CONSTRUCTIVIST APPROACHES IN THE SECONDARY SCHOOL MATHEMATICS CLASSROOM AND THEIR EFFECTS ON STUDENTS' LEARNING, INTEREST, AND SENSE OF CHALLENGE: A RE-ANALYSIS OF THE GERMAN TIMSS DATA

Mareike Kunter, Max Planck Institute of Human Development, Germany
Jürgen Baumert, Max Planck Institute of Human Development, Germany

Abstract

Constructivist learning theories argue that tasks and discourse modes that explicitly incorporate students' former experiences can form powerful learning environments. Furthermore, research shows that students develop intrinsic motivation such as domain-specific interest, when they feel challenged and personally involved. Accordingly, constructivist teaching settings in which students participate actively, bringing in their own experiences, may be well-suited to offer this kind of experience. This study addresses the following questions: a) How effective are naturally occurring elements of constructivist teaching in terms of learning outcomes? b) Are students' individual perceptions of challenge enhanced by constructivist approaches, and do these perceptions influence students' interest development? This study re-analyses data from the German sample of the TIMS Study and the TIMSS Video Study. In Germany, the international design was extended to a 1-year-longitudinal design, with additional student measures collected one year prior to the international study. For 1900 students from 80 classes, math achievement was assessed with the TIMSS achievement test, and mathematical interest and perceptions of challenge were assessed with questionnaires. To measure constructivist teaching approaches, video ratings of one mathematics lesson per class were carried out using a newly developed rating instrument. Multilevel regression analyses predicting math achievement and interest in grade 8 revealed a small, but positive effect of constructivist teaching on achievement development, but no such direct effect on interest development. Students' individually perceived sense of challenge was the best predictor of interest development. This sense of challenge, in turn, is higher in classes with more constructivist elements, suggesting an indirect effect of constructivist teaching on interest.

INTRODUCTION

Studies that compare student achievement on an international level such as the *Trends in International Mathematics and Science Study* (TIMSS), *Civic Education Study* (CIVED), *Progress in Reading Literacy Study* (PIRLS) by the International Association for the Evaluation of Educational Achievement (IEA) or the *Programme for International Student Assessment* (PISA) initiated by the Organisation for Economic Co-operation and Development (OECD) do not only seek to provide the participating countries with information as to how their students and educational systems rank compared to other countries. Rather, by collecting various data on student background variables, school systems, and teaching characteristics, they also aim at identifying the factors which may cause differences in educational outcomes. One conclusion that can be drawn from these international studies is that, although aspects of the overall structure of the school system without doubt account for some differences in learning outcomes, it seems to be the more proximal predictors such as different instructional practices which explain most of the differences between students' achievement (see also Hartel, Walberg & Weinstein, 1983; Scheerens & Bosker, 1997).

Consequently, several international studies have pursued the idea of identifying those characteristics of classroom instruction which have most impact on students' learning and development. One of the earliest studies was the IEA Classroom Environment Study (CES), in which teaching in various countries was assessed in terms of classroom management and instructional quality, and the effect on students' learning and their attitude towards the subject was examined (Anderson, Ryan & Shapiro, 1989). The study, which used observational as well as questionnaire data, revealed a positive influence of instructional quantity (e.g., opportunities to learn, homework assignments) on students' learning gains. However, most of the observed teaching behaviors describing instructional quality were unrelated to students' achievement scores. Instead, these variables seemed to affect students' academic engagement, which in turn had a positive influence on students' achievement gains (Anderson et al., 1989). More recently, the 1995 TIMSS Video Study, which was embedded in the 1995 TIMSS assessment, collected data on cultural patterns in mathematics instruction in three different countries. Classroom instruction in Japan, Germany, and the United States was videotaped in nationally representative samples and analyzed with regard to classroom organization, types of tasks, and patterns of discourse (Stigler, Gonzales, Kawanaka, Knoll & Serrano, 1999). The study revealed distinct teaching approaches in all three countries. In Japan, one of the highest achieving countries in TIMSS, a problem-oriented approach was common, with students working on complex, often open-ended problems. In contrast, lessons in Germany and the United States, where mean achievement scores were average or below average, tended to involve more tasks focusing on routines and exercises. Since the publication of these results, the Japanese approach to mathematical learning has frequently been posited as one of the best routes to high achievement (c.f. Stigler & Hiebert, 1999). This idea was taken up by the TIMSS 1999 Video Study, which observed mathematical instruction in seven countries, most of them with relatively high achievement scores in TIMSS assessments (Hiebert et al., 2003). The aim of this study was to examine whether one common pattern of instruction could be identified as the underlying cause for the high performance of the students in these countries. Results show that although teaching in these countries shared some similarities on the overt organizational level, there were considerable differences in instructional features such as type of content, complexity of tasks, proportion of routines to problem solving tasks, and authenticity of tasks. Thus, the somewhat disappointing conclusion to be drawn from this study seemed to be that no single "good teaching" approach could be identified, but that various methods may impact positively on students' learning.

Nevertheless, the existing international studies on classroom instruction demonstrate that various instructional approaches do exist, and that different methods can be combined in specific ways, with positive learning outcomes. They also show that overall aspects of classroom organization (e.g., amount of seat or class work and types of material used) seem to be less important features of instructional quality, and that it is the actual instructional content (e.g., the way the instructions are given and the characteristics of the tasks set) that seems worth exploring. However, if one aims to examine the impact of instructional features on learning or other student outcomes, the data from international comparison studies needs to be supplemented with more in-depth analyses of instructional and learning processes. For one thing, when comparing students' achievement in different countries, it is difficult to disentangle effects caused by differences in the overall educational system from the effects of different teaching approaches. Moreover, since most of the studies are usually based on a cross-sectional design, one cannot conclude that any teaching differences observed are causally linked to differences in achievement or other outcomes. Finally, because the 1999 TIMSS Video Study has shown that diverse methods seem to produce similar results, the question that needs to be answered next is which underlying general learning processes are at work. In order to understand fully the effects of different features of classroom instruction, theoretical frameworks describing how students actually learn and develop within their classrooms are required. A number of researchers have pointed to the necessity of moving beyond the conventional paradigm in instructional research, which describes student outcomes as a product of particular teaching inputs (e.g., Church, Elliot & Gable, 2001; Nuthall & Alton-Lee, 1990, 1995; Shuell, 1996). Approaches that take the interplay of students' learning and motivational processes into account seem particularly promising. The present paper draws on psychological learning theories and theories of motivational development to examine the effects of one particular teaching approach – namely the constructivist approach – on students' achievement and motivational development. It is not based on an international comparison, but on an in-depth analysis of teaching approaches within one culture.

The present study uses data from the German sample of the 1995 TIMS study. On account of the various national extensions to the international study design described below, this sample constitutes an excellent data base for studying the research questions raised.

WHAT IS GOOD TEACHING? THEORETICAL ASSUMPTIONS

Research on teaching has traditionally focused on aspects of classroom organization, following earlier models of instructional quality that stress the importance of effective time management and ensuring optimum time on task for all students (Carroll, 1989; Hartel et al., 1983; Walberg & Paik, 2000). Consequently, characteristics of effective classroom management such as clarity of structure, discipline, and feedback mechanisms have long been considered crucial to students' achievement gains (Brophy, 1999; Grouws & Cebulla, 2000; Walberg & Paik, 2000). This notion of teaching quality is based on a conception of learning as information processing (see R. E. Mayer, 2003; Shuell, 2001). Within this theoretical framework, it is assumed that the teacher, holding all the information that has to be learned, transfers it directly to the learners. One way of facilitating this transmission and the consequent processing of the information is a clear organization of the learning environment, in which students' attention is secured, the learning material is organized in such a way that it is easy to process, and retrieval is fostered by exercises and routines (see Gagné & Driscoll, 1988; R. E. Mayer, 2003; Shuell, 2001). There is ample empirical evidence for the positive effects of this type of classroom management, showing that students in well-organized classes in which time is used effectively show better learning gains than students in less structured environments (Anderson et al., 1989; Walberg & Paik, 2000).

Following recent theoretical developments, particularly in the field of mathematics and science learning, however, the focus has shifted from the description of structural conditions to a closer examination of the instructional features of the learning environment (Greeno, 1998; Grouws & Cebulla, 2000; Shuell, 1996). Recently, instructional research has focused on questions such as how the learning content is presented, what types of tasks are used, and what kind of learning processes take place.

Many of these analyses are based on constructivist learning theories. Within this theoretical framework, "knowledge" is no longer considered a neutral commodity that is transferred to everyone in the same way (Cobb, 1994; Cobb & Bowers, 1999; Collins, Greeno & Resnick, 2001; Greeno, 1994; Greeno, Collins & Resnick, 1996). Instead, learning is conceptualized as an active, constructive, and cumulative process, in which students are engaged in high-level cognitive activities, developing new concepts and understandings based on their former knowledge or preconceptions (Shuell, 1996). Especially in the field of mathematics and science education, it has been shown that powerful learning environments are those that enable students to actively construct their own knowledge (de Corte, Greer & Verschaffel, 1996). Learning situations using tasks and patterns of discourse that explicitly incorporate students' preconceptions and former experiences and thus trigger a meaningful engagement with the core ideas seem to offer unique opportunities for conceptual growth (Duit & Confrey, 1996). For instance, the positive learning effects of constructivist instruction programs such as the *Jasper Series*, which is based on the *Anchored Instruction Approach* of the *Cognition and Technology Group at Vanderbildt* (CTGV), and the *Middle School Mathematics*

Through Applications Project Group have been well documented, particularly when higher level thinking is involved (Bransford & CTGV, 1994; CTGV, 1992; Greeno & the Middle School Mathematics Through Applications Project Group, 1998; Hickey, Moore & Pellegrino, 2001).

Generally, these studies examine specifically designed learning contexts and thus report experimental or quasi-experimental data. Although this methodological approach provides sound evidence on the effects of certain instructional elements, it does not answer the question as to how effective naturally occurring elements of constructivist teaching are in terms of learning outcomes. The type of instruction found in the Japanese mathematics lessons in the 1995 TIMSS Video Study seems to reflect some of the basic ideas of constructivist learning theories, as students were confronted with complex problems and worked on these problems based on their own interpretations of the tasks. Moreover, teachers explicitly allowed various approaches to the tasks, and had the students discuss whether these approaches seemed valid (Stigler et al., 1999). As Japanese students were among the highest scoring in the TIMSS assessment, this may imply that constructivist approaches can be beneficial even in regular classrooms. This assumption is supported by a study by Staub and Stern (2002), which showed that elementary school children whose teachers reported a constructivist approach to learning as opposed to a direct-transmission view showed better achievement in demanding word problem tests. Similar evidence is described for the German TIMSS sample in the final years of secondary schools (Baumert & Köller, 2000), in which teaching styles where students work on complex problems without clear-cut solutions or are explicitly asked to link up various concepts and ideas were related to higher achievement in the TIMSS test. Thus, a constructivist approach to mathematics instruction that provides students with complex tasks and involves their own, individual knowledge bases, seems to support learning. As most of the data reported here comes from either cross-sectional designs or evaluations of deliberately designed learning settings, the question of whether elements of constructivist teaching can also foster student learning gains within a regular classroom situation remains to be addressed.

Furthermore, most research on instructional quality concentrates on students' domain-specific achievement gains as the most salient educational outcome. There is, however, growing consensus that certain motivational characteristics are important prerequisites that support the learning process, particularly when higher order learning gains are involved (e.g., Pintrich, 1999; Pintrich, Marx & Boyle, 1993). One of these motivational characteristics is an intrinsic motivational tendency, i.e., the disposition to pursue an activity for its own sake rather than because of the expected external consequences. This motivational disposition seems to be a relevant condition for high quality and sustained learning (Krapp, 2002; Pintrich, 1999). In the context of instructional research, the concept of domain-specific interest has often been used to describe intrinsic tendencies in students' learning (Hoffmann, Krapp, Renninger & Baumert, 1998). Within this approach, interest is conceptualized as a specific relationship between a person and a topic, object, or activity characterized by positive emotional experiences and feelings of personal relevance (value commitment). Various studies have shown that students with higher interest in a domain use more deeper-level-processing strategies, or show more engagement and persistence (Alexander & Murphy, 1998; Hoffmann et al., 1998; Krapp, Hidi & Renninger, 1992; Schiefele, 1998). In addition to the benefits of interest for the learning process, it has also been argued that intrinsic motivational tendencies may constitute desirable educational outcomes in themselves (Krapp, 2002; Ryan & Powelson, 1991). "Good teaching", one may argue, fosters students' cognitive and motivational development alike, and provides students with a motivational disposition to pursue certain preferred activities even beyond their required assignments (Maehr, 1976).

How might teaching support this motivational development? In order to identify conditions of the learning environment that support the development of interest or other intrinsic motivational tendencies, research usually draws on the theory of self-determination developed by Deci and Ryan (Deci & Ryan, 2000; Ryan & Deci, 2000; Ryan & Powelson, 1991). The theory states that the experience of self-determination which develops when a person's basic needs – i.e., the need for social relatedness, autonomy, and competence – are met, fosters intrinsic motivational tendencies (Deci & Ryan, 2000). Several studies have applied this theoretical framework to the school setting and have shown that students develop intrinsic motivation such as domain-specific interest or motivational involvement when they feel challenged and personally involved in their learning environments (Miserandino, 1996; Skinner & Belmont, 1993; Turner et al., 1998). This personal sense of challenge or involvement may be influenced by certain features of the learning environment (Ryan & Powelson, 1991). This is demonstrated convincingly by a study conducted by Turner and others (1998) into students' sense of involvement immediately after mathematics lessons. In this study, involvement was conceptualized similarly to the idea of situational interest and encompassed concentrated attention, deep comprehension, positive emotions, and intrinsic motivational tendencies. Using audiotapes and observational data, the researchers showed that students experience high levels of involvement especially in lessons which focused on conceptual understanding, in which students were held accountable for their own understanding, and in which the teacher stressed the intrinsic aspects of the learning process. Taking this evidence together, it can be expected that constructivist teaching settings in which students participate actively, and into which they are encouraged to bring their own experiences and prior knowledge, are particularly well-suited to offer the experience of self-determination as a precondition for the development of intrinsic motivational tendencies. Consequently, the second question addressed by this study is whether constructivist teaching approaches enhance students' sense of challenge, which in turn fosters interest development.

In summary, the purpose of this study is to examine the effect of constructivist approaches on students' learning and interest development in the context of regular secondary school mathematics classrooms. As pointed out above, most evidence on the effects of constructivist approaches on students' learning is based on data from experimental studies in which constructivist learning environments were deliberately designed. Do elements of constructivist teaching that occur in regular classrooms also have positive effects on students' learning? Moreover, because research stresses the importance of students' individual experiences for interest development, we analyze whether constructivist approaches enhance students' individual perceptions of challenge which, in turn, influence their interest development.

RESEARCH APPROACH

The study re-analyses data from the German sample of the Third International Mathematics and Science Study TIMSS. (Baumert et al., 1997b; Beaton et al., 1996) and the associated TIMSS Video Study (Stigler et al., 1999). In Germany, the international design of the TIMS study was extended to a longitudinal design (Baumert et al., 1997b). More specifically, additional achievement tests and questionnaires on motivation and perceptions of teaching were administered in grade 7, and again one year later to the same students in grade 8. Between these two measurement points, a subsample of classes took part in the TIMSS Video Study, with one mathematics lesson being videotaped for each participating class. The present study uses these video observations for a re-analysis focusing on the occurrence of constructivist teaching elements. These data thus provide us with a fairly large longitudinal sample of secondary students for whom achievement data, questionnaires on math-related interest, and perceptions of teaching are available, as well as additional observer ratings of their math classes.

METHOD

Sample

The sample used in this study is a subsample of the nationally representative TIMSS middle school sample. For the TIMSS Video Study, a random sample of 100 classes was drawn; because a number of classes dropped out over the course of the longitudinal study, the sample size is reduced to 80 classes in 80 different schools. The participants in this study are 1900 students (48.5 % girls) from all school tracks in Germany. Their mean age at the second measurement point (grade 8) was 14.8 years. Overall, 34% of the students were enrolled in lower track schools (*Hauptschulen*), 28% in the intermediate track (*Realschulen*), and 39% in the academic track (*Gymnasien*). Compared to the original TIMSS sample, this sample is slightly biased towards higher track schools.

Measures

For this study, measures from different data sources were combined and used on two different levels. Students' math achievement, interest, and sense of challenge were used on the individual student level, and the video observations on constructivist approaches were used on the class level.

Individual level: math achievement. Students' math achievement was assessed with the TIMSS achievement test. Conceptually, the TIMSS test covers various content areas and different performance categories, such as conducting routine and complex procedures, applying knowledge, or solving mathematical problems (Beaton et al., 1996). In general, the TIMSS test focuses on conceptual understanding and application of mathematical ideas rather than on fact retrieval. As part of the longitudinal design in Germany, students completed tests with overlapping item sets in grade 7 and, one year later in the international assessment, in grade 8. At both times, items from the international item pool were combined with a set of items taken from the First and the Second International Mathematics Study run by the IEA (Husén, 1967; Robitaille & Garden, 1989) and an earlier German study by the Max Planck Institute for Human Development. Individual achievement scores were estimated based on item response theory. Based on the international TIMSS item parameters (see Adams, Wu & Macaskill, 1997 for details), the item parameters for the national items were estimated using a maximum likelihood procedure (ML). Afterwards, individual mathematics scores were estimated (also ML estimates). To be able to describe students' achievement on one dimension, an equating procedure was used in which achievement at grade 8 served as a scale anchor. Consequently, most students have a negative value for achievement in grade 7, given that their achievement improved in grade 8.

Individual level: math-specific interest. Math-related interest was assessed by a four-item scale which was developed for the longitudinal study *Learning Processes, Educational Careers, and Psychological Development in Adolescence and Young Adulthood* (BIJU), conducted at the Center for Educational Research of the Max Planck Institute for Human Development in Berlin (Baumert, Gruehn, Heyn, Köller & Schnabel, 1997a; Baumert & Köller, 1998) and administered to the TIMSS sample as part of the national extension in both grade 7 and grade 8. The scale reflects the two dimensions inherent in the person-object approach to interest: value commitment and positive emotional valences (Krapp, 2002). Students answer questions on their feelings about mathematics and important they think the subject is. Examples are "How much do you look forward to mathematics lessons?" or "How important is it for you to know a lot in mathematics?". Answers are given on a 5-point scale ranging from 1 = "very much" to 5 = "not at all". For the analyses, items were recoded such that a high score reflects a high degree of interest. Reliability coefficients (Cronbach's α) were .81 in grade 7 and .78 in grade 8.

Individual level: sense of challenge. To assess students' sense of challenge as a possible mediator for the link between constructivist teaching and students' interest development, items from a questionnaire tapping students' perceptions of their math classroom and math teacher – again originating from the BIJU-Project – were administered to the students in grade 8. In the questionnaire, students rate their mathematics teacher's behavior and other aspects of the learning environment on a 4-point Likert scale. For this study, items from four different subscales tapping different aspects of students' experience of challenge were combined into one scale. These 14 items describe whether students experience the pacing of the lessons as appropriate (e.g., "Our math teacher works through lessons quickly, so that you always have to pay attention, but aren't completely overwhelmed"), the challenge they experience while working on tasks (e.g., "The exercises often include tasks that really make you aware of whether you've understood something"), whether they feel motivated and inspired by the teacher (e.g., "Our teacher can make even the most boring topic into something really interesting"), and the degree to which they feel errors or mistakes are treated constructively (e.g., "In math lessons, our teacher sometimes accepts our mistakes and lets us go on, until we realize ourselves that something is wrong"). All answers are given on a 4-point scale with 1 = "applies fully" to 4 = "does not apply at all". Items were recoded such that a high score reflects a high degree of challenge, and then combined into one score (Cronbach's α = .67).

Class level: constructivist teaching approaches. As part of the TIMSS Video Study, one mathematics lesson in each of the participating classes was videotaped between the two measurement points. All recordings took place during grade 8, the content could be chosen freely and thus varies from class to class. The recording procedures followed standardized guidelines (see Stigler et al., 1999 for details). The teachers' participation was voluntary, and they were asked to teach the lesson as 'normally' as possible. A questionnaire administered to the teachers after the recording revealed that most teachers felt that they had succeeded in doing so (Stigler et al., 1999).

These observations were used for a re-analysis with a newly developed high-inference rating instrument based on a set of scales developed by Widodo, Duit, & Müller (2002). The rating instrument analyses the occurrence of constructivist learning situations, in which students' knowledge is explored and in which they are given the opportunity to actively construct a conceptual understanding. Using several subcategories, observers rate whether the teacher explores students' prior knowledge and understanding, provides tasks that make use of this prior knowledge and involve cognitive conflict or demand conceptual restructuring, or shapes the classroom discourse in this way (see appendix for details). High inference ratings on these categories were made for the whole lesson on a 4-point Likert scale ranging from 1 = "does not apply at all" to 4 = "applies most of the time". For the present study, the four subcategories are averaged into one score. In order to achieve a high degree of reliability and validity, a rating procedure based on consensus judgment was applied. Each of the 80 lessons was rated independently by two raters, who had been trained in the use of the rating instrument beforehand with similar material. In case of discrepancy between the ratings, raters discussed their answers and determined a consensual rating, referring to the video material if necessary. The mean interrater reliability (intraclass coefficients) prior to this consensus rating was ICC = .73, and can be considered a conservative reliability estimate.

Class level: school track. Students from different school tracks can be expected to vary in their achievement levels, and possibly in other variables (Baumert et al., 1997b). To take these differences into account, the type of secondary school was included in the analyses. For the prediction models, two dummy variables were used, with the first ("high track") coded 1 for classes in the higher track (*Gymnasium*) and 0 otherwise, and the second ("low track") coded 1 for classes in the lower track (*Hauptschule*) and 0 otherwise.

Statistical Analyses

Missing data. Due to the longitudinal design and the combination of diverse data sources, complete data sets were not available for all students. Video ratings were available for all classes, but there was a considerable amount of missing data on the individual level. Analyses revealed that a small portion of the missing data was caused by the drop-out of low-achieving students, but that most of the missing data seemed to occur at random. In order to avoid a reduction of the sample size, missing values were imputed and complete datasets were produced for all students (Rubin, 1996). A multiple imputation method was employed using the NORM software (Schafer, 1999). Five datasets were produced in which missing values were replaced by estimated values. The software used for the analyses (WesVar, HLM, see below) can handle these multiple datasets simultaneously and produce combined parameters.

Multilevel analyses. The data used in this study are hierarchical in structure: students are nested within classes, and each class comes from one school. This clustered sampling procedure violates the assumption of the independence of observations held in conventional significance testing. Moreover, variables are used on two different levels. In this study, the hierarchical nature of the data is taken into account by using two different techniques. In order to test group differences in the individual-level variables, parameters are estimated using the WesVar software, which produces appropriate estimates and standard errors by taking into account the hierarchical structure of the data (Westat, 2000). As in TIMSS, a jackknife repeated replication technique was employed (Gonzales & Foy, 1997). For the regression models, a multilevel regression technique (HLM, Raudenbush, Bryk & Congdon, 2001) is used to consider the individual-level and class-level variables simultaneously. To facilitate the interpretation of the HLM models, all predictor variables were standardized to z-scores (m = 0, SD = 1). Thus, the coefficients shown in the models can be interpreted in much the same way as regression coefficients from conventional multiple regression models.

RESULTS

Descriptives

Table 1 reports the descriptive statistics for all measures; first for the whole sample and then separately for the different school tracks. Considering that a score of 1 on the video ratings means "does not apply at all", one can conclude that constructivist approaches are rather rare in German mathematics classrooms. This is, of course, in line with the findings of the 1995 TIMSS Video Study, which demonstrated that a rather information processing-oriented style involving high frequency of routines and exercises is dominant in German classrooms. There are, however, some constructivist elements to be found, and their frequency varies across school types. More constructivist elements can be found in the academic than in the vocational track. Students from different tracks also differ in their achievement and interest, with students in the academic track showing higher levels of achievement, but lower levels of interest than students in the lower tracks. There is, however, no difference in students' sense of challenge. The similar means for math-related interest at both measurement points seem to suggest that students' interest did not change over the course of the year. In fact, the correlation between the two variables is r = .55, indicating a moderate degree of stability. Thus, there is room for individual change in interest, even though the sample parameters as a whole did not change.

Table 1: Descriptive Statistics For All Variables, For The Whole Sample, And By School Track Including Results Of The F-Tests For Significant Mean Differences Between Tracks (Calculation In WesVar)

	Whole sample *M (SD)*	*Vocational track* *M (SD)*	*Intermediate track* *M (SD)*	*Academic track* *M (SD)*	*Test for tracks differences* *F*
Math achievement grade 7	-.20 (1.08)	-0.96^{a} (0.94)	-0.22^{b} (0.84)	0.47^{c} (0.90)	89.99 *
Math achievement grade 8	.43 (1.20)	-0.47^{a} (0.89)	0.37^{b} (0.89)	1.26^{c} (1.05)	125.50 *
Math interest grade 7	3.23 (0.84)	3.35^{a} (0.85)	3.20^{a} (0.85)	3.14^{b} (0.81)	3.88 *
Math interest grade 8	3.18 (0.88)	3.33^{a} (0.89)	3.16^{a} (0.91)	3.06^{b} (0.84)	8.04 *
Sense of challenge	2.53 (0.51)	2.59^{a} (0.49)	2.51^{a} (0.53)	2.50^{a} (0.52)	0.28
Constructivist teaching approaches (class level)	1.53 (0.38)	1.35^{a} (0.30)	$1.52^{a,b}$ (0 .32)	1.72^{b} (0.43)	7.60 *

Note: * p < .05

Means in each row with a different subscript differ significantly from each other at p < .05 (post hoc tests in WesVar).

The aim of this study was to examine the effect of different learning environments on students' learning and interest. To address this question appropriately, it is first necessary to establish the between-classroom variation in the outcome variables. Only if students in certain classes differ systematically from students in other classes is the question of potential influence of class variables relevant. Table 2 presents the intra-class correlation coefficients generated by the HLM analysis; the first column shows the amount of variance explained solely by class membership and the second column the between-classroom variance within the academic tracks. Without taking the type of track into account, students from different classes vary greatly in their math achievement, and to a lesser degree in their interest and sense of challenge. Once the effect of track membership is taken into account, about 10 to 14 percent of the variation found in the outcome variables and in the perception of challenge can be explained by class membership.

Table 2: Intra-Class Correlations Of The Individual-Level Variables For Class Membership And Class Membership Within School Tracks

	ICC class membership only	*ICC class membership within tracks*
Mathematics achievement grade 7	.44	.12
Mathematics achievement grade 8	.52	.14
Math-related interest grade 7	.08	.08
Math-related interest grade 8	.11	.09
Sense of challenge	.15	.14

Note: All coefficients are statistically significant at $p < .05$.

ICC: Intra-Class Correlation, proportion of variance explained by class membership

Effects of constructivist approaches on achievement and interest

In order to determine the effect of the instructional features on achievement and interest development, we carried out multilevel regression analyses. Separate models were calculated for effects on achievement and interest, respectively. In these analyses, we predicted students' achievement (or interest) in grade 8 using achievement (interest) in grade 7 and the perception of challenge as individual-level predictors and the observer-based ratings for constructivist teaching as class-level predictors. The descriptive data showed that students from different types of secondary school differed in their outcomes (interest and achievement), and that there were considerable differences in the occurrence of constructivist learning situations. Thus, type of school was included in consequent analyses to control for these differences.

Table 3 shows the results of the analyses for math achievement. With achievement in grade 7 being included as a predictor for achievement in grade 8, the coefficients of all other predictors can be interpreted as the effect on achievement gains.

The models only partially confirm the expected positive effects of constructivist teaching – there is a small, but positive effect of constructivist teaching on achievement gains. Students in classes featuring more constructivist teaching elements show slightly more learning gains than students from other classes. However, the subsequent analyses, in which the type of school track was controlled, show that the effect of constructivist approaches on math achievement is largely due to differences between classes from different tracks. When comparing students from classes within a track, the type of teaching approach does not seem to make a difference to achievement gains. The perceived sense of challenge had no effect on achievement in grade 8.

The analyses predicting interest development produce a different pattern, as can be seen in Table 4. Neither constructivist approaches, nor school type affect interest development. Rather, the individually perceived sense of challenge proved to be the best predictor of interest development. This means that students who experience their mathematics lessons as challenging develop a relatively high level of interest, regardless of the overall style of teaching in their mathematics classroom or the type of secondary school they attend.

Table 3: Results Of HLM Models Predicting Mathematics Achievement In Grade 8; Standardized Regression Coefficients With Standard Errors And Proportion Of Explained Variance Overall And Within Levels

Criterion / Predictors	Math achievement Grade 8 without school type b	(SE)	with school type b	(SE)
Individual variables				
Achievement grade 7	.47	(.03)*	.45	(.03)*
Sense of challenge	.00	(.02)	.01	(.02)
Class-level variables				
Low track [a]	-		-.20	(.04)*
High track [a]	-		.23	(.03)*
Constructivist teaching approaches	.13	(.05)*	-.02	(.03)
R^2 total	.45			.55
R^2 individual level	.22			.22
R^2 class level	.66			.87

Note: *b*: HLM regression weight; SE: Standard error of *b*; R^2: Proportion of explained variance
* p < .05
[a] dummy-coded, reference category: intermediate track

Table 4: Results Of HLM Models Predicting Math-Related Interest In Grade 8; Standardized Regression Coefficients With Standard Errors And Proportion Of Explained Variance Overall And Within Levels

Criterion / Predictors	Interest Grade 8 without school type b	(SE)	with school type b	(SE)
Individual variables				
Interest grade 7	.49	(.02)*	.49	(.02)*
Sense of challenge	.22	(.02)*	.22	(.02)*
Class-level variables				
Low track [a]	-		.05	(.04)
High track [a]	-		-.05	(.04)
Constructivist teaching approaches	.00	(.03)	.00	(.03)
R^2 total	.35		.35	
R^2 individual level	.31		.31	
R^2 class level	.64		.68	

Note: *b*: HLM regression weight; SE: Standard error of *b*; R^2: Proportion of explained variance
* p < .05
[a] dummy-coded, reference category: intermediate track

One theoretical assumption was that the sense of challenge students experience is fostered by constructivist learning approaches. This was tested in another set of multilevel analyses in which students' sense of challenge was predicted by the ratings of constructivist approaches. As can be seen in Table 5, students' sense of challenge is, in fact, higher in classes with more constructivist elements, regardless of the type of track. However, it should be pointed out that with an effect size of one-tenth of a standard deviation, this effect is rather small and only a small proportion of variance is explained. As only class variables were considered in these models, the amount of variance explained between classes is of particular interest; with constructivist teaching as the sole predictor, 4 % of this variance is explained. Nevertheless, these results suggest that constructivist teaching may have an indirect effect on interest, which is mediated by students' experience of challenge.

Table 5: Results Of HLM Models Predicting The Individual Perception Of Challenge With Constructivist Teaching Elements; Standardized Regression Coefficients With Standard Errors And Proportion Of Explained Variance Overall And Within Levels

Criterion	Sense of challenge			
Predictors	*without school type*		*with school type*	
	b	*(SE)*	*b*	*(SE)*
Class-level variables				
Constructivist teaching approaches	.09	(.04)*	.15	(.05)*
Low track [a]	-		.12	(.07)*
High track [a]	-		-0.5	(.05)
R^2 total	.01		.02	
R^2 individual level	.00		.00	
R^2 class level	.04		.14	

Note: *b*: HLM regression weight; SE: Standard error of *b*; R^2: Proportion of explained variance
* $p < .05$
[a] dummy-coded, reference category: intermediate track

CONCLUSION

The aim of this study was to describe effects of constructivist teaching approaches on students' learning and interest development in a large, representative sample. In addition, students' individual perception of challenge was considered in order to examine the theoretical assumption that constructivist teaching styles may foster students' interest indirectly via this sense of challenge.

The results confirm the theoretical assumptions of self-determination theory (Deci & Ryan, 2000; Ryan & Deci, 2000; Ryan & Powelson, 1991), which states that students' experience of autonomy and competence is one underlying cause for interest development, and they also point to the possibility that this sense of challenge may be enhanced in constructivist learning environments. The present findings thus indicate that a content-oriented perspective to the learning environment may be promising: an instructional approach providing students with the opportunity to restructure their own preconceptions and elaborate existing concepts seems to support the development of intrinsic motivational tendencies via the experience of challenge, even in regular classrooms. The results thus supplement the existing body of research on instructional quality, which has thus far focused mainly on structural elements of classroom organization. They cannot, however confirm the results from studies on the beneficial effects of constructivist teaching approaches in general, as no direct effects of constructivist teaching elements could be found on interest development, and the small effects on achievement observed in the sample did not persist when comparing students in the different school tracks.

One critical point that should be discussed in the light of these results concerns the validity of the video ratings. Because the original TIMSS Video Study aimed at describing general features of instruction within one culture, it was not designed to provide data on differential teaching effects within one country (Stigler et al., 1999). Using a single recording as an estimate of the typical instruction found in this class seems problematic. We cannot rule out the possibility that teachers prepared specifically for this occasion and showed teaching behavior that differed from their regular instruction. However, because teachers were not aware of the research question – especially in the case of the present re-analysis – a systematic bias in this direction does not seem plausible. Moreover, research on teaching behavior shows that teachers develop distinct styles of teaching that seem to be rather stable over time. For instance, a recent German video study observed classroom instruction in 13 physics classes over the course of six months (Seidel et al., 2002). Video analyses of 6 lessons per class revealed rather stable patterns of teaching for each participating teacher in terms of classroom organization and structure of discourse. Similar evidence was found in an observational study by D.P. Mayer (1999), who rated instructional practices in 17 high school mathematics classes for several weeks. In Mayer's study, only 24 % of the total variability in teaching practices was explained by within-class differences, indicating that teachers' instructional style varies comparatively little over time. Thanks to another German addition to the TIMSS Video design, we also have some data on the stability of aspects of teaching in our sample. Two additional lessons within the same lesson unit were recorded in 28 of the 80 classes used in the present study. In these classes, the mean correlation between the degree of constructivist orientation for all three lessons was $r = .58$, showing that there is a moderate degree of stability in the instructional approaches observed for each teacher. Furthermore, other studies which have used the same data base and studied the effect of other teaching variables combining video and questionnaire assessments have found almost identical results for both methodological approaches (Kunter, Baumert & Köller, 2003; Lüdtke, Köller & Baumert, 2001). Undeniably, increasing the number of recorded lessons would very much improve the reliability and validity of the observational measure. Still, bearing in mind that such a procedure would almost inevitably entail a reduction of sample size and would thus reduce the sample variability, we conclude that the advantage of being able to use the large TIMSS sample balances out the limitations of the one-lesson design.

One strong point of the study seems to be the combination of objective class variables with students' individual perceptions of the classroom. The results showed that the two types of student outcomes were affected by different aspects of the classroom environment. Whereas math achievement seemed to be influenced mainly by class-level predictors, these predictors did not influence students' interest development. Here, their individual perception of challenge was the best predictor. Even within a given learning environment, students may thus differ in their experiences, which may then influence their cognitive and motivational development in a specific manner. Thus, the use of different data sources to tap general instructional features and students' individual perceptions as two distinct aspects of the classroom context, and the subsequent combination of these different aspects within one multilevel model, constitutes an improvement on earlier models of instructional quality and studies of classroom climate. The literature on aptitude-treatment interaction could help to distinguish factors that influence students' experience in the classroom (Snow, Corno & Jackson, 1996). With the development of new multilevel techniques, it will, in the future, be possible to explore these kinds of complex models in an appropriate manner (Hox, 2002).

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APPENDIX

Overview of the rating system for constructivist approaches

Subcategory	*Description*
1. Making students aware of their learning status within the topic as a whole	Pointing out that knowledge does not consist of isolated fragments, but that concepts are closely interrelated. Making students aware of the meaning of the new content in relation to the topic as a whole: What is the new knowledge based on? What does the new knowledge aim at? Students are encouraged to incorporate the new concepts within their existing knowledge system. Example: The teacher reviews the topic and introduces new content: *In the last few lessons, you have learned to create tables with the help of functions. Today we won't be doing anything much different, only we are using a specific function.*
2. Exploring students' prior knowledge and conceptions	Accumulating and considering students' prior knowledge. This can consist of "naïve" concepts, or of ideas and concepts acquired in earlier lessons as long as these are fully understood by the students. Example: The teacher writes a new binomial formula on the blackboard: *We've done something like this already, have a look at it – what could we do?*
3. Presenting tasks that challenge students' thinking	Open problems encourage thinking and stimulate cognitive conflicts. This type of task calls existing convictions and ideas into question and supports conceptual change. The focus is on the nature of the tasks: What type of problem is presented? Example: The students first had to construct a triangle, having been given information about all three distances and all three angles. *Teacher: My next question is: For the next triangle, try to manage with fewer specifications, with less than 6. How many specifications do you want? I want to give away as little as possible about this triangle.*

Subcategory	*Description*
4. Addressing students' conceptions in an evolutionary way	Starting off with students' ideas and conceptions that concur with scientific conceptions, or beginning with pieces of knowledge that students are already familiar with. Using these elements, the scientific concepts are then developed step by step. It is important to note whether the ideas that are taken up are actually students' own conceptions. <u>Example:</u> *T: You are 1,70 meters high and a photograph is taken of you. You are standing in front of a wall and you now have a picture of you. What would you call that?* *S_1: The shape is the same, so when…* *L: That's significant. The shape is the same.* *S_1: In a different proportion.* *S_2: In a different scale.* *L: Yes, a different scale. And what do you call the relation between these two figures? Based on the photography? Well, you know that there are sometimes disappointments. Then you say, I can't see much resemblance, or… another word?* *S_2: Similarity.*