International Journal of Science Education
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsed20

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Published online: 07 Apr 2015.

International Journal of Science Education, 2015
Vol. 37, No. 8, 1225–1245, http://dx.doi.org/10.1080/09500693.2015.1029033

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Inquiry-Based Whole-Class Teaching with Computer Simulations in Physics

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In this study we investigated the pedagogical context of whole-class teaching with computer simulations. We examined relations between the attitudes and learning goals of teachers and their students regarding the use of simulations in whole-class teaching, and how teachers implement these simulations in their teaching practices. We observed lessons presented by 24 physics teachers in which they used computer simulations. Students completed questionnaires about the lesson, and each teacher was interviewed afterwards. These three data sources captured *implementation* by the teacher, and the *learning goals* and *attitudes* of students and their teachers regarding teaching with computer simulations. For each teacher, we calculated an *Inquiry-Cycle-Score* (ICS) based on the occurrence and order of the inquiry activities of *predicting*, *observing* and *explaining* during teaching, and a *Student-Response-Rate* (SRR) reflecting the level of active student participation. Statistical analyses revealed positive correlations between the inquiry-based character of the teaching approach and students' attitudes regarding its contribution to their motivation and insight, a negative correlation between the SRR and the ICS, and a positive correlation between teachers' attitudes about inquiry-based teaching with computer simulations and learning goal congruence between the teacher and his/her students. This means that active student participation is likely to be lower when the instruction more closely resembles the inquiry cycle, and that teachers with a positive attitude about inquiry-based teaching with computer simulations realize the importance of learning goal congruence.

Keywords: *Simulations; Inquiry-based teaching; Secondary school*

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1. Introduction

Computer simulations offer an excellent opportunity for conducting scientific inquiry, allowing students to develop their scientific literacy (de Jong & van Joolingen, 1998; Rutten, van Joolingen, & van der Veen, 2012). However, this requires that the computer simulations allow interaction with the learners that lets them use the simulation as a source for genuine inquiry activities (van Joolingen, de Jong, & Dimitrakopoulou, 2007). As a result, classroom use of computer simulations often does not go beyond the level of illustration (Windschitl, 2000). However, teachers' use of computer simulations could provide an opportunity to stimulate their students to express their ideas about a given domain or speculate on how to solve a problem (Smetana & Bell, 2013). This might clarify students' ideas and misconceptions for the teacher. Supplementing classroom use of computer simulations with a teacher-led discussion allows for guiding the learners' attention to important aspects of the research process and connecting the different stages of inquiry learning (Gelbart, Brill, & Yarden, 2009). However, what appears to have been sparsely researched is the most effective classroom use of computer simulations (Adams, Paulson, & Wieman, 2008), how the learning processes can be mediated by the teacher (Hennessy, 2006), and how to integrate computer simulations into a physics curriculum (Zacharia & Anderson, 2003). Moreover, much research on educational technology seems to be based on the assumption that its use takes place in isolation from other activities: in the absence of a teacher's guidance, and detached from curriculum and assessment structures (Hennessy, 2006).

Salinas (2008) provided a model that explains the added value new technologies can have when used instructionally. This model proposes connections between the learners' needs, the levels of Bloom's Taxonomy, the role of the instructor, and the appropriate technology to be used. Simulations can provide a suitable technology that can support the level of interaction needed for inquiry learning, but they would need to be augmented with appropriate instruction or pedagogy. In such a pedagogy, implementation of interactive activities can change the teacher's role from being a mere transmitter of information to becoming a facilitator of higher-order thinking skills (Gokhale, 1996). Teaching and learning in the whole-class setting can also be in line with a social-constructivist learning perspective, because whole-class use of simulations promotes more socially mediated classroom interactions (Smetana & Bell, 2013). While the central idea in constructivism is that understanding is constructed in one's own mind through 'learning by doing', the focus in social constructivism is more on creating knowledge in a group setting by knowledge sharing and distribution (Dori & Belcher, 2005). Inquiry-based whole-class teaching can support constructivist-based learning processes such as active and collaborative construction of knowledge, and connecting learning to students' prior knowledge and their present environment (Walker, 2007).

Clear learning goals are crucial for effective teaching (Marzano, 1998). According to Hmelo-Silver, Duncan, and Chinn (2007), it is important to prevent inquiry learning from resulting in a shift away from teaching a discipline as a body of knowledge:

both the processes and content of learning require adequate consideration. Combining the inquiry approach with concrete goals related to learning content means that the environment in which learning takes place resembles the context in which it is likely to be used. Salinas argued that his model facilitates the choice of appropriate technologies for achieving learning goals. However, as Salinas also argued, one of the main obstacles to the implementation of his model is that the teacher needs to adapt his/her role appropriately: the learning goals that are associated with higher levels of Bloom's Taxonomy call for the teacher to take on a role that is less directive and more supportive. In many current learning approaches for technology-supported instruction, insufficient attention is given to the role that the teacher should fulfill (Urhahne, Schanze, Bell, Mansfield, & Holmes, 2010). According to Salinas (2008), educators do not have an adequate understanding of what pedagogical principles should underlie the incorporation of such new technologies.

Teachers influence how students learn by varying the types of questions they ask. King (1990, 1992) distinguished recall questions and critical thinking questions, where recall questions require students to recall information that was presented earlier, and critical thinking questions require them to analyze, apply, and evaluate it. Creemers and Kyriakides (2006) made a related distinction between product questions and process questions, where product questions expect merely a single response from a student, while process questions expect students to explain their answer as well. Effective teachers not only pose many questions to their students to involve them in discussion; they also ask relatively many process questions (Creemers & Kyriakides, 2006).

When investigating teachers' questioning in teaching, it is informative not only to look at how often certain types of questions are posed, but also to determine how these questions are sequenced and followed up. A possible question sequence in the context of inquiry learning with computer simulations is: *predict*, *observe*, *explain* (Hennessy et al., 2007). When students merely observe a computer simulation as a whole class and subsequently listen to the explanation by the teacher, the learning situation is comparable to a traditional demonstration (Crouch, Fagen, Callan, & Mazur, 2004). Students' ability to predict outcomes does not appear to depend greatly on whether they have observed a demonstration or not. What appears to have greater impact on that ability is whether students were asked to predict the outcomes before observing and whether they had the opportunity to discuss the outcomes after observing, but before the teacher's explanation. Considering the learning profits this yields, the extra time needed for predicting and discussing seems more than worth it (Crouch, Watkins, Fagen, & Mazur, 2007). The value of prediction questions may lie in stressing what is important, and in the construction of a mental framework needed for exploring a phenomenon. Without such a framework, the level of detail in a situation can be too high for a student to remember relevant scientific ideas (Adams et al., 2008).

In the research literature, there is no general agreement on how inquiry learning should be defined; several conceptualizations exist, each emphasizing different aspects. Generally, the inquiry process starts with asking questions and generating hypotheses, continues with processes of investigation, and ends with conclusion and evaluation (Bell, Urhahne, Schanze, & Ploetzner, 2010). Making predictions involves reformulating a hypothesized relation between variables in such a way that it becomes clear how a change in an independent variable influences a dependent variable, for example, by using an 'if-then' statement (de Jong & van Joolingen, 1998). In this study, we consider the occurrence of phases of the *predict-observe-explain* cycle (P-O-E) in instruction as an indication of following the inquiry approach, as P-O-E was observed to be an important principle in the majority of inquiry approaches by Bell and colleagues (2010). However, we acknowledge that conceptualizing inquiry-based instruction as resemblance to P-O-E means that there is no attention to other aspects that a number of inquiry models emphasize, for example: planning, modeling, and communicating results to others.

Along with the goals of learning *about* science subjects and about *how* science works, use of an inquiry approach aims to counter students' decreasing interest and engagement in science. The level of engagement involved in inquiry learning can positively influence students' science-related attitudes (Osborne & Dillon, 2008; Rocard, 2007). Attitude toward a given instructional medium and instructional approach is an important factor influencing learning (Pyatt & Sims, 2012; Trundle & Bell, 2010). An attitude is a tendency to evaluate an object in terms of favorable or unfavorable attribute dimensions (Ajzen, 2001), which distinguishes attitudes from beliefs or opinions (van Aalderen-Smeets, Walma van der Molen, & Asma, 2012). In turn, teaching with computer simulations can positively impact attitudes toward learning (Khan, 2011; Vogel et al., 2006; Zacharia & Anderson, 2003).

The purpose of the present study was to investigate relations between teachers' use of computer simulations in whole-class teaching, and teachers' and students' attitudes and learning goals regarding such use of computer simulations. We observed physics teachers, all teaching one lesson using one or more computer simulations. Salinas (2008) argued that if teachers do succeed at appropriately tailoring their role to introduced technology such as simulations, this allows for the emergence of a 'new learning environment': one that is characterized not only by different roles for the teacher and students, but also by higher student motivation and improved learning outcomes. We wanted to know whether such presumed relations can be revealed by investigating the inquiry-based character of teacher *implementations*, and the *learning goals* and *attitudes* of students and their teachers related to teaching with computer simulations. With regard to learning goals, we focused on congruence between teacher and student learning goals, as this is an important aspect of the learning process. Learning can be disrupted by a lack of congruence between students' self-regulation and teachers' external regulation of learning processes (Vermunt & Verloop, 1999). Because our research approach of incorporating multiple teachers' inquiry-based, simulation-supported teaching practices as well as considering contextual factors is unprecedented, we believe our study contributes to the existing research literature.

2. Method

We focused our study on physics lessons conducted in Dutch secondary education. A physics lesson was eligible for observation when a physics teacher planned to use at least one computer simulation during whole-class interaction with the students. Arrangements for one lesson observation and subsequent teacher interview were made on the teachers' initiative. The participating teachers mostly taught with simulations from the PhET simulations suite available online (2014). Sometimes the teachers used simulations from other websites, but in all cases these represented a physics phenomenon in simplified form, and allowed for interactivity with the underlying model by the possibility of influencing several variables (de Jong & van Joolingen, 1998). Although each simulation has its own peculiarities, we considered those in this study as physics simulations in general, because our focus was not on the specific characteristics of simulations themselves, but on the teachers using these according to the P-O-E principle. The teachers mostly used simulations on mechanics, electricity, or wave phenomena.

2.1. Participants

The participants in the study were 24 Dutch secondary education physics teachers and the students in their classes. Most of the teachers were male (3 female, 21 male). Their ages ranged from 23 to 59 ($M = 39.4$; SD $= 8.97$), and their years of experience from 1 to 35 ($M = 11.0$; SD $= 9.82$). The classes consisted of 7 to 27 students ($M = 20.9$; SD $= 4.55$). In total, 501 students completed the study. The students' ages ranged from 12 to 19 ($M = 15.9$; SD $= 1.40$). The teachers were recruited by direct mailings, calls on online groups, professional newsletters, and at a professional physics education conference. As our recruitment was most successful at this conference, participating teachers probably have a higher than average interest in didactic development. Schools were distributed across the Netherlands.

2.2. Data Sources

To investigate relations among teachers' and students' *attitudes* and *learning goals*, and the *implementation* of the computer simulation in class, we collected data from teacher interviews, lesson observations, and student questionnaires. To prevent the interviews from influencing what was done during class, lesson observations always preceded the interviews. The teacher used at least one computer simulation during the observed lesson; the teacher and the students were video recorded; the students completed questionnaires during the last 15 minutes of the lesson; and after the lesson, the teacher was interviewed for about half an hour.

2.2.1. Lesson observations. During the lesson, the researcher was positioned at the back of the classroom with two cameras, filming how the teacher conducted the lesson. At the front of the classroom, two cameras recorded students' participation in the lesson. Recording began the moment the students entered the classroom and stopped when they started completing their questionnaires at the end of the lesson.

2.2.2. Questionnaires. Students were given questionnaires at the end of the lesson. Our questionnaire is based on four questionnaires (Apperson, Laws, & Scepansky, 2006; Davies, 2002; Maor & Fraser, 2005; Mucherah, 2003) that inquire about topics related to using computer simulations and the experiences of students and teachers. We selected questions from these questionnaires that are related to the teacher role, to control over the lesson discourse, and to engagement in the lesson. The questionnaires consisted of 27 items that could be answered on a 5-point Likert scale, and one open-ended question asking about what they considered were the three most important things to be learned during that lesson. This open question was also posed to the teacher. The purpose of this question was to determine learning goal congruence.

2.2.3. Teacher interviews. After the observation of a physics lesson and students' completion of the questionnaires, the teacher was interviewed. This semi-structured interview took about 30 minutes. To allow for full transcription afterwards, the interview was audio recorded. Along with several demographic questions, the interview consisted of 12 questions about teaching with computer simulations in a whole-class setting.

2.3. *Data Analysis*

2.3.1. Lesson observations. We analyzed the lesson observations to find out whether the teaching approach resembled inquiry-based teaching. Table 1 shows the scheme that we used to code the questions asked by the teacher. Any episode during which the teacher addressed the whole class was eligible for coding.

All transcribed lesson observations were coded by the first author. Six of the transcripts were double-coded by the second author and a student assistant. Because we worked with three coders, we determined inter-rater reliability using *Krippendorff's alpha*. We calculated the reliability of our approach for coding the teacher questions in three ways: our ability to discriminate between actual physics content questions (*recall*, *prediction*, *observation*, and *explanation*) and *other* questions; our ability to discriminate who answered questions (*answered by the teacher*, *answered by the student*, and *other*); and our ability to discriminate between the different kinds of questions (*recall*, *prediction*, *observation*, *explanation*, and *other*).

Our purpose in analyzing the observed lessons was to determine the extent to which the teaching approach seen resembles inquiry-based teaching. Two aspects of the pedagogical approach that we consider to be essential for inquiry-based teaching are active student participation and resemblance to the inquiry cycle. For each lesson observation we calculated two scores providing an indication of these aspects: a *Student-Response-Rate* (SRR) and an *Inquiry-Cycle-Score* (ICS). We calculated these

Table 1. Coding scheme for lesson observations

	Codes	Application	Examples
Teacher questions that are related to physics			
What kind of question is it?	Recall	Questions that students should be able to answer with the knowledge they already have	'In what unit is this variable measured?'
	Prediction	Students are asked to predict how a phenomenon will develop further before this has actually happened	'What happens if that variable is doubled?'
	Observation	The teacher inquires about what students are observing at that moment	'And what do you see right now?'
	Explanation	Students are asked to explain why a phenomenon has developed in a certain way	'Now how do you explain this result?'
Who answers the question?	Teacher	The teacher's question is answered by the teacher himself/herself	
	Student	The teacher's question is answered by a student	
Teacher questions that are not related to physics or fall within the categories below			
What kind of question is it?	Other	Students are personally addressed	'Alison?'
		Student answers are repeated back in the form of a question	'You're saying a lower frequency?'
		The teacher checks whether subject-matter is understood	'Is that clear?'
		The learning process is regulated	'What have we seen today?'

scores when the teacher asked at least three physics content questions. Active student participation (SRR) relates to the percentage of physics-related teacher questions that are answered by the students: [100 * N *teacher questions answered by student*/(N *teacher questions answered by teacher* + N *teacher questions answered by student*)]. We determined resemblance of the teaching approach to the inquiry cycle (ICS) by making an inventory of the extent to which the cycle of P-O-E was followed during the lesson. The phases of this P-O-E cycle relate respectively to the inquiry cycle phases of 'stating a hypothesis', 'performing an experiment', and 'drawing conclusions', and consequently do not cover the phase of 'orientation'. Hennessy et al. (2007) argue that this P-O-E cycle is one of the pedagogical principles on which research on the use of ICT in science has been based.

We assigned scores to sequences of coded questions by application of the following hierarchical scoring system: weight of the sequence *explanation* = 1; weight of *observation-explanation* = 2; weight of *prediction* = 3; weight of *prediction-observation* = 4; weight of *prediction-explanation* = 5; weight of *prediction-observation-explanation* = 6. This scoring system is based on the following rationale: without the phase of *prediction*, inquiry-based teaching is out of the question; *observation* can be considered as learning at a lower level of Bloom's Taxonomy compared to *prediction* and *explanation*; but *observation* does make an inquiry cycle more complete compared to a cycle in which explicit *observation* is lacking. For the determination of these sequences the *recall* and *other* questions are ignored, and sequences of similar questions are combined, such as an *observation* followed by an *observation*. Sequences only count when they are not overlapped by a sequence of higher weight. For example, the sequence P-P-P-O-E-E does not count as separate sequences of P, P-O, O-E, or E, as these are all overlapped by one P-O-E sequence.

2.3.2. Questionnaires. At the end of each lesson the students completed questionnaires. These questionnaires consisted of 27 items on a 5-point Likert scale, and one open-ended question. We performed exploratory factor analysis to analyze the responses to the items.

The open-ended question asked students what they considered were the three most important things to be learned during that lesson. Each class's teacher also answered this question. The purpose of this open question was to investigate learning goal congruence between the teacher and his/her students during the specific lesson. To measure learning goal congruence we used *cosine similarity* (Manning & Schütze, 1999). In computing cosine similarity, word frequencies in two texts are represented by vectors in a high-dimensional space. The cosine of the angle between these vectors is taken as a measure for similarity, yielding a number between 0 (no similarity at all) and 1 (perfect similarity). We computed both the congruence of learning goals within the group of students themselves, and the congruence between the learning goals of students with those of their teacher. We refer to these kinds of congruence as: learning goal congruence *group* and learning goal congruence *teacher*. In computing cosine similarity we converted the answers given by the students and teachers by taking the following steps: we retained only the nouns in the student and teacher responses (e.g. 'interference'); we replaced synonyms, plurals, and diminutives by their synonyms (e.g. 'waves' by 'wave'); and we removed capitalization, special punctuation, and multiple instances of the same word in one answer (e.g. replacing 'Lorentz force' by 'lorentz force'). We removed students with an empty answer sequence before calculating the mean learning goal congruence *group* over an entire class, because retaining empty answer sequences would otherwise inflate congruence scores. There were no teachers with an empty answer sequence.

2.3.3. Teacher interviews. Teacher utterances were eligible for coding when an utterance reflected the teacher's thoughts on the effects of whole-class teaching and learning with computer simulations. Utterances about the effects of teaching with computer simulations were divided into those attributing positive effects (e.g. 'A simulation can easily be included to make your point'), those attributing negative effects (e.g. 'You do have the risk of not showing the setups anymore'), and those stating that it does not make a difference compared to other educational means (e.g. 'I can't say that grades increased because of using these things'). After having inventoried these utterances in all of the interviews, we considered the extent to which these views on the effects of computer simulations on teaching and learning could be further specified according to more specific codes. In determining these codes we attempted to maintain a balance between conceptual delineation of differing themes and grouping together of conceptually related themes. This resulted in a coding scheme with 10 negative-effect codes, 1 neutral code, and 23 positive-effect codes (see our Supplemental Material accompanying the online version of this article).

An example will clarify how the coding process functioned in practice. Consider the following teacher statement: 'By using computer simulations, I can quickly show something on my interactive whiteboard, and by influencing variables the students directly notice what happens'. This statement was chunked and coded as follows: [By using computer simulations, I can quickly show something on my interactive whiteboard] = positive effect, and [by influencing variables the students directly notice what happens] = positive effect. Application of our coding scheme linked these statements to the following codes: [By using computer simulations, I can quickly show something on my interactive whiteboard] = *positive—time saving*, and [by influencing variables the students directly notice what happens] = *positive—direct feedback*. As we are interested in inquiry-based teaching with computer simulations, the codes most related to this concept were aggregated into one measure, which we refer to as: *N inquiry* utterances. We selected the codes for this aggregated measure by determining whether a code refers to affordances that support inquiry activities.

2.4. *Relating Pedagogical Aspects*

We assume that students will have a more positive attitude toward teaching with computer simulations when the teacher successfully adapts technology implementation and teaching approach to each other. Another assumption is that the impression one gets by interviewing a teacher about his/her attitude toward teaching with computer simulations to a certain extent resembles what a teacher actually does during a lesson observation. Our third assumption is related to the important role the teacher plays in aligning the use of computer simulations to learning goals (Smetana & Bell, 2012). We assume that when a teacher succeeds at such congruence, this will be reflected in positive attitudes expressed by the teachers and their students about teaching with computer simulations. In short, we expect that what a teacher does during implementation will be related to the learning goals and attitudes of the teachers and their students. To investigate whether this is supported by our data, we relate the types of data to each other by calculating correlations.

3. Results

3.1. *Lesson Observations*

Calculations of the inter-rater reliability of our approach for coding the teacher questions revealed that our ability to discriminate between actual physics content questions and *other* questions is .79 (95%CI: .65–.90), between by whom questions are answered is .75 (95%CI: .66–.83), and between the different kinds of questions is .61 (95%CI: .55–.66). According to the criteria proposed by Strijbos and Stahl (2007) and Strijbos (2009), these reliability results can respectively be interpreted as: excellent, excellent, and good. Initially, our data set consisted of 25 lesson observations and interviews of teachers. Retaining only those observations with three or more physics content questions resulted in the removal of one teacher from the data set.

Table 2 provides an overview of inquiry-based question sequences in each of the observed lessons. Two scores reflect each lesson's active student participation (SRR) and the extent to which the inquiry-cycle is evident (ICS).

3.2. *Questionnaires*

We analyzed the students' answers to the 27 questionnaire items by performing exploratory factor analysis based on *Alpha factoring* with an *Oblimin with Kaiser Normalization* rotation method. This method of oblique rotation was chosen because we expected the factors to be related. The correlation matrix revealed that there are no variables that correlate too highly with other variables ($R > .8$), which would have been an indication of multicollinearity. The *KMO-measure of sampling adequacy* is

Table 2. Teacher questions

Teacher	ICS	% Answered by … Student (SRR)	Teacher	Physics content questions posed by each teacher in chronological order[a]
Q	0	100	0	rrr
A	1	80	20	rrrrE
O	2	96	4	rrrrrrrrOOrrOOOOOrOOrOrrrE
P	3	100	0	rOrPr
I	3	100	0	ErrrrrrrrrEErE
B	4	69	31	OrrPrrOrrOOOO
J	5	48	52	rrOOOOrrrrOrEOOOrOrrPrr
X	5	81	19	OrOOOOrrOOEEOOErrrrEE
U	7	82	18	rrrrrrErrrOOOrOErOrEEEErEEEEEEErE
N	8	88	12	OOOOOOrrEOEOEOOrErrOrOOOOOOOOOOrOO
D	9	70	30	rErrrErrrrPPErrrrrrrrrrrrrErrrrrrOOOOEEr
C	10	57	43	rrrrOOPrrrrrEErOErrrOrrrrrrrrP
M	10	67	33	rrOOrOOEOrOOOrOrrOrOOEPOErrOrOOOOOOOOOrOOOr
W	11	78	22	ErrrPOrOOOEOOOrrrOrrrOPPOOOOOrrO
H	11	17	83	rOOOrrPEPOOEEEOrrr
K	12	60	40	rPPPrOrrPrErrEP
R	13	100	0	OOErrrPPEPPPPPPrOE
S	17	81	19	rrPPPEPEPPErErrOOOOOOOOOOOOOOOOrOrOOOOOEOr
E	18	100	0	rrrrrrrrrrrrrrrPrrPrrPrEPPErrEEEEPrrrrrrrrrrrrrrrrrrrrrrErrrrPrr
V	18	51	49	OErPEOrrOOrOrOOEOOOOrEPrrErrEEErOOOOOEO
T	18	72	28	PEEPPPrEPPPErEEPPr
G	19	63	37	OrrrOOOOPOEEPOEPrOP
F	20	88	12	EEPErPEEEEErrrPPOOOrOOEOP
L	29	12	88	PPrEOPOPOErOEOEPOOOOOErrPO

[a]Each code refers to a type of teacher question abbreviated as follows: r = recall, P = prediction, O = observation, and E = explanation. Questions in bold refer to teacher questions answered by a student; teacher questions that are not bold are answered by the teacher him-/herself. A darker shade of gray represents higher resemblance to the inquiry cycle.

Table 3. Pattern matrix for the exploratory factor analysis

Factor	1	2	3	4	5	6	7
I pay more attention during the lesson when computer simulations are used. (*Mu)	**.688**						
The use of a computer simulation makes it easier to stay focused on the lesson. (*Ap)	**.599**						
I like physics better when computer simulations are used. (*Mu)	**.596**						.322
The use of computer simulations supports my learning during the lesson. (*Ap)	**.475**						
It's fun when computer simulations are used in teaching. (*Da)	**.472**						.361
Using computer simulations helps me to improve my knowledge of physics. (*Mu)	**.431**				−.272		
I was always able to predict the course of the simulation. (*Da)		**.606**					
There is a clear link between the simulation used and the subject of the lesson. (*Da)		**.453**		.291			
I know what I have to remember from this simulation. (*Mu)		**.373**					
Our teacher encourages us to express our opinions. (*Mu)			**−.549**				
I feel free enough to express my opinions during discussions. (*Mu)			**−.479**				
−/− (Class discussions are inhibited by the use of computer simulations.) (*Ap)				**.433**			
Computer simulations clarify complex matters. (*Ma)	.284			**.306**	−.294		
Our teacher uses computer simulations to clarify a subject to the class. (*Mu)				**.217**			
I also use computer simulations outside formal class times. (*Da)							
Computer simulations make me realize how complex reality really is. (*Ma)					**−.601**		
Using computer simulations helps me to better understand the subject. (*Da)	.345				**−.454**		

(*Continued*)

Table 3. Continued

Factor	1	2	3	4	5	6	7
By using the simulation I learned how reality works. (*Da)					**−.414**		
Computer simulations help me to wonder about new things. (*Ma)					**−.388**		.317
The use of computer simulations helps with getting better grades. (*Ap)					**−.308**		
There is enough time to discuss with each other during the simulation. (*Da)						**.753**	
During the simulation I have enough time to think by myself what will happen. (*Ma)						**.520**	
The use of computer simulations increases my interest in the subject of the lesson. (*Ap)	.316						**.524**
When a computer simulation is used, I get new ideas. (*Ma)					−.302		**.412**
Using a computer simulation makes me think about the subject. (*Ma)					−.311		**.406**
Computer simulations should be used more often in other subjects. (*Da)	.214						**.381**
The use of computer simulations can really get class discussions going. (*Ap)			−.342				**.375**
Cronbach's alpha of the questions with factor loadings in bold	**.824****	**.541**	**.425**	**.300**	**.724****	**.594**	**.719****

Notes: Factor loadings < |.2| are suppressed; extraction method: alpha factoring; rotation method: Oblimin with Kaiser normalization; *Ap = Apperson, Laws, and Scepansky (2006); *Da = Davies (2002); *Ma = Maor and Fraser (2005); *Mu = Mucherah (2003); **labels for factors with Cronbach's alpha > .7: factor 1 = motivation; factor 5 = –/– (insight); factor 7 = inspiration.

.906, which is very good (Kaiser, 1974). The significant result of *Bartlett's test of sphericity* ($\chi^2(351) = 375.29$; $p < .001$) indicates that the correlation matrix is appropriate for factor analysis. The data screening did not result in the exclusion of variables. Because a clear point of inflexion in the curve could be discerned in the scree plot, we chose to extract seven factors (Field, 2009) (see Table 3), which together explain 4.0% of the total variance.

To measure reliability we calculated Cronbach's alpha for each factor (see Table 3). As Cronbach's alpha should be at least .7, the scales for factors 2, 3, 4, and 6 are not used for further analyses. The internal consistency of factor 1 is good, and for factors 5 and 7 acceptable (Field, 2009). We conceptually labeled factor 1 as representing *motivation*, as it combines items on supporting attention, enjoyment, and learning. Factor 5 combines items on realizing complexity, support of learning, and wonderment and is therefore related to *insight*. However, as all related items load negatively on the factor, we use the negative of the score of factor 5 as representing *insight.* Finally, factor 7 represents *inspiration*, as items on supporting interest, creative thinking, and the learning process load high on this factor. Table 3 shows additional factor details and the items that are related to each factor.

Table 4 shows the means of the learning goal congruence for each class. The measure M learning goal congruence *group* does not take into account what the teacher answered regarding the three most important things to be learned during that lesson. This measure only compares the students' answers with each other. The measure M learning goal congruence *teacher* compares the students' answers with the answers of their teachers.

3.3. Teacher Interviews

Our Supplemental Material accompanying the online version of this article shows a complete inventory of the results of coding the teacher interviews, from both quantitative and qualitative perspectives. It provides insight into what kind of teacher utterances the specific codes represent. The selection of codes that we report on in Table 4 specifically refer to the affordances of computer simulations for supporting inquiry-based teaching: *adjustable variables*, *direct feedback*, *illustration/visualization*, *supporting predictions*, *visualization of invisible phenomena*. We aggregated these codes into one measure: N *inquiry* utterances.

3.4. Relating Pedagogical Aspects

To allow for calculation of correlations between variables, these variables need to be measured at the same level (i.e. at the class or student level). All questionnaire variables are measured at the student level, and all variables based on the lesson observations and teacher interviews are measured at the class level. We therefore converted the questionnaire variables to the class measurement level by calculating the means per class for each variable. Table 5 shows a correlation matrix for all variables at the class measurement level.

We were primarily interested in significant correlations between variables derived from different data sources. Our findings in Table 5 show that there are three correlations that meet this criterion: the SRR significantly correlates with M factor *motivation* ($r = .43$, p (2-tailed) $< .05$), the ICS significantly correlates with M factor *insight* ($r = .50$, p (2-tailed) $< .05$), and N *inquiry* utterances significantly correlates with M learning goal congruence *teacher* ($r = .55$, p (2-tailed) $< .01$). Another noteworthy correlation between variables belonging to the same data source is the significant negative correlation between the SRR and the ICS ($r = -.45$, p (2-tailed) $< .05$). The outcome variables in Table 5 do not correlate with teachers' years of experience. There

Table 4. Learning goal congruence and frequencies of coded teacher utterances

		Teacher*																							
Teacher		Q	N	O	R	E	I	H	S	B	K	V	W	F	M	C	A	G	X	D	T	L	P	J	U
M learning goal congruence	Group**	.42	.52	.66	.49	.58	.50	.59	.66	.32	.26	.38	.44	.61	.57	.51	.43	.46	.41	.67	.38	.72	.40	.69	.58
	Teacher***	.20	.00	.00	.17	.16	.06	.25	.19	.05	.05	.09	.12	.22	.24	.11	.07	.14	.05	.41	.07	.19	.16	.32	.40
Frequencies of coded teacher utterances relating to *inquiry-based whole-class teaching with computer simulations*																									Totals
Adjustable variables	1	1	0	1	0	0	0	2	1	1	5	1	3	3	5	1	2	3	0	1	1	4	9	9	54
Direct feedback	0	0	0	0	0	2	0	0	1	0	0	0	0	1	0	1	2	1	1	0	1	0	4	1	15
Illustration/visualization	0	1	3	2	5	1	5	4	2	3	2	7	4	6	5	6	3	3	7	10	10	9	5	5	108
Supporting predictions	0	0	0	2	0	2	0	0	2	1	0	1	0	0	1	1	4	3	0	0	0	0	2	2	21
Visualization of invisible phenomena	0	0	0	0	0	0	0	0	1	3	1	0	3	0	0	2	0	1	3	0	0	0	0	7	21
totals (=N *inquiry* utterances)	1	2	3	5	5	5	5	6	7	8	8	9	10	10	11	11	11	11	11	11	12	13	20	24	219

Notes: *Teachers are ordered according to total coded teacher utterances relating to inquiry-based whole-class teaching with computer simulations; **M learning goal congruence of students with each other; ***M learning goal congruence of students with their teacher.

Table 5. Pearson correlations

Data source	Variable	SRR	ICS	M factor *motivation*	M factor *insight*	M factor *inspiration*	M learning goal congruence *group*	M learning goal congruence *teacher*	N *inquiry* utterances
Lesson observations	SRR	1							
	ICS	−.45*	1						
Questionnaires	M factor *motivation*	**.43***	.32	1					
	M factor *insight*	.14	**.50***	.70**	1				
	M factor *inspiration*	.22	.00	.62**	.55**	1			
	M learning goal congruence *group*	−.21	.24	.07	.15	−.18	1		
	M learning goal congruence *teacher*	−.22	.11	.06	−.02	−.07	.55**	1	
Teacher interviews	N *inquiry* utterances	−.27	.05	−.03	.04	−.11	.17	**.55****	1

Note: Significant correlations between variables from different data sources are printed in bold; $N = 24$.

*$p < .05$ (2-tailed).

**$p < .01$ (2-tailed).

is a significant negative correlation between class size and M factor *motivation* ($r = -.47$, p (2-tailed) $< .05$). Class size does not correlate with the SRR.

4. Limitations

When coding the questions posed by the teacher, we determined the type of each question (i.e. *recall*, *prediction*, *observation*, *explanation*, or *other*), by whom it was answered, and the sequences in which these questions were structured (i.e. the extent to which they approached the inquiry cycle). In the data analysis process the questions were coded, the sequences in which these are structured were weighted, and eventually two scores were calculated for each lesson. We acknowledge that in this process the information regarding what the questions were actually about was lost. Therefore, it is possible that a sequence that we consider P-O-E could, for example, span different conceptual domains, because of a switch to a different topic between an *observation* question and an *explanation* question. In this study, we chose to focus on the typological level to prevent the introduction of an extra source of subjectivity, which would result from additional coding on a conceptual level.

The system we used to assign weights to different sequences of questions is based on the assumption that the most preferable teaching approach follows the complete cycle of *prediction-observation-explanation*. However, as Chen (2010) argues, portraying inquiry learning as a deductive relationship between the tested hypothesis and evidence runs the risk of conveying an oversimplified view of scientific inquiry. Preferably, the tested hypothesis, evidence, and associated experimental conditions are inspected as a whole, supporting epistemological authenticity. This means that there is no fixed order in which inquiry learning activities necessarily take place: one inquiry learning activity is not *automatically* followed by another. In authentic inquiry learning, each learning activity is followed by determining what other learning activity is most *appropriate* to execute next. Our system of weighing sequences is suitable for measuring the extent to which the P-O-E cycle is approached, but capturing this epistemological authenticity on a higher level requires searching for alternative data analysis approaches. The epistemological authenticity of measuring scientific inquiry could also benefit from going beyond the aspects of *predict*, *observe,* and *explain*, for example, by including processes such as planning, modeling, and communicating results to others.

The factor analysis we performed on the answers to the questionnaires resulted in three reliable factors: *motivation*, *insight,* and *inspiration*. However, these constructs are based on a relatively small number of items (6, 5, and 5, respectively). Performing follow-up studies with questionnaires that are specifically developed for measuring these constructs would do more justice to their multi-faceted nature.

5. Discussion and Conclusions

We used an open-ended question to inquire about what students and their teachers considered to be the three most important things to learn during the lesson. By calculating the cosine similarity between the answers of the students and their teachers, we wanted to find out whether there was learning goal congruence. We believe that it makes sense to expect that when answering the question about the three most important things to learn, students will think more about the concrete lesson they have just received, and teachers will answer it by taking more of a bird-eye's view on the goals of the curriculum. If so, then that would lead to higher learning goal congruence between the students themselves, compared to the congruence between students and their teacher. Table 4 does show that the scores on M learning goal congruence *group* are structurally higher compared to the scores on M learning goal congruence *teacher*, but this does not mean this bird-eye's view assumption is correct, as the learning goal congruence scores for *group* and *teacher* are calculated in slightly different ways, making it impossible to compare them. Nevertheless, these two measures significantly correlate with each other ($r = .55$, p (2-tailed) $< .01$), which is an interesting finding in itself: apparently, our approach to calculating learning goal congruence among the students provides a good indication of congruence between the learning goals of the students and their teacher.

Reviews of the literature on the learning effects of computer simulations (Rutten et al., 2012; Smetana & Bell, 2012) found that most research of the past decade focused on individuals or small groups interacting with simulations. Very few studies reviewed considered the role of a teacher in a whole-class setting. Whereas the studies we reviewed provide information that is relevant to the design and learning effects of simulations, they lack ecological validity in the sense that they do not include the classroom dynamics in realistic teaching situations. The present study aims at filling this gap by relating the attitudes and learning goals of teachers and their students with what teachers actually do while teaching with computer simulations, using multiple data sources. We 'zoomed out' to the context of teaching practices and found four relations between pedagogical aspects related to inquiry-based teaching with computer simulations:

(1) Active student participation during implementation of computer simulations in teaching relates to students' positive attitude about its contribution to their *motivation*.
(2) Implementation of computer simulations in teaching that resembles the *inquiry cycle* relates to students' positive attitude about its contribution to their *insight*.
(3) Active student participation during implementation of computer simulations in teaching relates to low resemblance to the *inquiry cycle*, and vice versa.
(4) *Learning goal* congruence between a teacher and his/her students relates to the teacher's positive attitude about *inquiry-based* teaching with computer simulations.

The number of students in the class negatively relates to students' attitudes about the motivational contribution of teaching with computer simulations. However, we did not find a correlation between class size and active student participation (SRR). Apparently, students in large classes are less convinced that teaching with computer simulations contributes to their motivation. When class size and active student participation are indeed unrelated, giving extra attention in large classes to providing students with the opportunity to answer teacher questions themselves could be a way to counter the negative impact of class size on students' attitude about the motivational contribution of teaching with simulations.

In the present study we did not experimentally manipulate teaching practices. Consequently, we cannot make claims about causal relations. However, the approach taken in this study allowed us to observe teachers while they enacted their preferred way of teaching, unconstrained by imposed experimental conditions on teaching practices. During the lessons observed for the present study, the teachers were free in their choice of computer simulations and in their approach to teaching with them, supplying ecological validity. Our study shows that simply observing teaching practices supported by computer simulations without experimentally manipulating them allows interesting relations between pedagogical aspects to surface. Nevertheless, it remains interesting and necessary to investigate whether intervening in simulation-based teaching will expose similar relations.

Students have a more positive attitude to teaching with computer simulations in terms of contributions to their motivation and insight when the teaching approach has an inquiry-based character. An explanation based on Salinas' framework (2008) is that apparently in such a case the teacher's role is successfully tailored to the introduced technology, as inquiry-based teaching implies more active student participation. According to the framework, such a teaching approach precisely suits the affordances of computer simulations for optimally supporting the achievement of learning goals. However, our results show that teachers implement computer simulations generally by having their teaching approach resemble the inquiry cycle *or* by having their students participate more actively, but rarely by incorporating both aspects of inquiry-based teaching. Apparently, it is rather difficult to combine teaching according to the inquiry cycle with a shift of control to the students by having them answer the questions posed by the teacher. This combination seems hard, compared to having students answer questions without an inquiry-related character, for example, recall questions. The relations that we found between aspects of simulation-supported inquiry teaching and students' positive attitudes about this teaching approach are in line with the assumption that inquiry teaching approaches can increase students' engagement and interest in science subjects (Osborne & Dillon, 2008; Rocard, 2007). Our study sheds new light on introducing inquiry teaching by stressing the necessity to separately consider the extent to which learning activities approach the inquiry cycle, and the extent to which teachers provide students with the opportunity to answer the questions they pose. Our finding that these aspects of inquiry learning can be incompatible can be relevant for teacher training.

We found that teachers' positive attitude to teaching according to an inquiry approach co-occurs with congruence of learning goals between the students and the teacher. On an attitudinal level, this finding is in line with the reasoning by Hmelo-Silver et al. (2007), who stressed the importance of combining teaching the content of a body of knowledge, for example, about physics, with a teaching approach resembling its likely context of use. In this way, concrete learning goals and inquiry teaching processes are combined. Future research could focus on whether informing teachers about the importance of learning goal congruence and the positive effects of teaching with computer simulations according to an inquiry-based approach results in inquiry-based teaching in practice, in more positive attitudes about inquiry-based teaching with computer simulations, and in higher learning outcomes.

Acknowledgements

The authors would like to thank all the teachers and their students who participated in this study, and are grateful for the insightful comments from the referees. We would also like to thank Anjo Anjewierden for calculating cosine similarity, and the Fischer Working Group on Physics Education at the University of Duisburg-Essen for thinking along with us about analyzing the lesson observations.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Supplementary data

Supplemental data for this article can be accessed at http://dx.doi.org/10.1080/09500693.2015.1029033

References

van Aalderen-Smeets, S. I., Walma van der Molen, J. H., & Asma, L. J. F. (2012). Primary teachers' attitudes toward science: A new theoretical framework. *Science Education*, *96*(1), 158–182.

Adams, W. K., Paulson, A., & Wieman, C. E. (2008). *What levels of guidance promote engaged exploration with interactive simulations?* AIP Conference Proceedings, Edmonton, Vol. 1064, pp. 59–62.

Ajzen, I. (2001). Nature and operation of attitudes. *Annual Review of Psychology*, *52*(1), 27–58.

Apperson, J. M., Laws, E. L., & Scepansky, J. A. (2006). The impact of presentation graphics on students' experience in the classroom. *Computers & Education*, *47*(1), 116–126.

Bell, T., Urhahne, D., Schanze, S., & Ploetzner, R. (2010). Collaborative inquiry learning: Models, tools, and challenges. *International Journal of Science Education*, *32*(3), 349–377.

Chen, S. (2010). The view of scientific inquiry conveyed by simulation-based virtual laboratories. *Computers & Education*, *55*(3), 1123–1130.

Creemers, B. P. M., & Kyriakides, L. (2006). Critical analysis of the current approaches to modelling educational effectiveness: The importance of establishing a dynamic model. *School Effectiveness and School Improvement: An International Journal of Research, Policy and Practice*, *17*(3), 347–366.

Crouch, C. H., Fagen, A. P., Callan, J. P., & Mazur, E. (2004). Classroom demonstrations: Learning tools or entertainment? *American Journal of Physics*, *72*(6), 835–838.

Crouch, C. H., Watkins, J., Fagen, A. P., & Mazur, E. (2007). Peer instruction: Engaging students one-on-one, all at once. *Research-Based Reform of University Physics*, *1*(1), 40–95.

Davies, C. (2002). Student engagement with simulations: A case study. *Computers & Education*, *39*(3), 271–282.

Dori, Y. J., & Belcher, J. (2005). How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts? *Journal of the Learning Sciences*, *14*(2), 243–279.

Field, A. P. (2009). *Discovering statistics using SPSS*. London: SAGE Publications, Ltd.

Gelbart, H., Brill, G., & Yarden, A. (2009). The impact of a web-based research simulation in bioinformatics on students' understanding of genetics. *Research in Science Education*, *39*(5), 725–751.

Gokhale, A. A. (1996). Effectiveness of computer simulation for enhancing higher order thinking. *Journal of Industrial Teacher Education*, *33*(4), 36–46.

Hennessy, S. (2006). Integrating technology into teaching and learning of school science: A situated perspective on pedagogical issues in research. *Studies in Science Education*, *42*(1), 1–48.

Hennessy, S., Wishart, J., Whitelock, D., Deaney, R., Brawn, R., la Velle, L., … Winterbottom, M. (2007). Pedagogical approaches for technology-integrated science teaching. *Computers & Education*, *48*(1), 137–152.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, *42*(2), 99–107.

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, *68*(2), 179–201.

van Joolingen, W. R., de Jong, T., & Dimitrakopoulou, A. (2007). Issues in computer supported inquiry learning in science. *Journal of Computer Assisted Learning*, *23*(2), 111–119.

Kaiser, H. (1974). An index of factorial simplicity. *Psychometrika*, *39*(1), 31–36.

Khan, S. (2011). New pedagogies on teaching science with computer simulations. *Journal of Science Education and Technology*, *20*(3), 215–232.

King, A. (1990). Enhancing peer interaction and learning in the classroom through reciprocal questioning. *American Educational Research Journal*, *27*(4), 664–687.

King, A. (1992). Facilitating elaborative learning through guided student-generated questioning. *Educational Psychologist*, *27*(1), 111–126.

Manning, C. D., & Schütze, H. (1999). *Foundations of statistical natural language processing*. Cambridge, MA: MIT Press.

Maor, D., & Fraser, B. (2005). An online questionnaire for evaluating students' and teachers' perceptions of constructivist multimedia learning environments. *Research in Science Education*, *35*(2), 221–244.

Marzano, R. J. (1998). *A theory-based meta-analysis of research on instruction*. Aurora, CO: Mid-continent Regional Educational Laboratory.

Mucherah, W. M. (2003). The influence of technology on the classroom climate of social studies classrooms: A multidimensional approach. *Learning Environments Research*, *6*(1), 37–57.

Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections* (Vol. 13). London: The Nuffield Foundation.

Physics Education Technology. (2014). Retrieved March 26, 2015 http://phet.colorado.edu

Pyatt, K., & Sims, R. (2012). Virtual and physical experimentation in inquiry-based science labs: Attitudes, performance and access. *Journal of Science Education and Technology*, *21*(1), 133–147.

Rocard, M. (2007). *Science education now: A renewed pedagogy for the future of Europe*. Brussels: Office for Official Publications of the European Communities.

Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education*, *58*(1), 136–153.

Salinas, M. F. (2008). From Dewey to Gates: A model to integrate psycho educational principles in the selection and use of instructional technology. *Computers & Education*, *50*(3), 652–660.

Smetana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education*, *34*(9), 1337–1370.

Smetana, L. K., & Bell, R. L. (2013). Which setting to choose: Comparison of whole-class vs. small-group computer simulation use. *Journal of Science Education and Technology*, *23*(4), 1–15.

Strijbos, J.-W. (2009). A multidimensional coding scheme for VMT. In G. Stahl (Ed.), *Studying virtual math teams* (Vol. 11, pp. 399–419). New York, NY: Springer US.

Strijbos, J.-W., & Stahl, G. (2007). Methodological issues in developing a multi-dimensional coding procedure for small-group chat communication. *Learning and Instruction*, *17*(4), 394–404.

Trundle, K. C., & Bell, R. L. (2010). The use of a computer simulation to promote conceptual change: A quasi-experimental study. *Computers & Education*, *54*(4), 1078–1088.

Urhahne, D., Schanze, S., Bell, T., Mansfield, A., & Holmes, J. (2010). Role of the teacher in computer-supported collaborative inquiry learning. *International Journal of Science Education*, *32*(2), 221–243.

Vermunt, J. D., & Verloop, N. (1999). Congruence and friction between learning and teaching. *Learning and Instruction*, *9*(3), 257–280.

Vogel, J. J., Vogel, D. S., Cannon-Bowers, J., Bowers, C. A., Muse, K., & Wright, M. (2006). Computer gaming and interactive simulations for learning: A meta-analysis. *Journal of Educational Computing Research*, *34*(3), 229–243.

Walker, M. (2007). *Teaching inquiry based science*. LaVergne, TN: Lightning Source.

Windschitl, M. (2000). Supporting the development of science inquiry skills with special classes of software. *Educational Technology Research and Development*, *48*(2), 81–95.

Zacharia, Z. C., & Anderson, O. R. (2003). The effects of an interactive computer-based simulation prior to performing a laboratory inquiry-based experiment on students' conceptual understanding of physics. *American Journal of Physics*, *71*(6), 618–629.