expected practical feasibility in classroom and expected students' learning outcomes. Finally, subject matter experts were consulted in order to validate the scientific soundness of the outline of the design.

In the third design stage, partly designed intervention, students' initial involvement in the selected practice was investigated. The aim was to validate whether the selected authentic modelling practice was in line with students' competences, pre-existing knowledge base and did induce interest and motivation to study the practice in more detail. The first set of teaching and learning activities have been designed and enacted by a small group of students. The partly designed intervention has been screened by the members of the design team preceding enactment. The screening focussed on the content and expected outcomes of the respective teaching and learning activities. In addition, before enactment the set-up of the partly designed intervention has been discussed in detail by the researcher and the teacher to make explicit the underlying rationale and the expected outcomes (walkthrough). Finally, the partly designed intervention has been enacted by a group of students outside classroom (micro-evaluation).

The students were observed and interviewed in order to gain insight in their involvement and perceived level of difficulty of the modelling issue at hand.

In the fourth stage the complete intervention was constructed iteratively. The fourth stage consisted of two research cycles, respectively in two classes in two different schools with an evaluation and revision in between. The construction of the complete intervention was conducted in close cooperation with the teachers (expert appraisal), who were also committed to enact the intervention in their own classes. Teachers' tacit knowledge and expertise, i.e. their implicit or unarticulated knowledge learned and transmitted through experience and apprenticeships, was incorporated in the design in order to reduce discrepancies between curriculum design and actual classroom environments as much as possible (Kensing & Blomberg, 1998; Könings, Brand-Gruwel & Van Merriënboer, 2005; Könings, Zundert, Brand-Gruwel & van Merriënboer, 2007; Mankin, Cohen, & Bikson, 1997). The pedagogical decisions were described in design principles (McKenney, Nieveen, & Van den Akker, 2006). The try-out concentrated on the perceived meaningfulness by students, e.g. students' knowing *why what* to do at every step in the teaching-learning process. During the design process and in between the research cycles the complete intervention was screened by members of the design team. The focus was to evaluate the sequence of teaching and learning activities from students' perspective.

The last and fifth stage the students' learning outcomes related to models and modelling was tested in a case study in one class at one school. The case study was focused on students' gained insight in advanced model features purpose, goodness of fit, reliability and validity, as well as insight in the applied modelling procedure.

3. Analysis of authentic modelling practices

In our society many chemistry-related authentic practices are available. For example, practices aiming at quality evaluation of products, e.g. drinking water, food or consumer products for personal health, or practices with an emphasis on research, e.g. developing new catalysts or acquiring fundamental understanding of structure-property relations of proteins. Within such practices the specific attitudes, characteristic procedures and issue knowledge play an obvious role. The relevance of the skills and issue knowledge involved is not questioned, since the participants of such a practice have clear motives to use and extend these accordingly.

However, regarding the use of authentic modelling practices as contexts for learning, it should be noted that it 'cannot be expected that students are able to conceptualize the goals and direction to follow with the same width and depth as the professionals (Westbroek et al., 2009). Therefore, the suitability of authentic modelling practices for use as contexts for learning needs to be justified from educational points of view and students' perspectives.

Method

In four consecutive steps authentic modelling practices were searched, analyzed and selected based on the on the following aspects (Prins, 2008):

a. Students' interest: to what extend are students interested in and motivated for the modelling issue at hand;
b. Students' ownership: to what extend can students develop ownership and personal autonomy with a certain modelling issue;
c. Modelling procedure: to what extend are the main stages in the modelling procedure in the authentic practice in line with students' common sense notions;

d. Complexity: to what extend are students able to deal with the complexity of the modelling issue at hand, e.g. the number of factors and parameters involved;
e. Familiarity: to what extend are student familiar with the modelling issue at hand, e.g. which concepts and skills are already mastered by students and which are not.

As a first step, a list of authentic chemical practices, in which models were used as a predictive tool, was generated by internet search. The search was conducted in January 2004 with search machine Google using a combination of the keywords ‘modelling’, ‘procedure’, ‘predictive’, ‘chemistry’ and ‘practices’. The rationale for using this open search method was to acquire a broad range of authentic chemical modelling practices, including social, technological and research practices. Given concerns about the reliability of some internet resources, the validity of this search method was ensured by selecting only references to well established institutes, e.g. companies or governmental authorities. Solely Dutch websites were included in our search, since Dutch practices were expected to be more recognisable for Dutch students.

Secondly, each practice was reviewed according to a subset of the aspects, e.g., students’ interest (a), complexity of the issue (d), familiarity with the issue (e) and a conditional aspect related to the feasibility of performing laboratory work in classroom. This review process was conducted independently by two researchers. Both researchers compared and discussed their valuations on each aspect resulting in a final judgment of practices to be analyzed in the third step.

Thirdly, the selected practices were analyzed in depth to reveal the motives for model development, the modelling procedure and the issue knowledge involved, using relevant documents (reports, articles) and by expert-interviews. The interview data were analyzed from an interpretative perspective by two researchers independently (Smith, 1995). The focus was on the expert’s statements concerning the motives and purposes for model construction (feature I), the expert’s reflections on the characteristic modelling procedure (feature II) and the relevant issue knowledge involved (feature III).

Fourthly, the results of the in-depth analysis of the authentic chemical modelling practices were evaluated according to all aspects, e.g. students’ interest (a), students’ ownership (b), modelling procedure (c), complexity (d) and familiarity (e). This assessment process was conducted independently by two researchers as described in step 2.

Results
The internet search resulted in two practices valued as suitable for educational purposes: (1) modelling human exposure and uptake of chemicals from consumer products, and (2) modelling drinking water treatment. The latter practice was adapted into a context for learning and tested in classroom, primarily because of the availability, or relative easy development, of laboratory experiments related to water treatment. Below the major characteristics of the practice ‘modelling drinking water treatment’ are described. More details can be found in Prins, Bulte, Van Driel and Pilot (2008).

Design specifications
The authentic practice of modelling drinking water treatment is that of the chemical process engineers involved in the process of drinking water treatment in order to improve efficiency and minimize costs. The objective of this authentic practice is to identify and describe quantitative relations between the input and output concentration of undesired constituents depending on

relevant process variables. Such quantitative relations can be used to predict the quality of the drinking water after treatment as a function of the quality of the incoming (raw) water and the execution of the treatment process itself.

To develop such quantitative relations a characteristic modelling procedure is applied by modelling experts (Prins, Bulte, & Pilot, 2011). In broad outline, three distinctive stages can be distinguished, each evoking the application of specific scientific (biological, chemical and/or physical) and mathematical knowledge. The first stage involves the studying of the principles underlying the mechanisms of the treatment step in order to identify relevant process variables. This stage might include an orientation on process models already available and described in the literature. The second stage involves the gathering of experimental data under controlled conditions, both at the laboratory (pilot) scale and in real industrial plants. The third stage involves the development of a process model that describes the quantitative relations between input, output and relevant process variables. The modelling of the drinking water treatment is conceptualised in Figure 1. The block arrows indicate the flow of water with contaminants to be removed in treatment *step N*. $C_{iN,in}$ denotes the incoming amount of contaminant i, while $C_{iN,out}$ denotes the residual amount of contaminant i after *step N*. The removal efficiency in each step is affected by process variables, symbolised by pv_N.

In the authentic practice of modelling drinking water treatment, basically two modelling approaches are applied, namely the empirical and the mechanistic approaches. The mechanistic approach starts from a well-defined theoretical knowledge base, whereas the empirical approach aims to describe process behavior by fitting mathematical models to a set of experimental data. From a scientific (technological) point of view the mechanistic approach is preferred, since it strives to understand and describe mathematically the mechanics underlying the processes occurring in a given system. However, in many cases the underpinning theoretical knowledge is lacking, thus favoring an empirical approach.

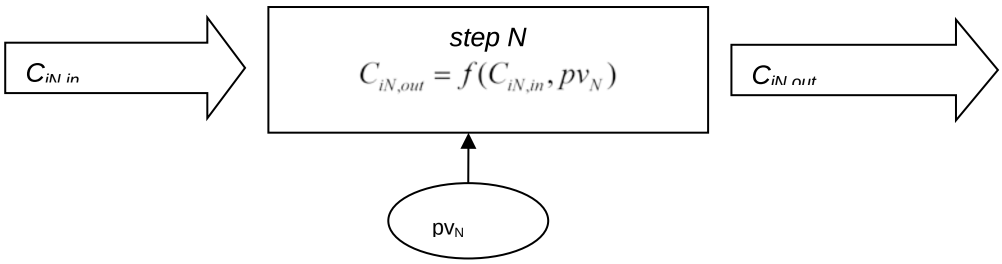

Figure 1: Conceptualised scheme of the modelling of the process of drinking water treatment. The block arrows indicate the incoming water stream, containing contaminants ($C_{iN,\ in}$) to be removed, and the outflowing water stream, with a residual concentration of contaminants ($C_{iN,\ out}$). The quantitative relation between output, input and process variables can be formalised by a formula $C_{iN,out} = f(C_{iN,in}, pv_N)$.

Outline of the design

The modelling of the complete drinking water treatment process comprises numerous steps, parameters and process variables. It was decided to ‘zoom in’ on the process of turbidity removal by coagulation/flocculation, based on valuations regarding students’ (cognitive) abilities (e.g. involved chemical and mathematical knowledge and students’ pre-existing knowledge base) and affective aspects (e.g. students' interests and sense of ownership). The major characteristics of the adapted authentic practice as context for learning are portrayed below.

Turbidity is caused by small particles, such as colloids and fine silt. During coagulation/flocculation treatment these particles are removed by adding a coagulant, such as ferric chloride. The efficiency of turbidity removal is affected by chemical process variables, such as the turbidity of the incoming water ($turbidity_{in}$), temperature (T), total salt concentration (c[salt]), acidity (*pH*) and the dose coagulant ferric chloride (V). In addition, several process conditions affect the efficiency of turbidity removal, such as the stirring method, frequency and duration. The dose coagulant (V) and process conditions can be directly manipulated. The coagulation/flocculation treatment is conceptualized as an input-output system, as depicted in Figure 2.

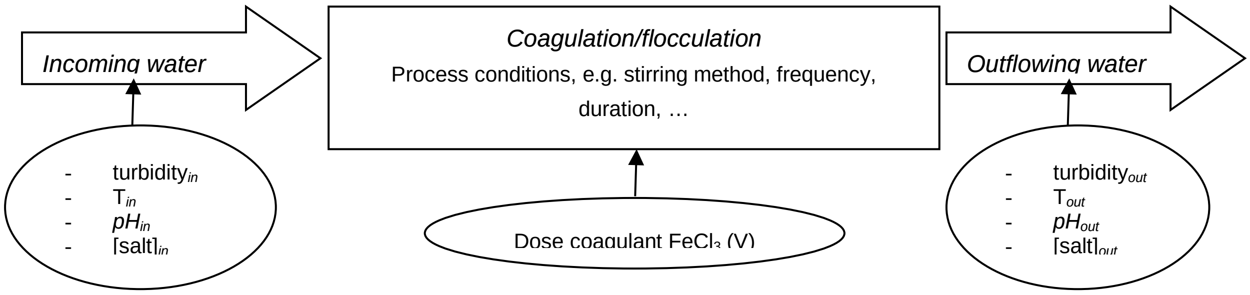

Figure 2: Conceptualised scheme of the coagulation/flocculation treatment process including relevant process variables. The block arrows indicate the flow of water.

The aim of modelling is to gain understanding how the various process variables influence the $turbidity_{out}$. The influence of the relevant chemical process variables is described by a regression model, such as $turbidity_{out} = f(turbidity_{in}, V, T, pH, [salt])$. The model is evaluated on epistemic values, such as purpose, goodness of fit, reliability and validity. The applied modelling approach can be typified as empirical (or black box, data-driven). The applied modelling process in the authentic practice consists of three distinct stages as depicted in Table 2.

Table 2: Overview of the modelling stages and accompanying situated knowledge in modelling turbidity removal by coagulation/flocculation

Modelling stages	Situated knowledge
Study the working of the treatment step	Coagulation/flocculation Process variables
Gather empirical data	Experiments under controlled conditions Correlation & regression
Develop a process model	Multiple regression

4. Development and empirical testing of the intervention

After having decided on the design specifications and the outline of the design, the challenge was to construct a complete intervention to achieve the benefits of authenticity. The development of the intervention was guided by a design framework as depicted in Table 3, building on the 5E Learning Cycle (Trowbridge, Bybee, & Powell, 2000) rooted in inquiry-based learning and the 'instructional version of an authentic practice' (Bulte, Westbroek, De Jong, & Pilot, 2006).

Table 3: Design framework for the construction of an intervention using an authentic practice as a context for learning, based on the 5E Learning Cycle and the instructional version of an authentic practice

5E Learning Cycle	**Design strategy / Instructional functions**
ENGAGE/orientate on the practice	Activities *elicit curiosity, interest and involvement.* Students are introduced to the practice at hand, e.g. its aims and societal embedding, and become motivated to study a particular problem posed in the practice. Students make connections with prior conceptual and procedural knowledge base and think about what they will learn during upcoming activities.
EXPLORE/zoom in on an exemplary problem	Activities *create a demand for knowledge* to solve the exemplary problem successfully. Students develop ownership of the exemplary problem and think of a route to solve the problem. Students become aware of the type of activities to conduct and the conceptual knowledge to learn.
EXPLAIN/solve the exemplary problem	Activities *guide learners to identify and improve upon mastered concepts, processes and skills, and to learn new competencies.* Students study articles and documents related to the exemplary problem, conduct hand-on lab activities to explore hypothesized relations between variables, analyze data with use of appropriate techniques and develop a (mathematical) model, until a satisfactory solution for the exemplary problem can be presented.
EVALUATE/reflect on the findings	Activities that allow learners to retrospectively *reflect and evaluate* upon the presented solution, e.g. a (mathematical) model, and their newly gained conceptual and procedural knowledge.
ELABORATE/express the findings	Activities provide learners with an opportunity to *express and communicate* what they have learned and to figure out what it means. Students share ideas with each other and with their teachers. Students draw up a project plan for solving a similar problem posed in the practice, to experience the broader applicability of the gained knowledge.

The design framework was also inspired by research on meaningful teaching-learning processes (Cobb, Stephan, McClain, & Gravemeijer, 2001; Kortland, 2001; Lijnse & Klaassen, 2004; Westbroek, 2005).

From the perspective of the intervention, the design framework in Table 3 articulates the requirements that a set of learning activities must meet to achieve the particular learning objectives. However, decisions regarding what science content to teach and tasks and materials that will help students make desired meaning are interrelated and should be thoughtfully made in light of desired goals for students and how students learn. Inspired by McKenney, Nieveen and Van den Akker (2006), we captured and described the major pedagogic decisions as design principles. Design principles are prescriptive in nature and focus on creating learning environments and products rather than describing how learners acquire knowledge and skills from these environments or products (Merrill, 2002). Design principles, in our interpretation, consist of strategy components that give rise to pedagogic effects, underpinned by theoretical notions, empirical experiences and/or practical considerations. Figure 3 depicts a conceptualized scheme of a design principle.

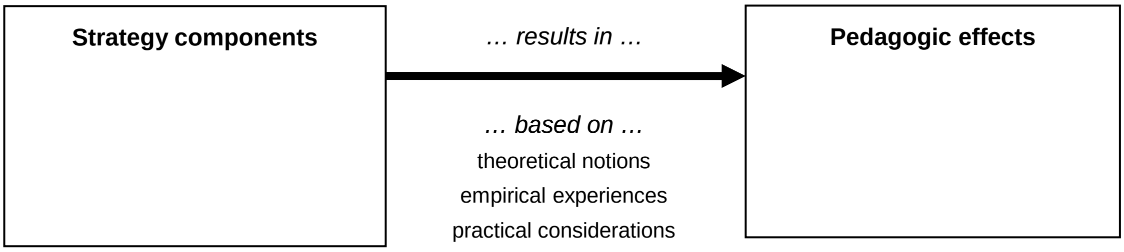

Figure 3: A design principle linking strategy components and pedagogic effects, underpinned by theoretical notions, empirical experiences and/or practical considerations

In this study the pedagogic decisions were categorised in three design principles, namely motives & purposes, models & modelling and chain of activities. The design principle of *motives & purposes* deals with involving learners in a focal event embedded in its cultural setting (Gilbert, 2006). This implies that the setting, the behavioural environment, the specific language and the extra-situational background knowledge are such that students become engaged in a modelling activity. The design principle of *models & modelling* deals with focusing learners on the essential generic content regarding models and modelling. The design principle of *chain of activities* deals with constructing a sequence of teaching-learning activities such that learners constantly know *why what* to do at every step in the process.

Method

The development of the intervention compromised three consecutive stages. In the stage partly designed intervention, the students' engagement in the practice and their prior knowledge base regarding the modelling issue at hand were investigated. In the stage complete intervention, the practicality of the designed intervention was empirically tested in two research cycles, with focus on students' experienced meaningfulness. In the stage implemented intervention, the intervention was investigated on the effectiveness, with focus on the students' learning outcomes related to models and modelling. Below, the research aims and applied formative evaluation methods in each stage are described.

Partly detailed intervention

In this stage we focused specifically on the students' initial engagement in modelling drinking water treatment. The modelling of drinking water treatment should appeal to students, evoke their interest and ownership, encourage autonomy and willingness to work and build on pre-knowledge and intuitive notions. The students' involvement should be initiated at the start of the intervention. Therefore, learning tasks were designed which were enacted by a group of students (Prins, et al., 2009). The learning tasks were thoroughly screened by the members of the design team in light of the complete intervention. The group consisted of 18 students, grade 10/11 (age 16-17) from three different schools in the city of Utrecht, the Netherlands. All students took chemistry classes at pre-university level. The students worked in groups of three persons. The enactment took place outside of the regular class situation. The teacher was member of the design team and well informed in the underlying pedagogy. In the first three learning tasks, students orientate themselves on the practice. In the fourth and last task, student teams were given the open task to draw up a plan of action to solve the exemplary problem of modelling the removal of water turbidity themselves. In this plan of action students express a series of modelling activities. The teacher did give help, feedback and coaching if needed. At the end each student team delivered a plan of action describing a modelling procedure to come to a solution for the modelling issue at hand. In addition, an evaluative group discussion was held in which students reflected on affective and cognitive aspects.

All plans of actions were analysed by two researchers independently to identify the different modelling stages and to judge the quality thereof. Preceding the analysis, both researchers developed and agreed upon a reference modelling procedure as evaluative framework. A rater consistency check was conducted by calculating the intraclass correlation coefficient using a two-way mixed effects model (Shrout & Fleiss, 1979). The group discussions were analysed from an interpretative perspective (Smith, 1995). Students' statements were coded according to criteria students' interest and ownership or familiarity and complexity. The inter coder agreement was tested for by calculating the percentage of statements coded equally by both researchers. We used 80 per cent as lower limit for a substantial level of agreement (Miles & Huberman, 1994).

Complete intervention

In this stage the complete intervention was designed and tested in the educational context it was designed for, e.g., students grades 10/11 (age 16–17), pre-university chemistry education. The design of the intervention was accompanied by a set of argued expectations of how the teaching-learning process is expected to take place and why it should operate according to the expectations (Lijnse, 1995). The method strongly resembles what Cobb, Confrey, DiSessa, Lehrer and Schauble (2003) described as 'design experiments' conducted in the classroom.

The intervention was tested in two research cycles, in four classes in two different schools in the period from 2008 till 2009. Between each enactment the realized teaching-learning process was evaluated, reflecting upon and adjusted. The complete intervention comprised eight lessons of 50 minutes, excluding time for self-study. The students were grouped into teams of four persons. The teachers were well acquainted with the content and pedagogy of the curriculum unit, since they were involved in the design. The evaluation focused on the practicality of the intervention. In particular, we focussed on the experienced meaningfulness from students' perspectives, e.g. why what to do at every step in the process.

The collected data sources were audio-taped conversations of student teams at work and written answers of student teams. Field notes were made to determine whether the teaching-learning processes were enacted in class as intended. The audio-taped conversations of the student teams at work were used as primary sources. The written answers were used to check the trends noticed. The conversations of the student teams at work were transcribed *verbatim* and coded from an interpretative perspective (Smith, 1995) by two researchers independently. The realized students' notions and attitudes were compared with those expected. A rater consistency check was conducted by calculating the intraclass correlation coefficient using a two-way mixed effects model (Shrout & Fleiss, 1979). In addition, every student filled in a written questionnaire individually after each lesson. The major purpose of the written questionnaire was to reveal students' valuations of the designed teaching-learning activities and to check to what extent students have a perspective and understanding of future activities to conduct to solve the exemplary problem. Finally, the findings and results were discussed by the whole research team to identify underlying considerations and to unravel students' perspectives.

Implemented intervention

In this stage the focus was on revealing the actual effectiveness of the intervention in classroom regarding students' learning outcomes related to models & modelling, e.g. the epistemic notions regarding models (purpose, goodness of fit, validity, reliability) and the process of modelling (pros and cons of a data-driven, empirical modelling approach). The intervention was tested in a small-scale case study, with a classroom and its teacher as the unit of analysis (Cobb, Stephan, McClain, & Gravemeijer, 2001). The data collection and analysis were concentrated around teaching-learning activities that embody the learning of epistemology of models and modelling. The collected data sources were audio-taped conversations of the student teams at work, written answers of the student teams, interviews with the student teams and field notes. The audio taped conversations and written answers were analyzed by two researchers independently. A rater consistency check was conducted by calculating the intraclass correlation coefficient using a two-way mixed effects model (Shrout and Fleiss, 1979).

Results

For sake of clarity we highlight the major findings and main conclusions. More details can be found in Prins, Bulte, Van Driel and Pilot (2009), Prins (2010) and Prins, Bulte and Pilot (2011).

Partly detailed intervention

Two major trends were identified within students' interest: 'appreciation of the clear link between chemical theory and practice' and 'the understanding of models and learning to construct models'. A major trend within ownership was that the issue encouraged students to think 'creatively about experiments'. The group discussion revealed that a majority of the students experienced the unit as interesting. Students especially appraised the high level of authenticity.

The results showed that students were familiar with the chemical concepts involved. As for the students' modelling approach, the findings suggest that the students were well able to articulate a modelling procedure in rudimentary sense. However, as it comes to the particular mathematical models employed, the results showed a more dispersed picture. Students were rather unfamiliar with the syntax of the formulas, the construction method and the empirical basis of the models.

In short, it was concluded that the practice of modelling drinking water treatment complied with student' interest and ownership in sufficient way. In addition, the issue of clearance of water turbidity by coagulation & flocculation showed to be in line with students' intuitive modelling notions.

Complete intervention

This stage aimed at designing an intervention which functioned in classroom according expectations. The practicality of the designed intervention was measured according to students' perceived meaningfulness, taken as students' being aware about why what to do at every step in the teaching-learning process. The structure of the final intervention, in terms of the development of situated knowledge and modelling skills coupled by content related motives

(Lijnse & Klaassen, 2004), is depicted in Figure 4. This final version was appreciated by students and teachers for the logical sequence, meaning and feasibility of the learning activities.

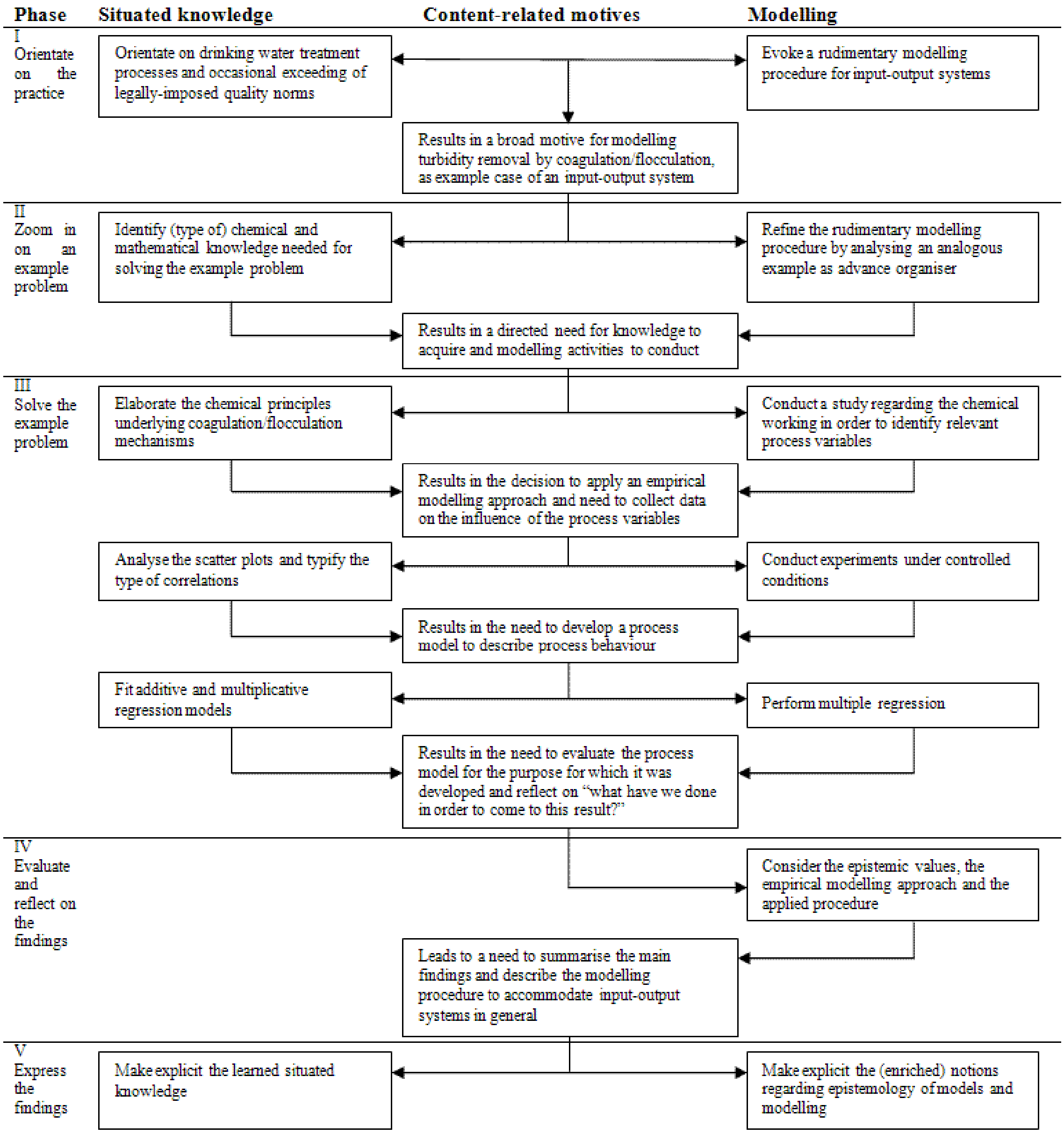

Figure 4: A structure of the teaching-learning process using the authentic practice 'Modelling drinking water treatment' as a context for learning. The boxes represent major stages in the teaching-learning process. The arrows indicate the flow of the process.

Implemented intervention

The designed intervention proved to foster students' insight into the epistemic values purpose, goodness of fit, reliability and validity (Prins, 2011). Students learned to describe and formalise the process behavior in mathematical models. In this respect, the modelling process resembles what Gravemeijer (1999) typified as emergent modelling: 'a process of gradual growth in which formal mathematics comes to the fore as a natural extension of the student's experiential reality'. Students developed competencies to reason in a formal way about modelling. In addition, students showed to be able to discuss the pros and cons of the applied empirical modelling approach. The majority of the students put forward relevant notions, e.g., the absence of a sound theoretical foundation and the need for a good data set (number and accuracy) to describe the process behaviour. However, only a minority of the students reflected upon the broader applicability of the learned empirical modelling approach for other input-output modelling issues.

5. Yield of this study

In this section we describe the emerged design principles underlying the design intervention, using the construct presented in Figure 3. The empirically validated design principles are grounded in the results from the classroom enactments. More information about the connection between the empirical results and the generalized design principles can be found in Prins (2010) and Prins, Bulte and Pilot (2011).

The design principle of *motives & purposes* deals with involving learners in a focal event embedded in its cultural setting (Gilbert, 2006). The design principle provides a couple of strategy components which focus on students' involvement, relevant situated knowledge and proper assessment. The design principle is shown in Figure 5.

Strategy components of motives & purposes		Pedagogic effects
- Provide an orientation base on the authentic practice, e.g. the societal embedding and relevance of the issues dealt with. - Select an example problem, posed in the authentic practice, for students to work on which is in line with their competencies. - Select essential situated knowledge for the example problem at hand. - Select an authentic assessment instrument, e.g. a report or factsheet. Elaborate with students the assessment product in the beginning of the teaching-learning process.	*… results in* → *… based on*	- Students see the societal relevance of the authentic practice. - Students develop broad interest and ownership for the example problem - Students activate their prior knowledge and recognise multiple routes for dealing with the example problem. - Students see the point of the activity and have sight on the learning gain. - Students experience authenticity by studying mock articles and manuals. - Students experience the assessment in line with the example problem and the work conducted.

- Theoretical notions:
    - Situated learning (Brown, Collins & Duguid, 1989; Lave, 1996);
    - Authenticity (Rule, 2006).
- Empirical experiences: students need to know from the very beginning how the assessment will take place. The assessment instrument should fit the example problem students have worked on.
- Practical considerations: just-in-time delivery of situated knowledge by using mock articles and manuals.

Figure 5: Conceptualised scheme of the design principle 'motives & purposes'

The design principle of models & modelling deals with focusing learners on the essential generic content regarding models and modelling. In present case the epistemology of models, e.g. purpose, goodness of fit, reliability and validity, and of the process of modelling, e.g. the pros and cons of the empirical modelling approach. The design principle is shown in Figure 6.

Strategy components of models & modelling

- Visualize and conceptualized the example modelling problem.
- Supply a worked-out analogous modelling problem as leading example/advanced organizer.
- Discuss different modelling approaches and give arguments. Involve students in selecting a suitable approach.
- Involve students' in a series of activities emphasizing the nature, characteristics and wording of the model.
- Let students apply their developed model for the real-world problem it was adapted from.
- Reflect on the modelling approach followed, assumptions and estimations made, and the possible effect of neglected variables.

… results in

… based on

Pedagogic effects

- Students' make explicit their intuitive notions regarding a modelling procedure.
- Students' have a broad view on the type of modelling activities to conduct.
- Students' epistemological view related to the selected modelling procedure is enhanced.
- Student get clear sight on advanced model features, e.g. purpose of modelling, goodness of fit, reliability and validity.
- Students are able to select generic knowledge regarding models and modelling for use in similar modelling situations.

- Theoretical notions:
    - Use of an analogous problem as an advanced organizer to scaffold students' learning (Ausubel, 1968);
    - Emergent modelling: stepwise formalisation of the empirical data (Gravemeijer, 1999).
- Empirical experiences: elaboration of the various modelling approaches fosters reflection in later stages.
- Practical considerations: applying the own developed model helps students to get insight in the scope, boundaries, and limits.

Figure 6: Conceptualised scheme of the design principle 'models & modelling'

The design principle of *chain of activities* deals with constructing a sequence of teaching-learning activities such that learners constantly know *why what* to do at every step in the process. The findings showed that students, in general, experienced the sequence of teaching-learning activities as meaningful. The design principle is shown in Figure 7.

Strategy components of chain of activities

- Use the procedure applied in the authentic practice, that is the sequence of activities, as backbone of a series of teaching-learning activities.
- Evaluate each designed teaching-learning activity from students' perspective.
- Plan regular meetings with student to look ahead to future activities.

… results in

Pedagogic effects

- Students regard the chain of activities as logical and meaningful.
- Students know why, what to do at every step in the process.
- Students keep sight on the progress, that is the tasks already accomplished and future tasks, while recalling the overall purpose of the modelling.

… based on

- Theoretical notions:
  - Design the teaching-learning process on a need-to-know base from students' perspective according to the problem-posing approach (Klaassen, 1995).
- Empirical experiences: the authentic procedure complies in rudimentary form with students' notions regarding a route to solve the example problem.
- Practical considerations: regular meetings are necessary to keep students 'on track' and to finish the project in time.

Figure 7: Conceptualised scheme of the design principle 'chain of activities'

6. Reflections on the use of authentic practices as contexts for learning

This research study supports the claim that learning environments that actually reflect real science practices fosters students' motivation, involvement and ownership and enables them to acquire knowledge in meaningful contexts (Edelson, 1998). However, an authentic practice needs to comply with a number of prerequisites to be suitable for use in pre-university chemistry (science) education:

- The objectives in the adapted authentic practice should match the learning goals of pre-university education;
- The example problem(s) should be shaped and conceptualised such that it (they) become(s) recognisable for students;
- An existing well defined procedure, in line with students' intuitive notions, should be available from which a sequence of teaching-learning activities can be derived;
- The situated chemistry (science) knowledge involved should be in line with students' (cognitive) abilities;
- Possible laboratory work, use of advanced computer tools, etc. should be practically feasible in the classroom.

The process of adaptation of an authentic practice into a context for learning is characterised by shifts of emphasis, applying simplifications, selecting and presenting chemistry (science) knowledge and paying attention to students' motives, attitudes etc. The main objective in the process of adaptation is to maintain the coherency within the constraints of the classroom. The heuristic value of the emerged design principles are limited within the following conditions:

- Pre-university chemistry education;
- Students grade 10-11 (age 16/17);
- Domain: models and modelling;
- Authentic modelling practices as contexts for learning.

In conclusion, the use of authentic practices as contexts for learning offers a valuable source of inspiration for designing teaching-learning processes and, if properly adapted, does lead to the intended learning outcomes. However, this conclusion is based on the adaptation of (only) one well defined authentic practice established after a thorough and prolonged design process. The teachers were given time to become acquainted with the underlying pedagogy and practical feasibility in the classroom. Future research is needed to contribute to and make explicit the design knowledge regarding the construction of authentic practice based curriculum materials.

Key sources

Prins, G.T., Bulte, A.M.W., & Pilot, A. (2011). Evaluation of a design principle for fostering students' epistemological view on models and modelling using authentic practices as contexts for learning in chemistry education. *International Journal of Science Education, 33*(11), 1539-1569.

Prins, G.T. (2010). *Teaching and learning of modelling in chemistry education. Authentic practices as contexts for learning*. Utrecht, Utrecht University. Available at http://igitur-archive.library.uu.nl/dissertations/2010-0525-200212/UUindex.html.

Prins, G.T., Bulte, A.M.W., Van Driel, J.H., & Pilot, A. (2008). Selection of authentic modelling practices as contexts for chemistry education. *International Journal of Science Education, 30*(14), 1867-1890.

Prins, G.T., Bulte, A.M.W., Van Driel, J.H., & Pilot, A. (2009). Students' involvement in authentic modelling practices as contexts in chemistry education. *Research in Science Education, 39*(5), 681-700.

References

Ausubel, D.P. (1968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart and Winston.

Brown, J.S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Bulte, A.M.W., Klaassen, K., Westbroek, H.B., Stolk, M.J., Prins, G.T., Genseberger, R., et al. (2005). Modules for a new chemistry curriculum, research on a meaningful relation between contexts and concepts. In P. Nentwig & D. Waddington (Eds.), *Context based learning of science* (pp. 273-299). Münster, Germany: Waxmann.

Bulte, A.M.W., Westbroek, H.B., De Jong, O., & Pilot, A. (2006). A research approach to designing chemistry education using authentic practices as contexts. *International Journal of Science Education, 28*(9), 1063-1086.

Clement, J. (2000). Model based learning as a key research area for science education. *International Journal of Science Education, 22*, 1041-1053.

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9-13.

Cobb, P., Stephan, M., McClain, K., & Gravemeijer, K. (2001). Participating in classroom mathematical practices. *The Journal of the Learning Sciences, 10*(1&2), 113-163.

Edelson, D.C. (1998). Realising authentic science learning through the adaptation of scientific practice. In B.J. Fraser, & K.G. Tobin (Eds.), *International Handbook of Science Education* (Vol. I, pp. 317-331). Dordrecht, The Netherlands: Kluwer.

Erduran, S., & Duschl, R.A. (2004). Interdisciplinary characterizations of models and the nature of chemical knowledge in the classroom. *Studies in Science Education, 40*, 105-138.

Gilbert, J.K. (2006). On the nature of "context" in chemistry education. *International Journal of Science Education, 28*(9), 957-976.

Gilbert, J.K. (2004). Models and modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education, 2*, 115-130.

Gravemeijer, K. (1999). How emergent models may foster the constitution of formal mathematics. *Mathematical thinking and learning, 1*(2), 155-177.

Grosslight, L., Unger, C., Jay, E., & Smith, C. (1991). Understanding models and their use in science: conceptions of middle and high school students and experts. *Journal of Research in Science Teaching, 28*(9), 799-822.

Harrison, A.G., & Treagust, D.F. (1996). Secondary students' mental models of atoms and molecules: Implications for teaching science. *Science Education, 80*(5), 509-534.

Kensing, F. & Blomberg, J. (1998). Participatory design: Issues and concerns. *Computer Supported Cooperative Work*, 7, 167-185.

Klaassen, C.W.J.M. (1995). *A problem-posing approach to teaching the topic of radioactivity.* Unpublished thesis. Utrecht, the Netherlands: Utrecht University.

Kortland, J. (2001). *A problem-posing approach to teaching decision making about the waste issue.* Utrecht, The Netherlands: Utrecht University.

Könings, K.D., Van Zundert, M.J., Brand-Gruwel, S., & Van Merriënboer, J.J.G. (2007). Participatory design in secondary education: is it a good idea? Students' and teachers' opinions on its desirability and feasibility*. Educational Studies*, *33*(4), 445-465.

Könings, K.D., Brand-Gruwel, S., & Van Merriënboer, J.J.G. (2005). Towards more powerful learning environments through combining the perspectives of designers, teachers, and students. *British Journal of Educational Psychology, 75*, 645-660.

Lave, J. (1996). Situated learning in communities of practice. In L. Resnick (Ed.), *Perspectives on socially shared cognition* (pp. 63-82). Washington D.C.: American Psychological Association.

Leont'ev, A.N. (1978). *Activity, consciousness and personality.* Englewood Cliffs NJ: Prentice-Hall.

Lijnse, P.L. (1995). 'Developmental research' as a way to empirically based 'didactical structure of science'. *Science Education, 79*(2), 189-199.

Lijnse, P.L., & Klaassen, K. (2004). Didactical structures as an outcome of research on teaching-learning sequences? *International Journal of Science Education, 26*(5), 537-554.

Mankin, D., Cohen, S.G., & Bikson, T.K. (1997). Teams and technology: tensions in participatory design. *Organizational Dynamics*, *26*, 63-74.

McKenney, S., Nieveen, N., & Van den Akker, J. (2006). Design research from a curriculum perspective. In J. Van den Akker, K. Gravemeijer, & S. McKenney (Eds.), *Educational design research* (pp. 62-90). London: Routledge.

Merrill, D.M. (2002). First Principles of Instruction. *Educational Technology Research & Development 50*(3) 43-59.

Miles, M.B., & Huberman, A.M. (1994). *Qualitative data analysis: A sourcebook of new methods* (2nd ed.). Thousand Oaks, CA: Sage.

Nieveen, N.M. (1999). Prototyping to reach product quality. In J.van den Akker, R. Branch, K. Gustafson, N. Nieveen, & T. Plomp (Eds.), *Design approaches and tools in education and training* (pp. 125-136). Dordrecht: Kluwer.

Nieveen, N. (2009). Formative evaluation in educational design. In Tj. Plomp & N. Nieveen (Eds.), *An introduction to educational design research* (pp. 89-101). Enschede, the Netherlands: SLO.

Penner, D.E., Lehrer, R., & Schauble, L. (1998). From physical models to biomechanics: A design-based modelling approach. *The Journal of the Learning Sciences 7*(3-4), 429-449.

Raghavan, K., & Glaser, R. (1995). Model-based analysis and reasoning in science: The MARS curriculum. *Science Education, 79*(1), 37-61.

Rule, A.C. (2006). Editorial: The components of authentic learning. *Journal of Authentic learning, 3*(1), 1-10.

Sadler, T.D. (2007). *The aims of science education: Unifying the fundamental and derived senses of scientific literacy.* Paper presented at the Linnaeus symposium on promoting scientific literacy, Uppsala, Sweden.

Shrout, P.E., & Fleiss, J.L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin, 86*(2), 420-428.

Smith, J.A. (1995). Semi-structured interviewing and qualitative analysis. In J.A. Smith, R. Harre, & L. Van Langenhove (Eds.), *Rethinking methods in psychology.* (pp. 9-26). Thousand Oaks CA: Sage.

Trowbridge, L., Bybee, R., & Powell, J. (2000). *Teaching secondary school science: Strategies for developing scientific literacy*. Upper Saddle River, NJ: Merrill

Van Aalsvoort, J. (2000). *Chemistry in products: A cultural-historical approach to initial chemical education.* Utrecht, The Netherlands: Utrecht University.

Van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (Eds.). (2006). *Educational design research*. London: Routledge.

Vygotsky, L.S. (1981). The genesis of higher mental functions. In J.V. Wertsch (Ed.), *The concept of activity in Soviet psychology*. New York: M.E. Sharpe, Inc. Armonk.

Westbroek, H.B. (2005). *Characteristics of meaningful chemistry education.* Utrecht The Netherlands: Utrecht University.

Westbroek, H.B., Klaassen, C.J.W.M., Bulte, A.M.W., & Pilot, A. (2010). Providing students with a sense of purpose by adapting a professional practice. *International Journal of Science Education, 32*(5), 603-627.

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