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Student Affect and Conceptual Understanding in Learning Chemistry

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Abstract: This study explores the relationship between affective and cognitive variables in grade 9 chemistry students ($n = 73$). In particular, it explores how students' situational interest, their attitudes toward chemistry, and their chemistry-specific self-concept influence their understanding of chemistry concepts over the course of a school year. All affective variables were assessed at two time points: at the middle of the first semester of grade 9, and at the end of the second semester of grade 9, and then related to students' postinstructional understanding of chemical concepts. Results reveal that none of the affective variables measured at the earliest time point have a significant direct effect on postinstructional conceptual understanding. Looking at the different affective variables as intermediary constructs, however, reveals a pattern in which self-concept and situational interest measured at the middle of grade 9 contribute to self-concept measured at the end of grade 9, which in turn, has a positive, significant effect on students' postinstructional conceptual understanding. These results reveal the importance of a strong and positive self-concept, the feeling of doing well in the chemistry class, for developing a meaningful understanding of scientific concepts. © 2006 Wiley Periodicals, Inc. J Res Sci Teach 44: 908–937, 2007

Keywords: chemistry; cognitive development; attitudes

A discussion with teachers or a perceptive look into a science classroom is sufficient to realize that the learning of scientific concepts is more than a cognitive process. Students' interests and attitudes toward science as well as their perceptions of how well they will perform in learning contexts (self-concept) may play important roles in developing a meaningful understanding of scientific concepts, an understanding that goes beyond rote memorization toward the ability to explain everyday phenomena with current scientific knowledge. Despite the apparent importance of affect in the learning process, research exploring this linkage is limited. This article addresses the following research question: how do students' interests, attitudes, and self-concept influence scientific understanding? Knowing which variables have more influence on learning may result in better understanding of changing classroom practice that supports students' conceptual understanding. This study looks empirically at possible relationships over time between these affective variables and conceptual understanding, and based on its results, briefly discusses possible implications for further research and classroom practice.

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Theoretical Perspective

Meaningful Conceptual Understanding

Various studies investigating the relationship between affective and cognitive variables equate learning with academic achievement and measure ''achievement'' either with multiple-choice items or short-answer questions (e.g., Häußler & Hoffmann, 2002; Marsh & Yeung, 1997; Schiefele, Krapp, & Winteler, 1992). None of these studies explain the type or level of knowledge that is measured: do they measure, for example, simple rote memorization, recall, paraphrasing, seeking connections among various pieces of information, or applying the newly learned information to everyday life phenomena? It is the latter two that comprise *meaningful conceptual understanding*, while the others are often test preparation strategies resulting in short-term knowledge. Other studies equate learning with achievement on standardized tests and grades (e.g., Singh, Granville, & Dika, 2002), also without further information on the level of knowledge that is being measured. However, it can be assumed that these studies measure test preparation strategies instead of meaningful conceptual understanding. Mattern and Schau (2002) explicitly state that they assessed ''students' connected understanding of science'' (p. 329) with concept maps. However, students did not develop concepts maps themselves. Instead, they received preconstructed concept maps in which one third of the concept words were left blank and a list of all possible fill-in-the-blank answers (concept words). Concept maps are visual, structured heuristics representing concepts, and their interrelationship (Novak, 1990, 1998) thus have the potential to elicit students' conceptual understanding. Mattern and Schau's (2002) way of using concept maps to measure connected scientific understanding is questionable. Simple rote memorizing might be sufficient to score high on these types of concept maps, in particular, because students received concept maps with links demonstrating the connectedness between properties of objects, events, or processes that define the particular concept. If students had been asked to articulate these connections and interrelationships for example, in self-developed concept maps, then that would have been a solid demonstration of conceptual understanding that goes beyond lower level of knowledge acquisition.

Conceptual understanding of science is a complex phenomenon. It incorporates an understanding of single concepts such as oxidation or of more complex concepts such as redox reactions (declarative or factual knowledge), which, following certain rules and models, combines multiple individual concepts (e.g., oxidation, reduction, particle model), resulting in a new concept. Thus, conceptual understanding comprises declarative knowledge, procedural knowledge (concepts, rules, algorithms) and conditional knowledge (the understanding of when to employ procedural knowledge and why it is important to do so; Paris, Cross, & Lipson, 1984).

In the context of this study, conceptual understanding is also interpreted as students' ability to apply the learned scientific concepts to scientific phenomena in everyday life situations. This includes, for example, the ability to recognize new information as something different from one's current understanding and beliefs, to identify inconsistencies, and to construct explanations to reconcile knowledge conflicts, or to seek connections among diverse pieces of information (Chan, Burtis, & Bereiter, 1997). Bereiter and Scardamalia (1993) describe these knowledge-processing activities as ''knowledge building,'' which describes the highest form of conceptual understanding.

This study's definition of conceptual understanding is similar to Alao and Guthrie's (1999) definition of conceptual understanding by emphasizing breadth and depth of knowledge. Breadth is related to ''the extent of knowledge that is distributed and represents the major sectors of a specific domain'' and depth to ''the knowledge of scientific principles that describes the relationship among concepts'' (p. 244). But my definition of conceptual understanding goes beyond Alao and Guthrie's term, as it includes not only mastery of concepts in a specific area of science. Alao and Guthrie (1999) characterized conceptual understanding as ''the knowledge of basic ecological concepts and the ability to use ecological principles to construct and explain the interactions within a food chain'' (p. 244). In this study multiple concept areas of the grade 9 chemistry curriculum are the knowledge basis of conceptual understanding (e.g., matter, physical properties and chemical reactions, conservation of mass, redox reactions, particle model, atoms and molecules) and their relationships and interactions are discussed within these concepts and with respect to everyday life phenomena (e.g., burning of candle, tarnish of silver cutlery) and topics in the area of Science, Technology, and Society (e.g., greenhouse effect, waste management and recycling).

In the next three sections I discuss theoretical and empirical considerations for each of the main affect components: interest, self-concept and attitudes.

Interest

Teachers and students alike often complain about the lack of interest in topics, and schooling in general, which results in students' boredom, apathy, and disruptive behavior or, particularly in science, in dropout from advanced science classes. Thus, researchers promoting interest focus on learning environments, features of the task or students' self-regulation strategies in order to alter students' interests (for an overview, see Hidi & Harackiewicz, 2000). In the context of these studies, interest is seen as an individual predisposition and as a psychological state, which is important for cognitive engagement, learning, and achievement (e.g., Ainley, Hidi, & Berndorff, 2002; Eccles, Wigfield, & Schiefele, 1998; Hidi, 1990; Pintrich & Schunk, 2002; Schiefele et al., 1992).

Interest researchers distinguish between three different types of interest: *personal or individual interest*, *situational interest*, and *topic interest* (Ainley et al., 2002; Hidi, 1990; Schiefele, 1998). Typically defined as ''a relatively enduring predisposition to attend to certain objects and events and to engage in certain activities'' (Ainley et al., 2002, p. 545), students' *individual interest* appears in a particular domain such as school subjects (science, history, mathematics), specific activities (music, sport, movies), or as a general interest in learning (Ainley, 1998). It influences students' selective attention, effort, and willingness to persevere in a task, and their activation and acquisition of knowledge (Krapp, Hidi, & Renninger, 1992; Renninger, 1992, 1998, 2000). In contrast, *situational interest* can be generated by particular conditions and/or concrete objects in the environment, for example, in the environment of the ''classroom'' by a certain text, group work, or students' active involvement in class (Mitchell, 1993). The third form of interest, *topic interest*, is trigged by a certain word, sentence, or paragraph (Ainley et al., 2002). Some researchers view topic interest as a form of individual interest (Schiefele, 1996, 1998; Schiefele & Krapp, 1996) as a ''relatively enduring evaluative orientation toward certain topics'' (Ainley et al., 2002, p. 546). Other researchers treat it as having both individual and situational components (Ainley et al., 2002; Renninger, 2000; Wade, Buxton, & Kelly, 1999).

Based on these varying views of interest, this study focuses on students' *situational subject interest* interpreted as an interest that students develop within a particular chemistry context and which is directly tied to the content of instruction and instructional tools (Mitchell, 1993; Schraw, Bruning, & Svoboda, 1995). Thus, over the course of the study, the assessment does not differentiate between the development of topic interest as (a) interest elicited by a text (Ainley et al., 2002), or as (b) an enduring orientation toward certain topics (Schiefele, 1996; Schiefele & Krapp, 1996).

Although various studies have stressed the importance of interest for school learning (Bergin, 1999; Hidi & Berndorff, 1998; Mitchell, 1993), others raise doubt about the importance of interest (Baumert, Schnabel, & Lehrke, 1998). Research investigating these links thus remains tenuous. Ainley and colleagues (2002) looked at the mediating processes from arousal of interest triggered by four different text titles to learning. The authors measured the mediating processes using an interactive computer task that recorded students' affective responses to the texts and their persistence with the text in real-time sequence followed by a test of text comprehension and recall after each text. Results show that both individual interest and specific text titles influenced students' topic interest. Topic interest influenced students' affective responses at the end of each text, affective responses were related to text persistence, and text persistence was then positively related to the test score at the end of each text, which was equated with learning. Although persistence at a task is an important prerequisite for development of meaningful conceptual understanding, such a behavior cannot be equated with learning as it is understood in this study.

Self-Concept and Its Relation to Interest

Individuals have perceptions and beliefs about themselves that are deeply rooted in their past achievement and reinforcement history. Thus, our behavior and actions in present learning situations are influenced by how we construe ourselves, that is, what we believe we are capable of, how we view ourselves in comparison with others, our judgment of how we are viewed by others, how we think we possess our knowledge, and what roles we suppose we are expected to play in learning contexts (Bong & Skaalvik, 2003). Educational psychologists have examined these self-perceptions for decades, and concluded that students with strong and positive self-perceptions set more challenging academic goals for themselves, persist longer on difficult tasks, feel less anxious in achievement situations, and enjoy their academic work more (for an overview, see, e.g., Bong & Skaalvik, 2003; Byrne, 1984; Marsh & Yeung, 1997). In particular, Marsh and Yeung (1997) and Helmke and van Aken (1995) present strong empirical arguments that self-concept leads to higher academic achievement.

The literature distinguishes two related constructs: self-concept and self-efficacy. Researchers in educational psychology often use both constructs interchangeably to explain the function of self in learning contexts, although they describe different functions of self. Self-concept describes a person's general perception of the self in given fields of functioning (Shavelson, Hubner, & Stanton, 1976), while self-efficacy illustrates a person's expectations of what she or he can accomplish in given situations. For example, a student's expectation to achieve an A on her next science test is an efficacy judgment (Bandura, 1986), while the statement "I have always done well in science" is a self-concept judgment (e.g., Marsh, 1986). These two statements illustrate another difference between self-concept and self-efficacy. While self-efficacy is inherently future-oriented because it represents a person's confidence in her/his successful accomplishment of, for example, the approaching science test, self-concept perceptions are past-oriented because relevant experiences need to be processed by self-schemas, which are created from the person's past experiences in science (Bong & Skaalvik, 2003).

Studies looking at students' subject-specific interests in science revealed that physics- and chemistry-specific interest are influenced by students' self-concept of their own achievement in chemistry or physics (e.g., Gräber, 1992; Häußler & Hoffmann, 1995). Other studies highlight a strong relation between self-concept and level of engagement, persistence in classroom activities (Skinner, Wellborn, & Connell, 1990) and achievement (Marsh & Yeung, 1997; Shavelson & Bolus, 1982). In contrast, self-efficacy is related to task choice (Bandura & Schunk, 1981; Pajares

& Miller, 1995), grade goals, and academic aspiration (Bandura, Barbaranelli, Caprara, & Pastorelli, 1996; Zimmerman, Bandura, & Martinez-Pons, 1992). Based on these research results and in light of this study's objective to concentrate on students' meaningful conceptual understanding instead of performance as measured with grades, I look at students' self-concept and its relation to interest, attitudes and conceptual understanding.

Self-concept is not interpreted in this study as a global construct. Instead, a person can be described as having multiple self-concepts; one type is specially formed with respect to academic domains and labeled in the literature as *subject-specific self-concept*. In this study I will concentrate on students' chemistry-specific self-concept, which can be described as students' knowledge and perceptions about themselves in achievement or performance situations in the chemistry classroom (Byrne, 1984; Shavelson & Bolus, 1982; Wigfield & Karpathian, 1991).

Attitudes and Their Relation to Interest and Self-Concept

Among educators and researchers alike, it is commonly assumed that students' attitudes in science influence their science course selections, their learning outcomes, and their future career choice (Koballa, 1988; Laforgia, 1988). Attitudes are, in general, defined as a predisposition to respond positively or negatively to things, people, places, or ideas. Attitude is not a unidimensional construct, but rather a multifaceted framework including affective, cognitive, and behavioral components (Simpson, Koballa, Oliver, & Crawley, 1994) with each component mutually influencing each other in an ongoing process. Attitudes toward science should not be mistaken with scientific attitudes, which as Koballa and Crawley suggest (1985), are more ‘‘aptly labeled scientific attributes’’ (p. 223) and embody ‘‘the characteristics or attributes of scientists that are considered desirable in students’’ (Koballa, 1995, p. 62). The present study concentrates specifically on *attitudes toward chemistry*, which refer to a person's liking or disliking of chemistry, or to having a ‘‘positive or negative feeling’’ (Koballa & Crawley, 1985, p. 223) about chemistry.

Research on attitudes to science is many-sided and includes topics such as students' attitudes toward schooling and different school subjects (e.g., science, mathematics, English); the influence of different instructional strategies on attitudes (e.g., hands-on or cooperative strategies; Freedman, 2002; Gibson & Chase, 2002; Soyibo & Evans, 2002; Wong, Young, & Fraser, 1997); and the influence of attitudes on student achievement. Often variables external to the classroom such as age, gender, ethnicity, and grade level are analyzed to determine their impact on attitudes as well (Greenfield, 1997; Rani, 2000; Sullins, Hernandez, Fuller, & Tashiro, 1995; Weinburgh, 2000).

Researchers in the area of attitudes operationalize attitudes in various ways. Simpson and Oliver (1990) for example, identified three subconstructs of attitudes that are related to achievement: attitudes toward science (enjoyment, interest), achievement motivation (effort), and science self-concept. They showed that science self-concept and achievement motivation were significant predictors of science achievement in 6th through 10th graders. Marsh (1992), using self-concept as one subconstruct of attitudes, reported a strong relationship between self-concept and achievement in eight school subjects. Dalgety, Coll, and Jones' (2003) scale construction for chemistry attitudes among university students included self-efficacy, based on expected performance in the course, rather than chemistry in general. Mattern and Schau (2002) investigated the causal relationships over time between attitudes toward science and science achievement for White middle school students and measured attitudes with three subconstructs:

affect (liking of science), cognitive competence (perceived self-competence of science), and value (usefulness of science). They found that a crosseffect model between attitudes and achievement over time was the best-fitting model. Thus, improvement in science does have an effect on students' attitudes towards science, and positive attitudes towards science also produce better achievement.

Results of research on attitudes toward science demonstrate the close connection between the different affective variables (interest, self-concept, and attitudes) and achievement. As mentioned above, achievement is often equated with results on standardized tests, while this study will measure conceptual understanding and then determine the best-fitting model of possible relationships between these different variables. Although some studies on student attitudes see self-concept as a subconstruct of attitudes (e.g., Dalgety et al., 2003; Mattern & Schau, 2002; Simpson & Oliver, 1990), this study views attitudes more narrowly, retaining self-concept as a separate psychological construct. Another distinguishing feature of my study is that I measure students' attitudes and their emotional response to chemistry as a discipline and not on students' attitudes towards the chemistry class. I also focus on students' chemistry-specific self-concept and not on a general school-specific self-concept.

Hypotheses

Based on this summary of theoretical considerations, there are three core hypotheses:

> Hypothesis 1: Students' situational subject interest will be positively related to subsequent conceptual understanding of chemical concepts.
> Hypothesis 2: Students' chemistry-specific self-concept will be positively related to subsequent conceptual understanding of chemical concepts.
> Hypothesis 3: Students' attitudes towards chemistry will be positively related to subsequent conceptual understanding of chemical concepts.

But how do these variables influence each other? As the review of the literature suggests, there is significant empirical evidence suggesting interrelationships between affect variables. A likely dynamic over time then would involve one of the affect variables acting as a mediating variable in the relationship between affect and conceptual understanding. Figure 1 demonstrates this proposed relationship. This mediating factor would allow not only direct effects on conceptual understanding as predicted in hypotheses 1, 2, and 3 but also indirect effects through some aspects of affect. Although the literature does not suggest a clear hypothesis about which affective variable plays a mediating role, the most likely model of the relationship between conceptual understanding, attitudes, self-concept, and situational subject interest would include self-concept as the mediating variable. This tentative hypothesis is based on solid empirical studies showing a causal link between self-concept and academic achievement in science and other subject areas (Helmke & van Aken, 1995; Marsh & Yeung, 1997) and a large-scale study finding no effect of interest on mathematics achievement (Baumert et al., 1998). Figure 1 reflects such a *multicomponent model* in which #3 self-concept is placed in the dotted ellipse. This suggests a final hypothesis:

> Hypothesis 4: Subject-specific self-concept will play the strongest mediating role of the affective variables considered. That is, at least one of the other affect variables at time 1 will have a positive effect on subject-specific self concept at time 2 and subject-specific self concept at time 2 will in turn have a positive effect on conceptual understanding.

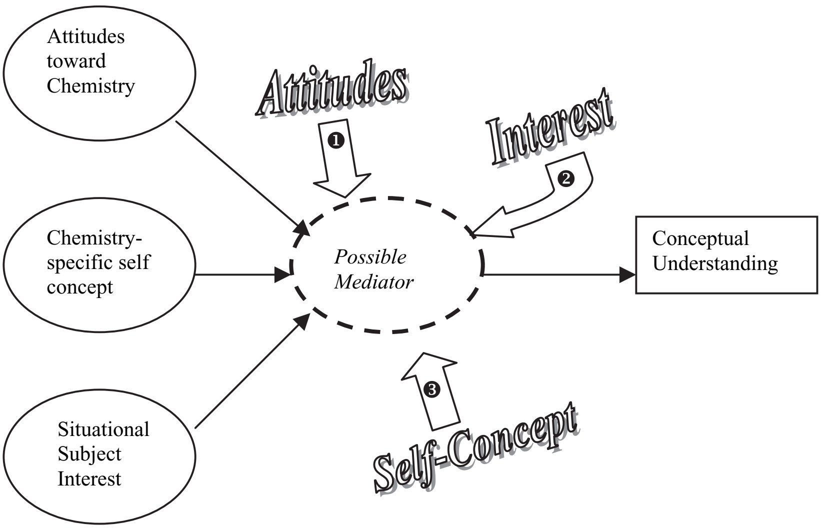


Figure 1. Overview of multicomponent model.

Methodology

Participants

The study took place in four grade 9 classes ($n = 73$) at four German Gymnasiums—a type of secondary school emphasizing university preparation—in a northern Bundesland (trans: State). Two schools were located in small cities (less than 60,000 residents) and two in the capital city of this Bundesland (approximately 120,000 residents). The four chemistry teachers were experienced teachers with at least 10 years of teaching chemistry at the Gymnasium. Two of the teachers had participated in one of my previous research projects; while the other two teachers volunteered to participate with their grade 9 classes after a letter describing the study was sent to all Gynmasiums in the northern Bundesland. At all four schools chemistry was taught in single 45-minute lessons, meeting three times per week. For all participating students (age 15 to 16) this was the first time in their school career that they had chemistry instruction.[1]

Curriculum and Instructional Approach

All four teachers followed the official grade 9 chemistry curriculum of the northern Bundesland in which the study took place. This curriculum focused on two broad, major concepts ‘‘changes of matter’’ and ‘‘the structure and matter of substances’’ (see Elemente Chemie, 1994). The teachers did not base their instruction on an approved textbook, and instead used teaching materials that were developed and field tested at the Leibniz Institute for Science Education (see Stork, Schulz, & Johannsen, 1993; Stork, 1988) reflecting both concepts. These materials were dived into six different teaching units and each teaching unit developed around specific conceptual topic areas: pure substance and mixtures (unit 1); air and combustion (unit 2); metallic oxides, oxidation, and reduction (unit 3); particle or continuum? (unit 4); carbon in gas (unit 5); and atoms and bonding (unit 6) (see Nieswandt, 2001a). These units retained the official content of the grade 9 chemistry curriculum but the pedagogical approach can be best described as mostly student centered. The teachers involved students as much as possible in the development of laboratory procedures throughout the school year and provided students in each unit with problems such as the developing of strategies that would result in minimizing of carbon dioxide emission in their neighborhood. These teaching approaches required students' to reflect on their own prior knowledge (scientific and nonscientific), and reviewing and applying the learned content. Furthermore, each unit contained a large number of hands-on activities. For example, at the beginning of the second teaching unit ''air and combustion,'' students did a series of laboratory exercises on the combustion reaction and related them to their everyday experiences. In following practical work they explored the importance of air for combustion reactions from the perspective of chemists (physical and chemical properties of air), and experienced an important law: conversation of mass. Over the course of the unit, students then discussed and explored with hands-on activities important sources and characteristics of a gas common in everyday life, carbon dioxide, including studying the greenhouse effect.

Two of the participating teachers were familiar with the teaching materials; they were involved in previous projects at the Leibniz Institute for Science Education, which had used these materials as well. I introduced the materials and the student-centered approach to the other two teachers in individual 2-hour workshops. However, differences in teachers' teaching approaches and emphases on certain topics may still arise. To minimize such effects, I met with all four teachers monthly throughout the study discussing the content and instructional methods. This procedure allowed for an adjustment of individual teacher's needs, and at the same time confirmed that each teacher's instruction was comparable with the other teachers' methodology as much as possible. However, in the data analysis that follows, statistical checks showed no significant differences between these four classes. Details of these checks are included as footnotes.

Research Design and Instruments

The lack of studies addressing the interplay of various affective variables on students' meaningful conceptual understanding of science instead of achievement or rote memorization resulted in an experimental research design assessing the variables at two consecutive time points: in the middle of the first semester of grade 9 and at the end of grade 9/beginning of grade 10. This design allows assessing causal effects of the affective variables at an earlier time point on postinstructional conceptual understanding.

A variety of instruments were developed as assessment tools for this study; Table 1 gives an overview of these different instruments. Because none of the students had formal chemistry instruction prior to grade 9, and because interest and self-concept are defined as affects that are closely related to the specific chemistry instruction, I assumed that the students had not developed chemistry-specific situational interests or chemistry-specific self-concepts prior to the start of the instruction. Although students may have been able to express certain attitudes toward chemistry as a discipline based on exposure to various media (TV, newspapers) or listening to adults or older peers, these attitudes may be more diffuse at the beginning of grade 9 then later in the school year after students were exposed to various topics of school chemistry instruction. Therefore, and to assess potential influences of the affective variables at an earlier time point on postinstruction conceptual understanding, all affect questionnaires were administered for the first time in the middle of the first semester (t1) and then at end of the second semester of grade 9 (t2). Questionnaires assessing conceptual understanding were given at all three time points, with data from the end of grade 9 (t2) and at the beginning of grade 10 (t3) analyzed here. Approximately 6 weeks of summer break separated time 2 and time 3.

Table 1
Overview of test instruments throughout the study

Middle of First Semester of Grade 9 t1	End of the Second Semester of Grade 9 t2	Beginning of Grade 10 t3
Situational Interest	Situational Interest	
Chemistry-specific self-concept	Chemistry-specific self-concept	
Attitudes toward chemistry	Attitudes toward chemistry	
	Conceptual understanding	Conceptual understanding

The questionnaire items assessing *conceptual understanding* were tasks pertaining to everyday problems (see Table 2), and the same items were given at t2 and t3. These items were piloted in a previous school year in two other grade 9 classes assessing students' comprehension of the wording and understanding of the contexts. The items' contexts reflect two major chemical concepts that were taught throughout grade 9: ‘‘Changes of matter'' and ‘‘structure and matter of substances.''

The affective constructs were assessed with self-report measures. (See Table 3 for the construct, their indicators, and the items constituting each indicator.). Seven survey items, each on a five-point scale (very well, well, fair, somewhat, not at all), contributed to the *self-concept* construct and were adopted from Gräber's study (1992), which in turn, was based on Jerusalem's study of self-concept (1984). The constructs *situational subject interest* and *attitudes toward chemistry* are each based on 9 and 10 items, respectively, each item on a four-point scale (strongly agree, agree, disagree, strongly disagree). The items assessing students' attitudes toward chemistry were adopted from Müller-Harbich and Wenck (1990a,b), who evaluated students' attitudes toward chemistry as a school subject, as a discipline, and students' attitudes toward environmental problems. The situational subject interest items were based on theories of interest (e.g., Ainley et al., 2002; Mitchell, 1993; Schiefele, 1998) and modified for this study's population from a questionnaire assessing interest in studying in various subjects (Schiefele, Winteler, & Krapp, 1988). Each questionnaire instructed the students that the chemistry-specific self-concept and situational subject interest items referred to the last teaching units, and that the attitudes items referred to their general attitudes towards chemistry independent of affect and conceptual understanding of the current experienced chemistry instruction. I administered all questionnaires, and students were encouraged to ask questions when they did not understand any of the items or the questionnaire instructions.

Table 2
Items of conceptual understanding questionnaires

Variable	Items (*Short Answer*)
Conceptual understanding	Jewelry made of silver and silver cutlery gets black stains after some time. These black stains are not removable by intensive washing. How can you explain these black stains? When you put a few drops of lemon juice into black tea the content of the mug gets visibly lighter. To what fact can you attribute this? During cold nights ice crystals often form on windows, although it did not rain or snow. How can you explain this phenomenon?

Note: the bilingual author translated all items from German into English retaining the German context.

Table 3
Items and indicators of affective constructs

Construct (Abbreviation)	Indicators (Abbreviation)	Items (*Including Scales Dimensions*) *Reverse Coded Item
Situational subject interest (subint)		*Strongly agree , agree, disagree, strongly disagree*
	Enjoyment of chemistry (enjoy)	When I learn something new in chemistry, I am willing to spend my free time on it.
		I would love to have more class periods in chemistry.
		I am looking forward to my chemistry class.
	Emotional/Intrinsic Engagement (engage)	It is fun for me to work at a chemistry problem.
		My chemistry class is the most important thing for me.
		When I am working at a chemical problem it can happen that I do not realize how time flies.
	Motivated meaning (meaning)	It is personally meaningful for me to be a good chemist.
		It is important for me to know a lot in my chemistry class.
		It is important for me to remember the content learned in the chemistry class.
Chemistry-specific self-concept (selfcon)	Confidence of understanding (confid)	*Very well, well, fair, somewhat, not at all*
		I understand/comprehend the content of my chemistry class . . .
		I bear the content of my chemistry class in my mind . . .
	Class contribution (contrib)	I participate in my chemistry class . . .
		I think my classmates believe that I am doing . . . in my chemistry class.
	Achievement appraisal (achapp)	I evaluate my achievement in my chemistry class as . . .
		I think my chemistry teacher evaluates my achievement in my chemistry class as . . .
		I expect my achievement in the chemistry class to be . . . in the future
Attitudes toward chemistry (attit)	Importance of discipline (discimp)	*Strongly agree, agree, disagree, strongly disagree*
		Chemistry is one of the most important disciplines.
		I think chemistry is an unnecessary discipline.*
		We should not spend so much money for research in chemistry.*
		Chemistry plays an important role in my life because I use many products of the chemical industry.
	Personal relevance (relev)	I think we would live healthier without chemistry.*
		Chemistry yields more advantages than disadvantages.
		I think chemical products are very important.
	Importance of chemical products (prodimp)	Today's life would be unthinkable without the results of chemical research.
		We could do without the products of the chemical industry.*

Data Analysis

For this study, answers to the open-ended questionnaire items assessing students' conceptual understanding were scored in one of two predetermined categories:

1. *Everyday descriptions*, which reflect either (a) common everyday conceptions students express in the particular topic area, and which are supported by previous research studies in the area of students' alternative ideas, or (b) failure to include any scientific terms that hint at a beginning of a scientific understanding.
2. *Scientific explanations*, which are comprised of two considerations: (a) the accurate use of scientific terminology to describe cause(s) of the phenomenon in question, with (b) the minimum level of expected sophistication at different time points linked to the grade 9 chemistry curriculum.

Two coders working independently scored all students' answers. Both coders had a science background and were trained using students' answers from the pilot study of the conceptual understanding questionnaire. During the data analysis I met regularly with both raters discussing the scoring process. Discrepancies between the raters were discussed and resolved. This discussion/resolution procedure was repeated until the inter-rater agreement reached 95%. An example of how students' answers were scored into the different categories can be seen in Table 4 (see also Nieswandt, 2001a,b, for further information).

A clear limitation in this study is the way in which the index of conceptual understanding was constructed. Based on the coding of written answers, several of the items (not listed) proved too

Table 4
Examples of students' answers and its scoring in two different categories

Categories	Student Answers at Different Time Points (*Abbreviated Items*)
Everyday descriptions	*Why does silver get black stains?* • The silver reacts with the air. (t2) • The air made the stains on the cutlery. (t3) *Why does lemon juice lighten black tea?* • The lemon juice is light colored and the tea is black; mixing of a lighter color with the tea makes the tea lighter. (t2) • The lemon juice mixes with the tea (diffusion) and because the lemon juice is much lighter than the black tea a "mixed color" resumes. (t3) *Why do ice crystals form even if it hasn't rained or snowed?* • The humidity of the air comes together with the coldness of the widows. (t2) • Plants give up humidity, which drops on the window. (t3).
Scientific explanations	*Why does silver get black stains?* • Silver oxidizes, that means it reacted with oxygen. It is silver oxide. (t2) • Silver is less reactive, because it is a noble metal, but it oxidizes at the air (first only the outer layer). (t3) *Why does lemon juice lighten black tea?* • The lemon juice reacts with the black tea. The product has other properties. (t2) • The lemon contains lemon acid, which reacts with the tea. A new product results. (t3) *Why do ice crystals form even if it hasn't rained or snowed?* • The air contains humidity, which freezes on the window at low temperatures. (t2) • The humidity of the air condensates on the window, which is cooled by the air. There the little droplets freeze to little "flowers". (t3)

difficult for students, such that no students gave a scientific explanation, or only one or two students did. Therefore, out of five original conceptual understanding items, two of the items were dropped due to limited or no variance. As a result, to have sufficient number of items measuring conceptual understanding, the index was constructed as the percentage of scientific explanations given for three conceptual understanding items from time 2 (end of grade 9) *and* the same three conceptual understanding items from time 3 (beginning of grade 10). Ideally, conceptual understanding should be measured entirely *after* the affective characteristics are measured (i.e., time 3) to assess the direction of possible causal relationships unfolding over time (Davis, 1985). In analyses not shown, however, similar early measures of conceptual understanding (at time 1) had no significant effect on affective characteristics (at time 2), suggesting that the most plausible causal direction is as tested in these models, with affect influencing conceptual understanding rather than the reverse. There were no significant differences between chemistry classes/teachers in conceptual understanding.

Descriptive statistics for all observed affective variables are shown in Appendix 1.[2] Reliability of each of the indicators as listed in Table 3 was assessed using Cronbach's alpha. For all indicators except ''Importance of Chemical Products,'' alphas ranged between .70 and .83, with five indicators having alphas greater than .80. The index ''Importance of Chemical Products'' had a low alpha (.41), in part due to the fact that it is based on only two items. Exploratory factor analysis showed that items loaded strongly and positively on a single factor, suggesting that the decision to combine items to form these indicators was appropriate. For all indicators, skewness and kurtosis measures are within acceptable limits ($+1.5$ to -1.5).

A structural equation modeling (SEM) approach was used to address the research questions of this study statistically. This analysis strategy was chosen because the data set contains multiple indicators of most of the key variables. In brief, a structural equation model has two parts. The first part is the measurement model, which estimates how the measured indicators load on their respective conceptual factors (or latent variables). The second part is the structural model, which estimates how the set of latent variables and any single measure, nonlatent variables relate to one another. The SEM approach makes full use of the multiple indicators but it is also a more robust modeling strategy than the two-step index construction and regression technique often presented in similar studies. It explicitly takes measurement error into account in the estimation process, statistically modeling what all researchers know: our measures aren't perfect.

SEM allows measured ''indicators'' to contribute with varying strength to the more conceptual latent variables, and intercorrelations among and between error terms, indicators, and latent variables can be estimated. Moreover, this statistical method can also take into account correlation among measures over time (Arbuckle & Wothke, 1999; Bollen, 1989). This approach may highlight subtle effects not shown in ANOVA or ordinary least squares regression results. Because SEM does not require stringent assumptions (e.g., zero correlations between independent variables), SEM estimates are less likely to be biased than ordinary least-squares regression results. The software package AMOS was used to calculate generalized least-squares estimates for the structural equation models. Schumacker and Lomax (2004) suggest that the generalized least-squares approach is more appropriate than maximum likelihood under conditions of nonnormality.

Before proceeding to the results, the overall analytical strategy should be reviewed. As Figure 1 indicates, the analysis addresses whether any of the affective characteristics, attitudes toward chemistry, chemistry-specific self-concept, or situational subject interest, plays a mediating role to influence conceptual understanding. As such, each of the models tested here uses different latent variables as the mediator, and so the models are not nested in one another—one model is not simply the same as the previous model with the addition of one or more parameters. Therefore, it is not possible to compare directly the fit of one model to another. The analytical strategy here is to specify models that fit the data appropriately (using both theoretical considerations and modification index diagnostics provided by AMOS), and then compare patterns of significant effects at the structural level. Decisions about whether to include correlated errors in each model were based in the first instance on theoretical concerns. For example, initial models included correlated errors between indicators measured at different time points, such as ‘‘importance of discipline’’ measured at time 1 and ‘‘importance of discipline’’ measured at time 2. If these correlations were not significant, they were dropped in subsequent modeling attempts. Other correlated error parameters were added to models if the modification index suggested significant improvements in model fit. Thus, the goal here is not to find a single ‘‘correct’’ model, but to decide which if any of these affective characteristics is most likely to play a mediating role in the development of conceptual understanding.

Results

Direct Effects on Conceptual Understanding

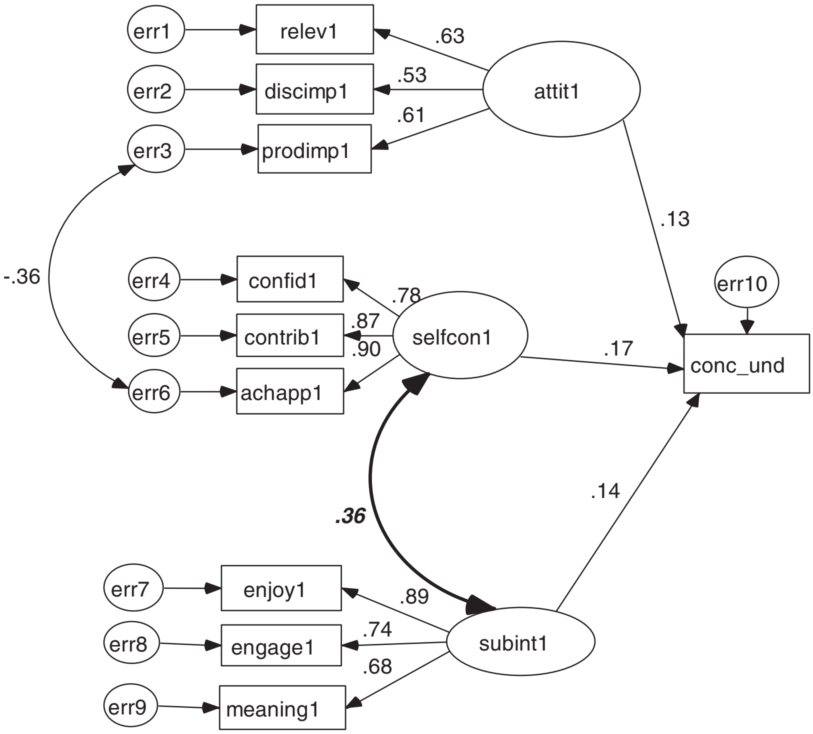
The first model to be tested is the basic model of the effects of attitudes toward chemistry, chemistry-specific self-concept, and situational subject interest (all measured at t1) on the index of subsequent conceptual understanding. The standardized results of the basic model are depicted in Figure 2, with unstandardized estimates, fit statistics, and other details shown in Table 5. The dependent variable ‘‘conceptual understanding’’ is the percentage of scientific answers at the posttreatment measure at the end of grade 9 and beginning of grade 10 (t2 and t3 combined, six items total). Unlike the constructs of attitudes, self-concept, and situational interest, in this and subsequent models, the dependent variable is not a latent variable; it is a direct measure of understanding in the different conceptual topic areas. In the diagram in Figure 2 and subsequent models, standard conventions are used, so that latent variables are shown in ellipses, while direct measures are shown in rectangles. Straight arrows represent paths showing direct effects, while curved arrows indicate correlations. As discussed above, an important advantage of the structural equation approach is the capacity to model error, that is, to estimate measurement error rather than assuming that it does not exist. Error terms included in the model are indicated with circles.

The basic model has a reasonable fit based on several different fit statistics ($\chi^2 = 26.8$, $df = 31$, $p = .68$; Comparative Fit Index (CFI) = 1.00, and Root Mean Square Error of Approximation (RMSEA) = .000, although some weakness in fit is reflected in the Parsimony-adjusted Comparative Fit Index (PCFI) = .69).[3] At the measurement level, all indicators load in the expected direction, with statistical significance. Turning to the structural results, however, no long-term direct influence is found for any of these constructs on conceptual understanding.

The latent variable that comes closest to having a statistically significant effect on conceptual understanding is chemistry-specific self-concept ($\beta = .17$ (standardized estimate), $b = .021$ (unstandardized estimate), $p = .22$), although an inspection of the standardized path coefficients in Figure 2 suggests that all long-term impacts of affect on conceptual understanding are weak. A significant structural effect that is retained in subsequent models is the correlation between self-concept and situational subject interest ($r = .36$, $p = .026$).[4]

Mediated Effects on Conceptual Understanding

In the next models, the following question is investigated: given no long-term direct influence of these constructs on conceptual understanding, which (if any) of these constructs serves as a



Legend:

relev:	Personal Relevance	discimp:	Importance of Discipline
prodimp:	Importance of Chemical Products	attit:	Attitudes toward Chemistry
confid:	Confidence of Understanding	contrib:	Class Contribution
achapp:	Achievement of Appraisal	selfcon:	Self-Concept
enjoy:	Enjoyment of Chemistry	engage:	Emotional/Intrinsic Engagement
meaning:	Motivated Meaning	subint:	Situational Subject Interest
conc_und:	Conceptual Understanding	err:	Error

Figure 2. Standardized estimates for basic model of influence of affective domain at time 1 on conceptual understanding with no mediator (generalized least-squares estimates, $n = 73$, statistically significant structural paths in bold).

mediating influence on conceptual understanding? All three affect variables are considered as intermediary constructs.

Attitudes as a Mediating Construct. Figure 3 and Table 6 consider the possibility that attitudes toward chemistry as a discipline function as the intermediary construct. In this model, t2 measures of attitudes mediate the influence of t1 measures of attitudes, self-concept, and situational subject interest. In turn, the latent variable of attitudes at t2 is allowed to have an effect on conceptual understanding. In addition to the mediating effects, self-concept and situational interest at t1 are allowed to have direct effects on subsequent conceptual understanding.

The results shown in Figure 3 and Table 6 suggest that attitudes toward chemistry, as measured here, are unlikely to play an important mediating role in the development of conceptual understanding. Although the overall model shows a good fit to the data ($\chi^2 = 49.9$, $df = 57$, $p = .74$; CFI = 1.00, PCFI = .73, and RMSEA = .00), and the measurement model is solid,[5] the

Table 5

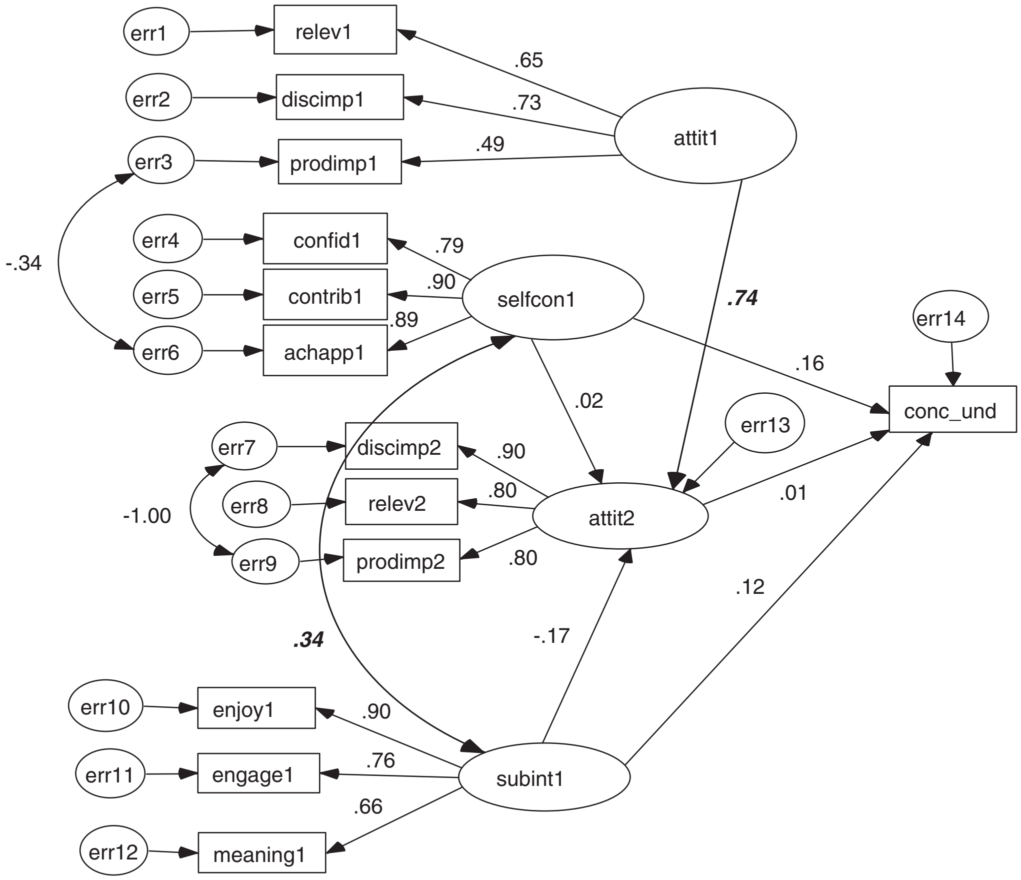
Basic structural equation model of influence of affective domain on conceptual understanding (see figure 2)

Path	Loading		Standard Error	Critical Ratio		p Value
Measurement model						
Attitudes toward chemistry (t1)						
Importance of discipline (discimp1)	1.00					
Personal relevance (relev1)	0.90		0.36	2.50		.01
Importance of chemical products (prodimp1)	0.78		0.34	2.29		.02
Self-concept (t1)						
Achievement appraisal (achapp1)	1.00					
Class contribution (contrib1)	0.68		.081	8.36		<.001
Confidence of understanding (confid1)	0.58		.080	7.24		<.001
Situational subject interest (t1)						
Enjoyment of chemistry (enjoy1)	1.00					
Emotional/intrinsic engagement (engage1)	0.78		.15	5.11		<.001
Motivated meaning (meaning1)	0.62		.13	4.84		<.001
Structural model						
Attitudes (t1) → conceptual understanding (t3)	0.029		0.036	0.80		.42
Self-concept (t1) → conceptual understanding (t3)	0.021		0.017	1.21		.23
Situational subject interest (t1) → conceptual understanding (t3)	0.018		0.018	.97		.33
Self-concept (t1) ↔ situational subject interest (t1)	1.28		.58	2.22		.026
Fit indices	χ^2	*df*	p	CFI	PCFI	RMSEA
	26.8	31	.68	1.00	.69	.00

structural model shows very weak effects of intermediate attitudes on conceptual understanding ($\beta = .01$, $b = .001$, $p = .96$). Moreover, early self-concept and situational interest do not have statistically significant effects on chemistry attitudes at time 2. The model does show that attitudes toward chemistry are fairly stable in that the attitudes construct at t1 has a significant effect on attitudes at t2 ($\beta = .74$, $b = .81$, $p < .001$). As in the basic model, self-concept and situational interest at time 1 do not have significant effects on subsequent conceptual understanding. Also, the constructs of self concept and situational interest at t1 are again significantly correlated with each other ($r = .34$, $p = .036$). Comparing standardized coefficients in Figure 3 underscores that the influence of attitudes toward chemistry at time 2 is virtually nonexistent even relative to the weak effects of self-concept and situational interest.

Clearly, then, there is no empirical support for a process in which the array of affect variables contributes to stronger attitudes toward chemistry, which in turn, produces improved conceptual understanding.

Interest as a Mediating Construct. If attitudes toward chemistry do not play a mediating role, perhaps situational interest does. The model shown in Figure 4 and Table 7 investigates that possibility. Once again, the model fits well ($\chi^2 = 53.1$, $df = 55$, $p = .55$; CFI = 1.00, PCFI = .71, and RMSEA = .00), and the measurement model is fairly strong, though showing some weakness in the indicators of attitudes toward chemistry (t1). Results here show that situational subject interest is a stable characteristic, with subject interest at t1 having strongly positive and very significant effects on the intermediate construct of situational subject interest at t2 ($\beta = .51$, $b = .45$, $p = .001$). Attitudes towards chemistry have a weakly positive, although not statistically significant effect on subsequent situational subject interest at t2 ($\beta = .28$, $b = .50$, $p = .15$) and self-



Legend:
relev: Personal Relevance
prodimp: Importance of Chemical Products
confid: Confidence of Understanding
achapp: Achievement of Appraisal
enjoy: Enjoyment of Chemistry
meaning: Motivated Meaning
conc_und: Conceptual Understanding
discimp: Importance of Discipline
attit: Attitudes toward Chemistry
contrib: Class Contribution
selfcon: Self-Concept
engage: Emotional/Intrinsic Engagement
subint: Situational Subject Interest
err: Error

Figure 3. Standardized estimates for model of influence of affective domain on conceptual understanding with attitudes toward chemistry as mediator (generalized least-squares estimates, $n = 73$, statistically significant structural paths in bold).

concept at t1 has no effect on situational interest at t2 ($\beta = .13$, $b = .096$, $p = .27$) once the within time point correlation between situational interest and self-concept is controlled ($r = .26, p = .12$). Importantly, however, in this model there is finally a significant influence on conceptual understanding—situational subject interest at t2 has a strong positive effect ($\beta = .37$, $b = .058$, $p < .01$). Hence, this model does not suggest that situational subject interest acts as a mediator of the broader affective influences from time 1, because only early situational subject interest impacts intermediate situational subject interest. The model does suggest, however, that situational interest has a direct effect on conceptual understanding, but it does so over the shorter term.

Table 6

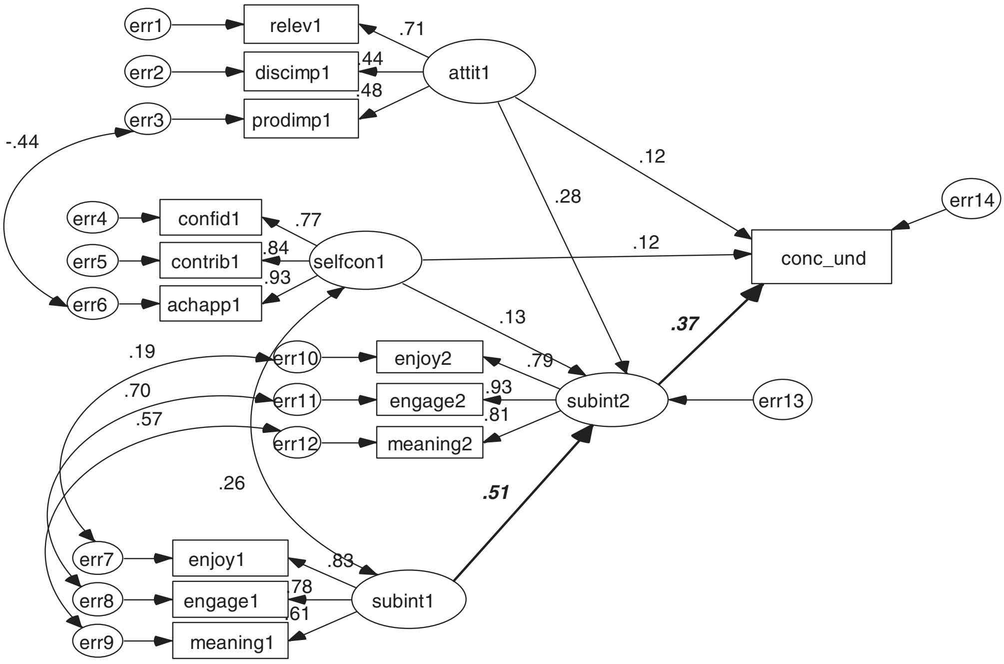
Model of influence of affective domain on conceptual understanding with attitudes toward chemistry as mediator (see figure 3)

Path	Loading	Standard Error	Critical Ratio	*p* Value
Measurement model				
Attitudes toward chemistry (t1)				
Importance of discipline (discimp1)	1.00			
Personal relevance (relev1)	0.63	.18	3.54	<.001
Importance of chem. products (prodimp1)	0.44	.15	2.95	.003
Self-concept (t1)				
Achievement appraisal (achapp1)	1.00			
Class contribution (contrib1)	0.73	.085	8.62	<.001
Confidence of understanding (confid1)	0.59	.079	7.44	<.001
Situational subject interest (t1)				
Enjoyment of chemistry (enjoy1)	1.00			
Emotional/intrinsic engagement (engage1)	0.78	.15	5.16	<.001
Motivated meaning (meaning1)	0.59	.12	4.73	<.001
Attitudes toward chemistry (t2)				
Importance of discipline (discimp2)	1.00			
Personal relevance (relev2)	0.72	.14	5.23	<.001
Importance of chem. products (prodimp2)	0.63	.12	5.20	<.001
Structural model				
Self-concept (t1) → attitude (t2)	0.014	.098	.14	.89
Situational subject interest (t1) → attitude (t2)	−0.14	.099	−1.40	.16
Attitude (t1) → attitude (t2)	0.81	.21	3.85	<.001
Self-concept (t1) ↔ situational subject interest (t1)	1.18	.56	2.10	.036
Attitude (t2) → conceptual understanding (t3)	0.001	.018	.046	.96
Self-concept (t1) → conceptual understanding (t3)	0.020	.017	1.12	.26
Situational subject interest (t1) → conceptual understanding (t3)	0.014	.018	.79	.43

Fit indices	χ^2	*df*	*p*	CFI	PCFI	RMSEA
	49.9	57	.74	1.00	.73	.00

Self-Concept as a Mediating Construct. Figure 5 and Table 8 look at the final possibility that chemistry-specific self-concept functions as a mediating construct. Like the previously presented models, this model has an acceptable fit ($\chi^2 = 45.2$, $df = 57$, $p = .87$; CFI = 1.00, PCFI = .73, and RMSEA = .00). The measurement model shows loadings that are as expected, again with somewhat low loadings for the indicators of attitudes toward chemistry at time 1.

In this model, we find evidence that chemistry-specific self-concept acts as a true mediator in that both early self-concept and early situational interest contribute to intermediate self-concept, which in turn, has a positive effect on conceptual understanding. Attitudes toward chemistry at time 1 neither have an impact on intermediate self-concept nor on subsequent conceptual understanding. However, the mediating role shown in the structural model is clear: self-concept (t1) stabilizes through t2 ($\beta = .52$, $b = .51$, $p < .001$), in combination with situational interest (t1) positively influencing self-concept at t2 ($\beta = .47$, $b = .51$, $p < .001$), culminating in intermediate self-concept having a positive effect on the index of conceptual understanding ($\beta = .50$, $b = .058$, $p < .01$). Note as well in Figure 5 that the standardized coefficients show that the relative contribution of subject interest at t1 to self-concept at t2 is nearly equal to that of early self-concept on later self-concept. This promising dynamic appears even after controlling for initial correlation between situational subject interest and self-concept at time 1 ($r = .34$, $p = .039$).[6]



Legend:
relev: Personal Relevance
prodimp: Importance of Chemical Products
confid: Confidence of Understanding
achapp: Achievement of Appraisal
enjoy: Enjoyment of Chemistry
meaning: Motivated Meaning
conc_und: Conceptual Understanding
discimp: Importance of Discipline
attit: Attitudes toward Chemistry
contrib: Class Contribution
selfcon: Self-Concept
engage: Emotional/Intrinsic Engagement
subint: Situational Subject Interest
err: Error

Figure 4. Standardized estimates for model of influence of affective domain on conceptual understanding with situational subject interest as mediator (generalized least-squares estimates, $n = 73$, statistically significant structural paths in bold).

Summary

The results of the four models show that although there is no long-term *direct* influence of affect on conceptual understanding, there are more complicated processes unfolding over time that contribute to meaningful conceptual understanding. The third model suggests that although situational subject interest has no long-term unmediated effects, situational subject interest does have shorter term, positive effects on conceptual understanding (hypothesis 1 partially supported). None of the models show statistically significant effects of attitudes on conceptual understanding (hypothesis 3 not supported).

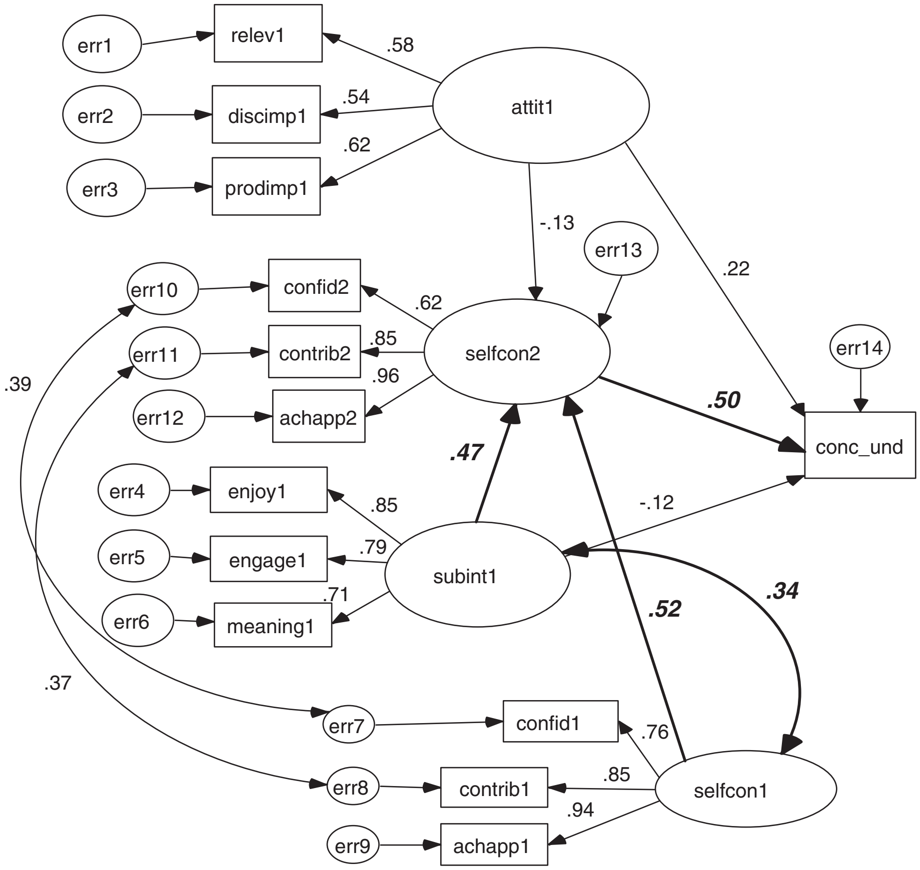
The final model (Figure 5 and Table 8) highlights a more broadly mediating role of chemistry-specific self-concept in which initial situational subject interest stimulates better self-concept that ultimately results in greater conceptual understanding (hypothesis 2 partially supported, hypothesis 4 supported). Even if situational interest is not perfectly sustained through the school year, early situational subject interest may generate ongoing positive self-concept, which has been shown here to have a positive effect on conceptual understanding.

Table 7

Model of influence of affective domain on conceptual understanding with situational subject interest as mediator (see figure 4)

Path	Loading	Standard Error	Critical Ratio	*p* Value
Measurement model				
Attitudes toward chemistry (t1)				
Importance of discipline (discimp1)	1.00			
Personal relevance (relev1)	1.21	.63	1.93	.054
Importance of chem. products (prodimp1)	0.79	.41	1.94	.052
Self-concept (t1)				
Achievement appraisal (achapp1)	1.000			
Class contribution (contrib1)	0.61	.078	7.81	<.001
Confidence of understanding (confid1)	0.51	.075	6.83	<.001
Situational subject interest (t1)				
Enjoyment of chemistry (enjoy1)	1.00			
Emotional/Intrinsic engagement (engage1)	.94	.20	4.62	<.001
Motivated meaning (meaning1)	.57	.13	4.36	<.001
Situational subject interest (t2)				
Enjoyment of chemistry (enjoy2)	1.00			
Emotional/intrinsic engagement (engage2)	1.08	.16	6.73	<.001
Motivated meaning (meaning2)	0.90	.13	6.83	<.001
Structural model				
Self-concept (t1) → situational subject interest (t2)	0.096	.086	1.11	.27
Situational subject interest (t1) → situational subject Interest (t2)	0.45	.14	3.24	.001
Attitude (t1) → situational subject interest (t2)	0.50	.34	1.46	.14
Self-concept (t1) ↔ situational subject interest (t1)	0.83	.53	1.56	.12
Attitude (t1) → conceptual understanding (t3)	0.033	.052	.64	.52
Self-concept (t1) → conceptual understanding (t3)	0.014	.015	.92	.36
Situational subject interest (t2) → conceptual understanding (t3)	0.058	.021	2.74	.006
Fit indices	χ^2 *df*	*p*	CFI PCFI	RMSEA
	53.1 55	.55	1.00 .71	.00

Some circumspection is in order. First, and as noted previously, the dependent variable, conceptual understanding, is an index constructed using items over two time periods, the end of grade 9 and the beginning of grade 10. Ideally, conceptual understanding would be measured with more items at a single time point *after* affect characteristics are assessed. Second, the absence of significant effects of attitudes toward chemistry may well be due to the relative weakness of the measurement of this construct, which is evident, for example, in the lower standardized estimates for the indicators of attitudes compared to those of chemistry-specific self-concept and situational subject interest. Although a strength of the analysis is that it assesses contributions to conceptual understanding *over time*, the complexity of the models given a relatively sample size is a concern (Ding, Velicer, & Harlow, 1995). A small sample size can lead to reductions in statistical power (leading to failure to detect significant effects) and compromised stability of estimates (Schumacker & Lomax, 2004). All the SEM models presented here were recalculated in analogous ordinary least-squares regressions, however, and the pattern of significant and nonsignificant paths was precisely the same in all cases, which suggests an acceptable level of stability in the estimates. The small number of cases precluded estimates of a considerably more complicated model, one in which all three affect constructs are included as mediators. The ability



Legend:

relev:	Personal Relevance	discimp:	Importance of Discipline	achapp:	Achievement of Appraisal
prodimp:	Importance of Chemical Products	attit:	Attitudes toward Chemistry	selfcon:	Self-Concept
confid:	Confidence of Understanding	contrib:	Class Contribution	enjoy:	Enjoyment of Chemistry
engage:	Emotional/Intrinsic Engagement	meaning:	Motivated Meaning	subint:	Situational Subject Interest
conc_und:	Conceptual Understanding	err:	Error		

Figure 5. Standardized estimates for model of influence of affective domain on conceptual understanding with chemistry-specific self-concept as mediator (generalized least-squares estimates, $n = 73$, statistically significant structural paths in bold).

to estimate such a model, however, would allow more direct comparisons between models, because the series of models could be seen as nested.

Conclusions and Implications

The purpose of this study was to develop an understanding of how affective variables such as situational subject interest, chemistry-specific self-concept, and attitudes toward chemistry influence conceptual understanding over time of two major chemical concepts: "changes of matter" and "structure and matter of substances." The findings demonstrate a first and by no means comprehensive understanding of the importance of students' chemistry-specific self-concept and their situational subject interest in developing a meaningful conceptual understanding. In general, a solid perception of themselves as doing well in chemistry, which is based on

Table 8
Model of influence of affective domain on conceptual understanding with self-concept as mediator (see figure 5)

Path	Loading	Standard Error	Critical Ratio	p Value
Measurement model				
Attitudes toward chemistry (t1)				
Importance of discipline (discimp1)	1.00			
Personal relevance (relev1)	0.83	.35	2.38	.018
Importance of chem. products (prodimp1)	0.76	.35	2.17	.030
Self-concept (t1)				
Achievement appraisal (achapp1)	1.00			
Class contribution (contrib1)	0.63	.070	9.05	<.001
Confidence of understanding (confid1)	0.53	.071	7.50	<.001
Situational subject interest (t1)				
Enjoyment of chemistry (enjoy1)	1.00			
Emotional/Intrinsic engagement (engage1)	0.89	.15	5.86	<.001
Motivated meaning (meaning1)	0.67	.12	5.30	<.001
Self-concept (t2)				
Achievement appraisal (achapp2)	1.00			
Class contribution (contrib2)	0.63	.068	9.32	<.001
Confidence of understanding (confid2)	0.38	.070	5.42	<.001
Structural model				
Self-concept (t1) → self-concept (t2)	0.51	.098	5.20	<.001
Situational subject interest (t1) → self-concept(t2)	0.51	.13	4.07	<.001
Attitude (t1) → self-concept (t2)	−0.23	.22	−1.09	.28
Self-concept (t1) ↔ situational subject interest (t1)	1.14	.56	2.06	.039
Attitude (t1) → conceptual understanding (t3)	0.047	.039	1.22	.22
Self-concept (t2) → conceptual understanding (t3)	0.058	.022	2.65	.008
Situational subject interest (t1) → conceptual understanding (t3)	−0.014	.024	−0.60	.55
Fit indices	χ^2 *df*	*p*	CFI PCFI	RMSEA
	45.2 57	.87	1.00 .73	.00

previous positive perceptions of success in the chemistry class (self-concept at time 1), and which is supported by strong interest in various chemistry contexts, results in students' meaningful conceptual understanding. According to the analysis presented here, this process is not linear. There appears to be a kind of "value added" when early situational interest accompanies ongoing strong self-concept. Similarly nonlinear dynamics have been suggested by other researchers and seem necessary in the long run for students' successful scientific understanding of chemistry concepts (Bong & Skaalvik, 2003).

The finding that subject-specific self-concept plays a key role, among affective characteristics, in the development of understanding supports previous research (e.g., Häußler & Hoffmann, 2000; Helmke & van Aken, 1995; Marsh & Yeung, 1997). The results here extend the literature by taking meaningful conceptual understanding as the dependent variable, and by examining the influence of affect longitudinally.

Students' stable and positive chemistry-specific self-concept throughout the school year reflects their ongoing satisfaction and self-esteem in the chemistry class. Because the students did not have chemistry prior to starting grade 9, I can assume that they developed a chemistry-specific self-concept during the duration of the course. With this in mind, it seems that their strong and stable self-concept is closely related to the content of the course and to the teachers' instructional methodology. The student-centered teaching approaches allowed students to actively participate in the classroom, which then may have supported students' perception of doing well in chemistry. This result should be treated with caution, however. Because students had other science courses such as biology and physics in previous grades, they would have had biology- and physics-specific self-concepts, which then may have influenced the development of their chemistry-specific self-concept. Furthermore, students might have developed a generalized science self-concept, a self-concept that goes across all science disciplines and may be based on inquiry and problem-solving opportunities. Students may perceive themselves as doing well in science because all these subjects foster curiosity about natural phenomena, facilitate observation, exploration, and discussion of scientific phenomena, and include hands-on activities. Being exposed to instruction that focuses on these intrinsic motives may have catalyzed students' positive chemistry-specific self-concept. More in-depth research is necessary to explore not only the prominence of such a general science self-concept, which may be best described as an *inquiry self-concept*, but also how *discipline-specific science self-concepts* influence each other and students' conceptual discipline-specific understanding.

A secondary finding is that students' situational subject interest is a stable characteristic throughout the school year and has a direct effect on conceptual understanding, but it does so only over the shorter term (see Figure 4). This result indicates that arousing situational interest early is not sufficient for long-term conceptual understanding; it must be sustained over time. The final model with self-concept as a mediating construct (see Figure 5) underlines this finding. This model, as well as Figure 3, ultimately suggests that efforts to build positive attitudes toward chemistry generally are not so important because attitudes (as measured here) do not reliably contribute to either situational interest, subject-specific self-concept, or to conceptual understanding.

Classrooms are learning environments in which teachers can stimulate situational interest through external factors such as specific teaching situations and/or interesting lesson topics or more specifically, in a chemistry classroom, through demonstrations or laboratory activities. All teaching units of this study integrated hands-on activities and real world applications aimed at stimulating students' situational interest. The short-term effect of situational interest on conceptual understanding suggests the vital importance of not only triggering and "catching" positive interest (Hidi, 2000), but also maintaining positive interest throughout the school year. Figure 4 does suggest some stability in situational interest, but this could reflect inherent stability, that interest can be "stocked" within an individual student, or it could reflect the innovative, consistently hands-on, student-centered curriculum used in the study. Mitchell (1993), for example, stresses that holding an individual's situational interest requires learning conditions that make the content meaningful with respect to students' actual and future oriented goals and motives. Educational psychologists emphasize that such goals and motives are multifaceted and range from mastery goal orientation (desire to learn and comprehend the content), performance orientation (desire to demonstrate competence) to instrumental goals (desire to learn because of future career aspirations) and social goals (desire to be with friends) (e.g., Harackiewicz, Barron, Pintrich, Elliot, & Thrash, 2002; Pintrich, 2003.) Although this study did not look specifically at students' goal orientation, the results indicate that students interpreted the learning opportunities that the teacher provided as a "meaningful learning episode" (Boekaerts, 1999, p. 42). Thus, students' goals and motives in all their possible variations seem to be in alliance with the learning conditions. Clearly, more research is necessary looking at the relationship of specific learning conditions, students' goals, affects, and conceptual understanding.

Both results have implications for the development of optimal learning situations. All four teachers involved in this study strove for a student-centered approach through engaging students in various laboratory activities, teacher demonstrations, and providing applications of scientific concepts in everyday life through topics such as Greenhouse effect, sewage treatment, or redox reactions in everyday life (e.g., copper roofs, rusting of iron products). The teachers involved students regularly in the development of laboratory procedures and provided their students with problems without a procedure to resolve it (e.g., develop strategies to reduce the carbon dioxide production and emission in your neighborhood). This student-centered approach was implemented throughout the school year to avoid the familiar pattern of energetic school year starts, full of hands-on activities and insistence on student participation, followed by mid-year lulls, weighted down with rote preparation for standardized tests and textbook-based exercises, any influence of early efforts to generate positive affect on conceptual understanding dissipates by the end of the year. Although the study did not focus on the implemented instruction, its results hint at the importance of a student-centered approach: Developing and sustaining students' individual interest and subject-specific self-concept seem to correspond with hands-on and personally relevant teaching approach, which at the same time provides students with the sense of ownership over their learning and fosters their sense of independent mastery (self-concept.) Presenting science as a stable body of expert knowledge and employing students in recipe-like laboratories will quite likely discourage them from coming up with their own investigations and explanations (Schwab, 1962), which then may negatively influence situational interest, and eventually subject-specific self-concept. In short, the findings in this study generally justify the use of student-centered pedagogical approaches even if such approaches influence conceptual understanding only indirectly through bolstering of situational interest and self-concept.

Although this study found that attitudes toward chemistry as a discipline had no statistically significant effects on conceptual understanding, it cannot be ruled out that attitudes would have an effect, if other measures of attitudes were used or different teaching strategies or topics were employed. More research is needed to better conceptualize and measure attitudes toward science and specific science disciplines. It seems important to recognize that attitudes toward chemistry and science in general are also shaped by nonschool influences (e.g., media, peers, parents), especially with respect to controversial topics such as evolution or genetic engineering, and therefore, should be considered in future research tracing the influence of specific pedagogical and curricular strategies on attitudes. In addition, results of studies investigating the effect of various instructional methods (e.g., cooperative learning vs. lecture methods; Soyibo & Evans, 2002) or the long-term impact of inquiry-based learning on attitudes toward science (e.g., Gibson & Chase, 2002) hint that these different classroom-based variables need to be considered in further research on the interplay of affective variables and conceptual understanding.

Future research should also go beyond affect to address the role of *engaged behavior*. This component includes engagement and persistence in classroom activities (Skaalvik & Rankin, 1995, 1996), help-seeking behavior (Ames, 1983, 1992), active participation in class, asking content-related questions, completing homework regularly and doing more than what is required. Such an engaged behavior is likely to reflect situational subject interest, which as the result of this study indicates, is likely to influence self-concept, which then may have a positive effect on students' conceptual understanding. Further investigation is necessary to understand these effects.

Affect (e.g., interest, self-concept, attitudes), engaged behavior, and conceptual understanding may be related, in the aggregate, to a *participatory classroom climate*, a climate that takes students' participation seriously throughout the course (e.g., inviting and responding to student questions) and not only when it is convenient for the teacher. Such a classroom climate may also achieve other aims, for example, improving social skills. A *responsive classroom climate* may positively influence affect by engendering among students the feeling and certainty that their learning needs are seriously taken into consideration, with the teacher reacting flexibly based on her/his students needs. More concrete descriptions of such classroom climates should be developed in future studies, which would have to be intensively classroom-based, combining self-reports with systematic observation of the teacher as well as interactions between teacher and students and among students themselves. Such studies might reveal that *teaching style* is more vital when student affect is taken into account than a specially designed curriculum. The present study did not focus on either the teacher or the specially designed curriculum, although the implementation of the curriculum was quite homogeneous across classes.

The close connection between interest and self-concept found in this study supports previous research (e.g., Todt & Schreiber, 1998), but more research is necessary to gain deeper understanding of this connection, aside from the impact on science learning. In particular, a research design for the purpose of testing possible bidirectional (i.e., nonrecursive) relationships should include considerably more cases than the presented study, and additional measures to act as instruments (Arbuckle & Wothke, 1999).

Finally, I have advocated the development and use of appropriate measures of conceptual understanding, measures that reflect the ability to make connections between various pieces of information (individual concepts), to apply the newly learned information to everyday life phenomena and to explain in ones' own words. The measure of meaningful conceptual understanding used in this study certainly has deficits, but it represents a step forward. The distinction between "academic achievement," which also often involves rote memorization and other forms of lower level knowledge, and what I call "meaningful conceptual understanding" is not merely semantic. The National Science Board survey shows a quarter of respondents believe in astrology, with double-digit growth in belief in the paranormal (National Science Board, 2004). Developing meaningful conceptual understanding can counteract trends such as this. Students who develop conceptual understanding are more likely to retain it compared to rote memorization. The ability to make links between concepts and see applications in everyday life are key components of students' scientific literacy. This, in turn, may result in a more scientifically knowledgeable citizenry and in a decrease of beliefs in pseudoscience such as astrology and the paranormal.

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Notes

[1] In this Bundesland, science is taught in a discipline-based format (rather than "general science") starting with Biology in grade 5, Physics in grades 7 or 8, and Chemistry in grade 9.

[2] A one-way ANOVA of the measured variable of conceptual understanding showed no significant differences between classes. Similarly, one-way ANOVAS showed no significant between class differences in any of the measured indicators of affect.

[3] In structural equation models, a good fit has a χ^2 test with high p values, much above .05. Guidelines suggest appropriate fits with Comparative Fit Index (CFI; model compared with independence model) $>.95$ and Root Mean Square Error of Approximation (RMSEA) $<.05$. With the Parsimony-adjusted Comparative Fit Index (PCFI), values closer to 1 represent a comparatively better fit (Schumacker & Lomax, 2004, pp. 79–106).

[4] Including a series of dummy variables representing the different classes/teachers into the model shown in Figure 2 showed no statistically significant teacher effects, and no difference in patterns of statistical significance among the substantive variables.

[5] Careful readers might be concerned about the unexpectedly large correlation between error terms of indicators of attitudes at time 2, which, with rounding error, is estimated at −1.0. The model was reestimated with the correlated error coefficient fixed at a lower value (−.50) with no significant impact on the pattern of effects.

[6] Including a series of dummy variables representing the different classes/teachers into the model shown in Figures 3–5 showed no statistically significant teacher effects, and no differences in patterns of significance among the substantive variables.

Appendix 1: Descriptive Statistics for Observed Variables

Variable	Mean (t1)	SD (t1)	Mean (t2)	SD (t2)
Attitudes toward chemistry				
Importance of discipline (min. 4, max. 16)	12.7	2.3	12.9	1.9
Personal relevance (min. 3, max. 12)	8.4	1.8	8.4	1.6
Importance of chemical products (min. 2, max. 8)	6.1	1.4	5.9	1.3
Self-concept (t1)				
Achievement appraisal (min. 3, max. 15)	10.5	2.3	10.6	2.1
Class contribution (min. 2, max. 10)	6.7	1.7	6.6	1.6
Confidence of understanding (min. 2, max. 10)	7.2	1.6	7.4	1.4
Situational subject interest (t1)				
Enjoyment of chemistry (min. 3, max. 12)	6.6	2.4	6.7	2.1
Emotional/intrinsic engagement (min. 3, max. 12)	6.9	2.2	7.3	1.8
Motivated meaning (min. 3, max. 12)	7.7	2.1	8.4	2.1
Conceptual understanding (percentage correct, t2/t3)	.42	.24		

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