Predicting Positive Activating Emotions during Mathematics Learning: the Relative Importance of Different Situational and Personal Factors

Abstract

The study aims to assess the relative importance of a large number of variables for predicting students' positive activating emotions during mathematics learning. Participants were 668 first-year upper secondary school students from 33 schools of different sizes and locations. Two questionnaires were distributed, one assessing students' perceptions and beliefs about their learning situation in mathematics in general, and the other assessing the characteristics of a particular mathematics lesson and the students' emotional experiences during this lesson. Single-construct and multivariate models for predicting students' emotions were computed. The results show that the multivariate models were the most efficient, predicting as much as 59% of the variance in students' emotional experiences. The two most important constructs were students' type of motivation and perceived degree of learning, which together predicted 48% of the students' emotions. Single-construct models predicted, at most, 36%. The relative and absolute predictive ability of different motivational constructs are reported. The relationships between constructs and their implications for teaching are discussed.

Keywords: positive activating emotions, personal factors, situational factors, upper secondary school, multivariate

1 Introduction

Contemporary research has shown that, although long neglected, students' emotions play an important role in different aspects of learning. It has been shown that people are more likely to pay attention to, remember, and learn from situations that elicit emotional reactions, than from those that do not (Holland & Kensinger, 2010; Kensinger, 2009; Reisberg & Heuer, 2004). Positive emotions have been shown to be associated with elevated dopamine levels in the brain, which improves cognitive flexibility and attention, as well as long-term and working memory functioning, all of which are important for learning (Ashby, Isen, & Turken, 1999). Also, efficient learning often requires an ability to sort out relevant information and principles from detailed information, and creative thinking is required to be able to adapt and apply what has been learned to new situations. Such abilities are facilitated by positive emotions. From their review, Fredrickson and Branigan (2005) concluded that there is strong evidence that positive emotions broaden the scope of cognition and attention, i.e., allow unusual, flexible, creative, integrative, and efficient thinking, while also promoting a focus on global features of information, rather than on detail. This was corroborated by their study, in which 104 college students completed a global–local visual processing task, and an open-ended Twenty-Statement-Test (TST). Students who had been positively primed showed increased attention to global features in the visual processing test as well as a wider repertoire of thought-actions in the TST, compared to those who were in a more neutral state. Although somewhat less conclusive, their results also indicated that negative emotions reduced the breadth of thought-actions and led to a particular emphasis on attention to detail rather than a global perception. Furthermore, the control-value theory (Pekrun, 2006) posits that positive activity-related emotions, elicited by cognitive control and value appraisals, influence the availability of cognitive resources, motivation, and learning strategies, that in turn influence performance in a joint manner.

Emotions are also important to the motivational aspect of learning. Most definitions of emotions include a motivational component pertaining to the direction and intensity of the need for action that is elicited by the individual's cognitive appraisal of the situation. In these models, emotions are considered as a system of several related processes, appraisals being one of them, serving to "…prepare appropriate behavioral reactions to events with potentially important consequences" (Scherer, 2005, p. 701). Thus emotions not only serve to evaluate the relevance of events, but also to instigate and coordinate actions, including evoking and directing necessary resources. Hence, emotions have important implications for students' engagement in achievement settings. For example, self-determination theory (SDT) (Ryan & Deci, 2000) states that an individual's intrinsic motivation is either based on appraisals of previous emotional experiences from similar situations, generating prospective positive emotions for the task, or the emotions that are elicited by the task—"here and now." The identified and integrated types of motivation are characterized by being instigated and sustained by external reasons rather than by prospective or on-going positive emotions. However, in these types of extrinsic motivation, where the regulations or values have been taken in and transformed so they emanate from a sense of self, positive activating emotions are also common – which may later lead to positive prospective emotions in similar situations (Ryan & Deci, 2000). Pekrun, Goetz, Titz, and Perry (2002) argued that both positive and negative emotions can be divided into activating and deactivating emotions, defined by their ability to either stimulate or diminish an individual's motivation. Pekrun et al. (2002) provided evidence from several of their studies that positive activating achievement emotions (e.g., enjoyment) stimulate effort and intrinsic motivation while negative deactivating emotions, e.g., boredom, will generally lead to withdrawal and irrelevant thinking. Later, Pekrun et al. (2010) showed that boredom is deleterious for effort and intrinsic motivation, and ultimately, academic performance.

We acknowledge that learning is possible even when energized by negative emotions (e.g., anger, frustration) and that knowledge about details is often necessary for the development of a global understanding. However, in school today there is often a focus on details, e.g., procedures and facts, while a global understanding of the underlying idea of procedures and/or how facts are interrelated is often missing (Hiebert, 2003). Furthermore, while learning is not always driven by positive emotion, stimulating positive activating emotions in mathematics classrooms would promote positive attitudes towards mathematics (Eagly & Chaiken, 1993; Pekrun, 2006). Thus, research on how to stimulate positive emotions is valuable.

Considering the significance of emotions for learning, it is important to determine which variables are most conducive of the emotions that are beneficial for learning. When making this determination, it is helpful to acknowledge the different roles emotions can play in learning processes. It has been suggested that emotions have several functions in motivational processes, e.g., as explicit goals for engagement in an activity, as indicators of the degree to which a student has internalized external goals (Ryan & Deci, 2000), or as regulators and directors of effort invested in goal pursuit—by signaling the rate of progress (Carver & Scheier, 1990). Furthermore, emotions have been argued to be indicative of the level of the student's own skills in relation to the challenges (Csikszentmihályi, 1990), and to be antecedents of expectancies of success (Weiner, 1985) and perceived task value (Wigfield & Eccles, 2000). These appraisals are made in the nexus between situational features and the students' personal characteristics. Therefore, students' emotions may differ not only between situations, but also between individuals who experience the same situation. This implies that to develop a meaningful understanding of students' emotions in different learning situations, researchers need to acknowledge the complexity of motivational processes. In addition, researchers need to simultaneously consider several personal and situational variables that might influence students' perceptions of, and the emotional outcomes of, the learning situation. This "holistic" approach has been advocated by several authors, such as Op 't Eynde and Turner (2006), who argue that "A multilevel approach that incorporates several planes of analysis, corresponding to personal, interpersonal, and community values, appraisal processes, etc., will probably result in the most complete understanding of students' emotional experiences and learning activities." (p. 372).

The present study is the first in a project aimed at closely investigating how students' emotional experiences, cognition, and behavior are formed by the interactions of personal and situational variables. Studies of emotions often take as their starting point one specific theory and the variables defined within the theory. In this paper, the relative importance of variables, generated from several theories of emotions and motivation, for predicting students' positive emotions during authentic classroom situations, is investigated.

2 Theoretical framework

2.1 Emotions

Although there seems to be little consensus on the definition of emotions (Izard, 2007) they are commonly described as brief, interrelated, and synchronized responses to some external or internal event of particular significance for the organism (e.g., Scherer, 2001). The responses are considered to encompass various aspects, such as: cognitive appraisals, physiological events (e.g., neurological and hormonal), action tendencies (motivation), verbal and non-verbal expressions, and feelings. Feelings are conceptualized as subjective experiences that reflect the total pattern of emotional reactions, while still being a part of the emotion system, where they serve to monitor the individual's internal state and interaction with the environment (Scherer, 2005). Emotions are classified with respect to their valence and to the effect they have on the individual's behavior: negative/activating, negative/deactivating, positive/activating, and positive/deactivating (Pekrun, et al., 2002). The positive/negative dimension pertains to the character of the event experienced by the individual. An activating emotion provides energy for sustained engagement while deactivating emotions deter further engagement. For reasons mentioned earlier, only negative/deactivating and positive /activating emotions are in focus of this paper. Somewhat more details about these emotions are given later in this section. Furthermore, emotions can pertain to different aspects of the student's situation: life in general, attending school, the learning situation, or the activity of learning (Goetz, Hall, Frenzel, & Pekrun, 2006). In this paper, emotions are defined as brief reactions to specific learning activities in mathematics classrooms. Moreover, emotions are measured in terms of the feelings students report in relation to the task(s) conducted. Given the relatively short duration and situation-dependence of these feelings, we view them as identical to state emotions (Pekrun, et al., 2002) – as opposed to the more long-lived and more general notions of moods or personality traits.

Enjoyment is classified as a positive activating emotion, associated with several aspects of learning, such as self-regulation (Artino & Jones, 2012), creativity (Goetz, et al., 2006), and well-being (Pekrun, 2006). Fredrickson (2001) argues that enjoyment, or joy as she conceptualizes it, provides the energy to play, push the limit, or be creative. Though enjoyment is suggested to be "aimless," interest and curiosity have been suggested to be activating emotions that focus attention and elicit an urge to explore, pursue novelty, take in new information, and expand the self (Fredrickson, 2001; Izard, 2007). Hence, enjoyment, curiosity, and interest are highly adaptive emotions in learning situations, where "…the playfulness of the emotion joy combines with the exploratory and information seeking of the emotion interest" (Ainley & Ainley, 2011, p. 5). Excitement has also been identified as a positive activating emotion (Schacter, 2011).

Boredom is commonly described as an emotion comprising unpleasant feelings, reduced arousal and motivation to engage in the activity, altered perception of time, and specific facial, postural and verbal expressions (Pekrun, et al., 2010). Although Pekrun et al. (2010) propose that boredom will be reduced by excitement and curiosity, they argue that boredom is not equivalent to a lack of positive emotions—which would be a rather neutral state, neither motivating the individual to avoid, nor to engage in, the activity. Instead Pekrun et al. (2010) define boredom as a negative deactivating emotion, which implies a motivation to actively avoid an activity. In this paper, boredom is viewed as the opposite of positive activating emotions (corroborated by our validation procedure, see the "Method" section). Thus, our emotion construct spans a negative deactivating–positive activating, rather than a neutral–positive activating, continuum and comprises items measuring interest, excitement, curiosity, enjoyment, and boredom. In the present paper, students' position on this continuum will be referred to as students' "emotions" or "emotional experiences," depending on the context.

2.2 Variables affecting emotions

In what follows, we will use several theories to describe the variables that are included in this study and explain why they were included. As implied above, emotional reactions are to a large extent elicited by an interaction between the learner and some aspects of the environment. Thus, students' emotions in a learning situation will be affected by variables inherent in the student as well as in the situation in which the learning takes place. Although the variables are often in a nexus in-between the person and situation, we will describe them under the subheadings "personal variables" and "situational variables," respectively.

In our search for variables that are important for the arousal of emotions during learning, we have, in addition to focusing on theories of emotions, focused on theories of motivation because emotions are key variables in many motivation theories. In what follows, we justify our selection of variables by illustrating the theoretical relationship between these variables and students' emotional experiences in academic situations. The names of the variables included in the study are italicized.

2.2.1 Influence of personal variables on emotions

There is no consensus on the definition of motivation among researchers. However, the following general definition captures the elements considered by most scholars to be central to motivation (Schunk, Pintrich, & Meece, 2008): “Motivation is the process whereby goal-directed activity is instigated and sustained” (p.4). Thus, goals play a central role in motivational behavior. Emotions are associated with evaluations of how well our efforts contribute to the fulfillment of our goals, the importance of goal attainment (e.g., for self-worth), and the extent to which we perceive that we have control over our behavior and its outcomes (Pekrun, 2006; Schutz & DeCuir, 2002). Emotions might encourage us to continue the behavior, or act as a disruptor, allowing us to redirect attention to other important goals, if present. The kind of goals students possess influences students’ emotional experiences. In achievement goal theory (Elliot & Covington, 2001), individuals with *performance goals* are assumed to link performance, relative to others, with self-worth (Covington, 2000). Thus, for students with performance goals, the main instigator of behavior in academic situations is a need to protect or enhance self-worth. In contrast, students with *mastery goals* are assumed not to make the connection between performance and self-worth. Instead, their behavior is considered as primarily driven by a need for understanding and the associated sense of satisfaction or enjoyment. Students with performance goals are not expected to experience positive emotions in situations where they risk revealing weaknesses, while students with mastery goals might perceive those situations as positive challenges—and thus experience more positive emotions. Students with performance goals might, however, experience both enjoyment and pride when attaining a goal. Pekrun, Elliot and Maier (2006) found that mastery goals predicted positive activating emotions, such as enjoyment, and correlated negatively with boredom.

Attribution theory (Weiner, 1985) contends that the perceived success or failure of attaining a desired goal will trigger emotions. Such emotions will be primarily positive when the goal is attained, and negative when the goal is not (Weiner, 1985). But the theory also assumes that emotions arise from how an event is evaluated. Such attribution-dependent emotions are dependent on the dimension (locus, stability, and control dimension) of the perceived cause of the outcome (Weiner, 1985). Thus, the attribution of success or failure that students make is another variable that affects emotions. In this study the students’ perceived *internal locus of control* for successful outcomes is included as a variable. The control-value theory of achievement emotions (Pekrun, 2006) also delineates “prospective outcome emotions.” These emotions are not elicited as a consequence of the success or failure of an activity, but in anticipation of its outcome. The nature of these emotions is dependent on outcome expectations and outcome value. A strong expectancy of success in performing an activity that is expected to lead to a highly valued outcome is assumed to arouse anticipatory joy. After a successful outcome, the retrospective outcome emotion of enjoyment will arise. Thus, students’ *expectancy of success* and the subjective value of the outcome (measured in this study as *“utility value*”) are variables that are important for the arousal of positive emotions during the activity.

Self-determination theory (SDT) (Deci & Ryan, 1985; Ryan & Deci, 2000) proposes that the behavior of an individual is aimed at satisfying innate psychological needs for competence, autonomy, and relatedness. *Perceived learning* that arises from an activity is an indication for students that they are competent and it therefore arouses positive emotions. SDT argues that not only the level (i.e., how much motivation), but also the type of motivation has implications for emotional experiences. SDT distinguishes between "*intrinsic motivation*," where the individual engages in an activity for its own sake, i.e., because it is enjoyable, and "extrinsic motivation", where the behavior is initiated and sustained because of expectancies on the outcome of the activities (e.g., a good grade). However, there are several types of extrinsic motivation, differing in the degree to which behavior is self-determined or, in other terms, the degree to which the motive for a behavior has been internalized by the individual and integrated as a part of his or her self. "*Identified motivation*," which is a highly self-regulated, or autonomous, extrinsic form of motivation, often has consequences for emotions and behavior similar to those of intrinsic motivation (Ryan & Deci, 2000). This type of motivation is more likely to generate positive emotional experiences than are behaviors that are perceived as being to a high extent controlled by extrinsic factors, e.g., time limits, external rewards, or threats (Ryan & Connell, 1989). In SDT, emotional experiences are considered both as outcomes and goals. For intrinsically motivated individuals the activity itself arouses positive emotions, such as satisfaction, enjoyment, etc. This emotional experience is the goal that initiates and/or sustains a behavior.

Epistemological beliefs pertain to individuals' beliefs about the nature of knowledge, where it resides, and how it is constructed and evaluated (Hofer, 2004). Research indicates that students' epistemological beliefs influence cognition as well as motivation to learn (Bodin & Winberg, 2012; Bråten & Strömsö, 2006; DeBacker & Crowson, 2006; T. M. Winberg & Berg, 2007), which in turn are related to affective experiences during learning (Harackiewicz, Barron, Tauer, & Elliot, 2002; Pekrun, et al., 2006). Although there are different views on how epistemological beliefs should be construed, descriptions normally comprise a continuum from dualistic to relativistic beliefs. Dualistic beliefs can be described as representing a view of knowledge as certain and unchanging, and consisting of isolated fact to be learned, while depending on an authority for guidance and as a provider of knowledge. An individual with relativistic beliefs acknowledges his or her active role in learning and the ambiguity and context dependence of knowledge, and considers knowledge as a coherent structure rather than a collection isolated facts. In this paper, we have measured *simplicity beliefs* that pertain to the degree to which facts etc. are perceived to be interrelated, and *certainty beliefs* pertaining to which extent knowledge is believed to be unchanging over time. Research indicates that learning situations that do not match learners' epistemological beliefs, e.g., in terms of the amount of autonomy required or the character of the intellectual task (e.g., task difficulty or novelty), might appear as overwhelming, alternatively not challenging enough for students to engage in learning and may cause emotional experiences that influence the students' motivation and learning behavior. (Finster, 1989; Moore, 1994; Windschitl & Andre, 1998).

2.2.2 Influence of situational variables on emotions

The control-value theory postulates that students' control over actions, and their perceptions of the value of these actions, are the main determinants of which activity-related emotions will arise from an activity (Pekrun, 2006). However, the controllability and academic values are mediators of the impact of the social environment on activity emotions. According to Pekrun (2006), important features of the social environment "…include quality of instruction, induction of values, autonomy support, goal structures, and achievement-related expectancies of significant others, as well as feedback and consequences of achievement" (p. 325). In Table 1 below, the variables of the social environment included in this study are presented and described under each of the features presented by Pekrun (ibid.) Some of these variables could be interpreted as pertaining to several of the features (e.g., clarity of goals is displayed under Goal structure but could also be seen as a feature of Quality instruction). The following exemplifies how social antecedents in the learning environment, via control and value appraisals, can affect activity emotions: A student feels related to significant others and perceive that they regard learning as important. She also perceives that her teacher likes mathematics and teaching it to the students. This relatedness with significant others facilitates the integration of their perception of the value of learning activities (Eagly & Chaiken, 1993; Ryan & Deci, 2000). Furthermore, clear goals of the learning activities, which allow students to monitor their progress in relation to the goals, in combination with providing scope for the student to influence the process of learning (autonomy support) in order to attain the goals, would promote a sense of control over the activity. Positive appraisal of control over, and value of, learning activities would instigate enjoyment (Pekrun, 2006).

Table 1. Situational constructs measured in the present study, listed under Pekrun's (2006) features (italicized).

Variable	Description
Quality of instruction	
Teacher support	Perceived amount of support from the teacher
Task difficulty	Perceived difficulty of assigned tasks
Task novelty	The tasks are unfamiliar or provide new perspectives
Peer discussion	Amount of interaction with peers about subject matter
Induction of values	
Peer attitude	Peers' attitude towards the subject
Relation to peers	Students' comfort with classmates
Teacher enthusiasm	Student perceives that the teacher enjoys the subject and its teaching
Autonomy support	
Autonomy support	Perceived autonomy support provided by the teacher
Goal structures	
Clarity of goals	Perceived clarity of what is supposed to be learned
Perceived quality goals	Student perceives that understanding is important, not just completing as many of the assigned textbook tasks as possible
Expectancies of significant others	
Supportive family	Family thinks it is important that students learn and provides help with learning when asked for
Feedback and consequences of achievement	
Teacher discussion	Amount of student-teacher subject matter discussion

3 Research questions

The present study was designed to investigate whether a multi-theoretical approach can contribute to an enhanced understanding of students' emotional experiences during mathematics learning situations and to investigate how variables generated from the different theories together contribute to the prediction of students' emotional experiences.

The specific research questions are:

- What is the relative importance of the different variables for describing and predicting students' emotional experiences?
- How do single-construct models compare with multivariate models as ways to describe and predict students' emotional experiences?
- What are the relationships between the predictive variables in the multivariate models?

4 Method

4.1 Participants

The participants were 668 first-year upper secondary school students (323 males, 341 females, 4 non-responses) from 33 Swedish upper secondary schools. Data were collected in collaboration with the Swedish Schools Inspectorate with the objective of obtaining a sample that would reflect demographics in terms of school size and location. All students in the study were taking Mathematics A, a course compulsory for all students in nation-wide programs in upper secondary schools in Sweden.

4.2 Materials

Two questionnaires were developed. Questionnaire 1 consisted of 46 items pertaining to students' thoughts about learning in mathematics, about the nature of mathematical knowledge, and about the social context for mathematics learning in school. Questionnaire 2 consisted of 43 items to be answered immediately after a mathematics lesson. The items pertained to the students' emotional and cognitive evaluation of the lesson, and the perceived characteristics of the teaching and the social climate during the particular lesson. These main areas were divided into more detailed constructs. For sample items of each construct, see Table 2.

The items about achievement goals were translated directly from Elliot and Murayama (2008), while the items in the areas of motivation type and perceived autonomy support came from Deci and Ryan (1999), and from Ryan and Connell (1989), respectively. In the areas of epistemological beliefs (Hofer, 2004), attributions (Black & Deci, 2000; Weiner, 1985), and emotional experiences (Pekrun, Goetz, & Perry, 2005), theoretical structures of constructs, rather than specific items, were adapted and operationalized. Items designed to measure students' generalized expectancy of success in mathematics were inspired by previous work on expectancy-value theory (Wigfield & Eccles, 2000). ”Situational” features, such as task difficulty or novelty, family and peer attitudes, goal clarity, were inspired by motivation theories, as described above, and operationalized by the authors.

Items in both questionnaires used a five-point Likert scale, ranging from “strongly disagree” to “strongly agree”.

Table 2. *Sample items in the different constructs, and distribution of constructs on questionnaire 1 and 2 respectively.*

Construct in Questionnaire 1	n	Sample item
Autonomy support, general	6	My teacher listens to how I would like to do things during the lessons in this subject.
Internal locus of control	4	I can improve or reduce my talent for this subject by myself. When things have gone well for me in this subject, it has usually been because I have talent for it.
Epistemological beliefs, certainty	4	What we have learned in this subject will still be true in the future.
Epistemological beliefs, simplicity	6	Most of the time the various things we learn in this subject are unrelated to each other.
Expectancy of success	3	In this subject, I am quite sure I will achieve test results that I am happy with.
Intrinsic/identified motivation type	8	I work with the assignments I get during the lessons in this subject because I like it. I work with the assignments I get during the lessons in this subject because it is important to me.
Mastery goals	3	My goal is to learn as much as possible in this subject.
Performance goals	5	My goal in this subject is to perform better than the other students in the class.
Peer attitude	2	I think my friends enjoy this subject.
Supportive family	2	In my home there is someone who thinks it is important that I have knowledge in this subject.
Utility value, general	3	I will need what I learn in this subject to do well in life outside school.
Construct in Questionnaire 2		**Sample item**
Autonomy support, specific	5	I had the opportunity to influence how I would work with the assignments during this lesson.
Clarity of goals	2	It was clear what I should learn from this lesson.
Peer discussion	4	When I came across something I did not understand, I discussed it with other students.
Perceived learning	5	I learned a lot in this lesson.
Perceived quality goals	5	I feel that the important thing during this lesson was how well I understood what we were working with.
Positive emotions*	5	I enjoyed the lesson The work was boring The topic we worked on was exciting I was curious on the topic we worked on during this lesson The content of this lesson was interesting
Relation to peers	3	The other students treated me in a nice way.
Task difficulty, specific	9	I did not have to stretch myself to manage what we worked with during the lesson.
Task novelty	2	What I concluded was surprising to me.
Teacher discussion	2	I discussed a lot with the teacher about what we were working with.
Teacher enthusiasm	2	The teacher seemed to enjoy having this lesson with us.
Teacher support	6	The teacher was aware of that I learned what we were working with during the lesson. The teacher explained so that I understood.
Utility value, specific	3	What we worked with is likely to be useful for me in my future studies.

*The dimensionality of this construct indicated a negative-deactivating to positive deactivating emotion continuum. For the sake of brevity, and to reflect the meaning of high scores in this construct, we have chosen the notion "positive emotions".

4.3 Procedure

After validation, the questionnaires were distributed by the Swedish Schools Inspectorate as part of the Swedish School Inspection's 2009 quality audit of mathematics in Swedish upper secondary schools (T. Mikael. Winberg, Hellgren, & Palm, 2014). Students completed Questionnaire 1 individually in the classroom during a mathematics lesson. Within two weeks Questionnaire 2 was completed at the end of a mathematics lesson, to assess the particular situation and outcomes. The questionnaires were then merged so that each respondent's answers for Questionnaires 1 and 2 could be linked in the data analysis.

4.4 Data analysis

4.4.1 Schematic description of workflow

1. Both questionnaires were validated in four rounds, comprising Principal Component Analysis (PCA) of students' responses to the items and subsequent interviews about problematic items.
2. Items were grouped according either to the predefined theoretical constructs to which they were claimed to belong in extant questionnaires or, if they had been constructed by the authors, to the underlying theoretical structure they were designed to match.
3. After grouping the items, PCA was performed to investigate the internal structure of the constructs and assess their validity.
4. If the constructs were found valid, they were used separately in single-construct Partial Least Squares (PLS) base models to predict the variation in students' emotional experience during the lesson, allowing direct comparison of the ability of single constructs to predict students' emotions. Non-valid constructs were discarded.
5. Students' scores on the different PLS-base model components were then used in a top model, allowing analysis of relationships between the different constructs as well as of the relative importance of the single constructs for the ability of the multivariate models to predict emotions.
6. A reduced top-model was calculated, using only the variables that were found to be the most important, according to statistical indices, in the full top model.

A more detailed account of the data analysis procedure is given in what follows.

4.4.2 Validation procedure

The validity of constructs was examined using PCA to study the dimensionality and internal consistency of the constructs. The PCA was followed by interviews with the respondents to check the interpretations of items that did not show the expected patterns of co-variation with the other items within a construct. Problematic items were revised, and the validation procedure was repeated. Four validation rounds were performed. For some constructs, statistical validity in terms of cross-validity (Q^2) was still difficult to obtain. In these cases, face-validity judgments (with respect to dimensionality and correlation between items, and alignment with theory), and construct eigenvalues >1 were used as the criteria for inclusion in the next step, the hierarchical PLS analysis.

Q^2 is obtained by deleting one-seventh of the data at a time, calculating predicted values for them by using the remaining data, and comparing the predicted values with the observed values. This is repeated until all data has been left out and predicted once. Q^2 is the proportion of the variation in the observed data that could be predicted by the model. Hence, Q^2 could be considered a measure of the models' ability to predict new, "external" data – in contrast with R^2, which is a measure of how well the model fits, or describes, the underlying data.

To evaluate the quality and validity of the PLS top model, it was assessed with respect to extreme observations that might have had undue influence on the direction of the predictive components. This was done by calculating the distance to the model (DmodX), Hotellings, and Observation risk for all students. While the two first measures give information on whether an observation should be regarded as an outlier or not, the latter is an estimate of the effect of a single observation on the models' predictions (i.e., the residuals). Only moderate outliers were found. Because deletion of these had no significant effects on residuals, all outliers were included in the final model. No observation had undue influence on the model, in terms of Observation risk. Furthermore, cross-validation ANOVA was performed to assess the validity of the model, i.e., its ability to predict "new" data, and not merely fit the existing data well. This showed that the prediction residuals were significantly smaller than the variation around the global average, i.e., that the model had a significant ability to actually predict emotions for "new" students, and not merely by chance succeed in predicting outcomes for the particular sample $F(663) = 212{,}9$, $p = 0.00$.

4.4.3 Relative variable importance

Data analysis was conducted using Simca P+ 12 statistical software (Umetrics, 2009). Prior to PLS analysis, data were scaled to unit variance (UV) and mean-centered. UV scaling corresponds to the assumption that all variables are equally important, and is regarded as the most objective approach when there is no information about the data prior to analysis (Eriksson et al., 2006). Every column in the x-matrix was divided by the standard deviation for each variable, giving every scaled variable unit (equal) variance. When centering the variables, the average value for each variable was calculated and subtracted from the data, resulting in an average point at which the center of the coordinate system was placed to facilitate the fitting of the components in the multivariate space.

For each theoretical construct, a single-construct PLS base model, with students' emotional experiences as an outcome variable (Y-variable), was computed. The proportion of the variation in the prediction variables (R^2_X) and the outcome (R^2_Y) described by each model, as well as the proportion of the variation of students' emotions that could be predicted by the respective models (Q^2), are reported in Table 3. Default Simca Q^2 limits were used to determine the significance of the model components, reflecting a 95% significance level. After the base models had been computed, a top model was calculated to model the relationships between all the constructs and to assess their relative ability to predict students' emotions during the specific lesson (Figure 1).

Table 3. *Overview of the fraction of total variation in student responses to items in each construct that can be described (R^2_x) and the fraction of the variation in the emotion construct that can be described (R^2_y) and predicted (Q^2) by the respective model. (A) is the number of components and (n) is the number of students who have responded to the items in each model. Top ten variables, according to VIP values, are above the dotted line.*

Construct	A	n	R^2_X	R^2_Y	Q^2
Intrinsic/identified motivation	1	633	.35	.53	.30
Perceived learning	1	624	.56	.37	.36
Teacher enthusiasm	1	531	.75	.22	.22
Teacher support	1	657	.45	.21	.20
Autonomy support, general	1	561	.55	.18	.17
Autonomy support, specific	1	546	.32	.17	.15
Peer attitude	1	430	.63	.17	.16
Task novelty	1	505	.67	.17	.16
Mastery goals	1	640	.59	.28	.14
Clarity of goals	1	504	.76	.17	.16
Teacher discussion	1	523	.77	.12	.11
Task difficulty, specific	1	668	.20	.13	.11
Expectancy of success	1	532	.63	.13	.12
Utility value, specific	1	587	.60	.14	.11
Internal locus of control	1	562	.30	.10	.09
Peer discussion	1	534	.35	.11	.09
Perceived quality goals	1	615	.36	.10	.08
Utility value, general	1	639	.53	.22	.07
Epistemological beliefs, simplicity	1	562	.31	.06	.04
Relation to peers	1	529	.60	.04	.04
Performance goals	1	562	.65	.05	.04
Supportive family	1	560	.61	.04	.04
Epistemological beliefs, certainty	1	638	.42	.16	.01
Positive emotions (outcome variable)	1	624	.63	N/A	.41
Top model	2	528	.33	.62	.59
Reduced top-model	2	528	.48	.60	.58

5 Results

5.1 Relative importance of predictive variables

Looking at the individual variables, it is shown in Tables 2 and 3 that the two most influential variables for predicting emotions pertain to the students' perceptions of themselves. They are: the type of motivation the students have (R^2_Y = 53%, Q^2 = 30%), and their perceived learning (R^2_Y = 37%, Q^2 = 36%). This means that as much as 30–36% of the variance can be predicted by a single variable - motivation type or perceived learning. Thus, students who experienced positive emotions in mathematics during the specific lesson had an intrinsic motivation for learning mathematics or had identified an extrinsic regulation. They also felt competent, in terms of high perceived understanding of what they did.

The study shows that some of the situational variables pertaining to students' perceptions of their teachers' work and attitudes also explain much of the variance in students' emotional experiences (Table 3). Teacher enthusiasm has a R^2_Y of 22% and a Q^2 of 22%. The values for teacher support were 21% and 20%, general and specific autonomy support (18% and 17%, versus 17% and 15%, respectively), and clarity of goals (17% and 16%). Together they describe 36 % and predict 35% of the variation in the emotion construct (model not shown), and are all

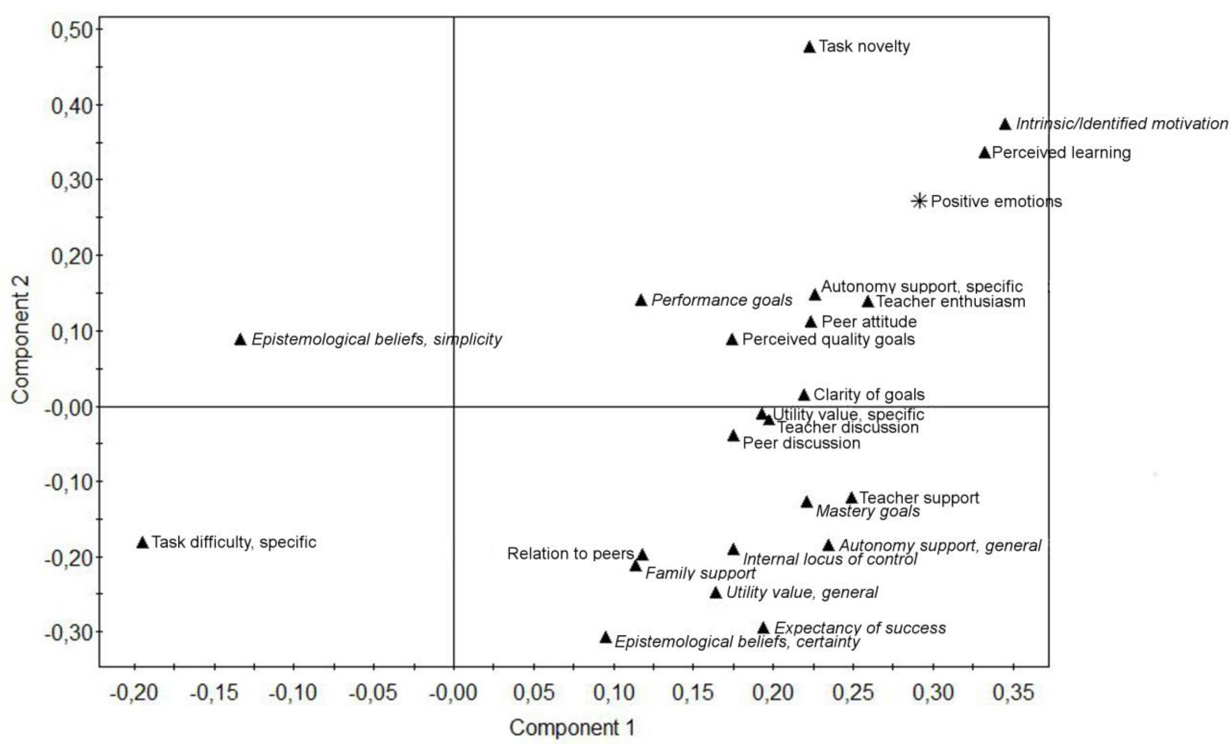

Fig.1 Loading plot of the top-model, predicting students' positive activating emotions (indicated by the star) during a mathematics lesson. Predictor variables (triangles) are students' general thoughts about mathematics and learning as measured in questionnaire one (italicized) and their perceptions of the characteristics of the specific lesson, as measured in questionnaire two

among the most important variables, having VIP values larger than 1 in the top model (Figure 1 and Table 4) and the highest predicted variance of the situational variables (Table 3).

Table 4. *VIP values of variables in the top model (Figure 1). VIP:s higher than 1 indicates an important variable, while variables with VIP:s lower than 0.5 are generally considered unimportant*.

Variable	VIP
Intrinsic/identified motivation	1,66
Perceived learning	1,59
Teacher enthusiasm	1,24
Teacher support	1,19
Autonomy support, general	1,12
Autonomy support, specific	1,09
Peer attitudes	1,07
Task novelty	1,07
Mastery goals	1,06
Clarity of goals	1,05
Teacher discussion	0,95
Task difficulty, specific	0,93
Expectancy of success	0,93
Utility value, specific	0,92
Peer discussion	0,84
Internal locus of control	0,84
Perceived quality goals	0,83
Utility value, general	0,79
Epistemological beliefs, simplicity	0,64
Relation to peers	0,57
Performance goals	0,56
Supportive family	0,55
Epistemological beliefs, certainty	0,46

5.2 Comparison of single-construct and multivariate predictive models

As can be seen in Table 3, the top model (Figure 1) was able to predict a high degree of the variation in students' emotions. The single-construct models predict up to 36% of the total variation in students' emotions (see Table 3), although significantly less than the top model (t (23) = -25.6, p = 0.000). Together, the two most important variables, i.e., motivation type and perceived learning, describe and predict 48% of emotions (model not shown), while the top model, using all the constructs as prediction variables, describes 62% of the variation in students' emotions and is able to predict emotions to as much as 59%. Reducing the number of variables by only including variables with a VIP over 1 in the top model resulted in a marginal decrease in the predictive ability (less than one percentage point) and descriptive ability (two percentage points) of the reduced top model, with the internal relationships between the selected variables being virtually identical to the ones found in the original model. Paired t-tests showed that

Observation risk and DmodX values were significantly lower with the reduced model (t (528) = - 5.36, p = 0.000; and t (528) = - 2.56, p = 0.011, respectively). Hence, the reduced model showed a better fit for all students than did the full model.

Thus, in general, bivariate and multivariate models were better than univariate (single-construct) models for predicting students' emotions. However, the ten most important variables were sufficient to produce a very good model for predicting students' emotions and the inclusion of additional variables only marginally increased the predictive ability of the model.

5.3 Relationships between predictive variables

For those not acquainted with the graphical output of PCA and PLS, a brief description of how to interpret loading plots, e.g., Figure 1, might be helpful. Variables located close to each other in the loading plot are positively correlated and (possibly) convey similar information. Variables that are located on opposite sides of the origin, connected by an imaginary straight line through the origin, are negatively correlated. The further out from the origin of the plot a variable is located (i.e., the higher loading it has, relative to the other items), the more significant the variable is in the model. In PLS, an independent variable located far out from the origin and in the same direction as the dependent variable is significant for explaining variation in the dependent variable, in this case emotions.

One result of the present study is that students' emotions can be explained and predicted to a large extent by the ten most important variables in the top model. These variables share a significant amount of variance that describes and predicts students' emotions, as illustrated by their adjacency in Figure 1—that is, students who experience positive emotions during the activity of learning mathematics are mostly intrinsically motivated or have identified an extrinsic regulation. Generally speaking, they tend to have mastery goals, and perceive that they learn and understand the mathematics on which they work. These students often have teachers that set up clear goals, provide tasks that are novel for the students, support the students' autonomy while providing structure and explanatory support, and/or show that they enjoy mathematics and teaching it to the students. In addition, these students usually have peers who are also positive towards the study of mathematics. Similarly, students who do not experience positive emotions in mathematics during the lesson often feel that the goals are unclear, that their teacher does not like the subject or teaching them, and perceive that they are controlled and/or not given sufficient explanatory support. Their reasons for doing mathematics tend to be neither intrinsic, nor identified as truly their own, and they do not perceive that they understand what they are doing.

6 Discussion

6.1 Conclusions

This study provides insight into relationships between students' perceptions of different aspects of mathematics learning and their emotional experience during learning, and enables explanations of the type of teaching and teacher behaviors associated with students' emotions. This is important for the development of teaching that promotes positive emotions during mathematics learning, to enhance learning and increased enrolment in mathematics-intensive study programs.

The study shows that students' emotional experience on the negative-deactivating to positive-activating continuum can to a large extent be explained by their type of motivation and their perceived learning. That is, it is important that students engage in the subject matter activity because they expect it to be enjoyable, or they fully acknowledge and embrace the instrumental value(s) of the activity, and perceive themselves as successful in the process of learning. Students may be forced to engage in mathematics learning, but if their motives are not perceived as autonomous, and if they do not perceive themselves as competent when they carry out their assignments, they are not likely to experience curiosity, excitement, and enjoyment. Together, motivation type and perceived learning describe and predict 48% of the variation in students' emotional experience. This indicates that actions taken by the teacher to target only one or two specific factors may be successful in enhancing students' emotional experience of mathematics.

In addition to motivation type and perceived learning, there were several situational variables, all highly associated with the students' emotions that are directly manageable by the teachers. These variables provide specific guidance for teacher behaviors that are important for stimulating students' positive emotions. The variables describe teachers who have fully clarified the lesson goals, provide novel tasks, show enthusiasm for the subject and for teaching the particular class, provide sufficient explanations in a nice way, and keep track of students' learning while supporting their autonomy.

The above variables have much variance in common. This means that teachers who score high on one of these variables mostly score high on the others. For example, the three variables clarity of goals, task novelty and teacher enthusiasm together explain 40% of the variance in students' emotions. Adding autonomy support does not add any explanatory ability, and exchanging teacher enthusiasm for teacher support changes the explained variance by only 2 percentage points. This, of course, does not mean that a teacher can decide to either give students good explanations or to show their appreciation for the subject and for teaching it, and expect that both approaches will result in equally positive emotional experiences for the students. It means that teachers who show students that they are interested and have positive emotions towards the subject tend to do all of these things. The increased predictive performance of the complex model, compared to single-construct models, supports the assumption made earlier in this paper that a multivariate perspective is necessary to understand how different learning situations affect students' emotional experiences. However, there is still a need to investigate in more detail how different characteristics of students and learning situations together influence students' emotions.

6.2 Understanding the relationship between students' emotional experience and the most important predictive variables

The importance of motivation type and perceived learning for students' emotions may be understood by way of different theories of motivation. However, the results seem to be particularly well explained by self-determination theory. According to SDT, people have basic psychological needs that, when fulfilled, elicit positive emotional reactions. One of these needs is autonomy. Thus, the more intrinsic or internalized a motive for performing an activity is (represented by a high score on the motivation type variable), the more the need for autonomy is fulfilled and the more positive reactions are evoked. A correlation between motivation type and emotions has also been found in other contexts (see Ryan & Deci, 2000, for a brief summary). Another basic need is the feeling of competence. Thus, when students in the study perceive that they have learned (represented as high scores on the variable perceived learning), their feeling of competence increases, and when a goal or need is met people tend to feel positive emotions.

6.3 Understanding the relationships between the most important personal and situational variables

The multivariate approach of the study allows for an integrated picture of students' perceptions and beliefs about their learning and the teaching. The study shows that both of the personal variables that were most associated with students' emotional experiences, i.e., motivation type and perceived learning, were also associated with the most important situational variables, which are directly manageable by the teacher. The relationship between these situational variables and motivation type also fits well with self-determination theory, which states that "social contextual conditions that support one's feelings of competence, autonomy, and relatedness are the basis for intrinsic motivation and becoming more self-determined with respect to extrinsic motivation" (Ryan & Deci, 2000, p. 65). Firstly, when it comes to extrinsic motivation:

> Because extrinsically motivated behaviors are not inherently interesting and thus must initially be externally prompted, the primary reason people are likely to be willing to do the behaviors is that they are valued by significant others to whom they feel (or would like to feel) connected…This suggests that the ground work for facilitating internalization is providing a sense of belongingness and connectedness to the persons…disseminating the goal. (Ryan & Deci, 2000, p. 64).

Such relatedness to the teacher, and adoption of her goals for the mathematical activity, is more likely to be found when a teacher treats the students in a nice way and shows that he or she likes to teach her students (Berg, 2005). If the teacher also shows that he or she thinks mathematics is fun, and clearly conveys the teaching goals, the students will understand what goals this significant other is valuing (including the idea that mathematics is fun). Thus, the variables of teacher enthusiasm and clarity of goals would facilitate a relatively autonomous extrinsic type of motivation. Also, by providing a frame of reference, clear understandable goals help students feel competent. The variable of teacher support includes students' perceptions of explanations and structure provided, which directly affects their sense of competence and, consequently, their more autonomous forms of extrinsic motivation. Activities that have positive emotional value, such as those that have the appeal of novelty, are a prerequisite of intrinsic motivation (Ryan & Deci, 2000). According to SDT, autonomy support is critical if an external regulation is to be integrated, rather than introjected, and, consequently, also to a more autonomous form of motivation.

The connection between these situational variables and students' perceived learning is quite straightforward. Autonomy support includes showing faith in students' capabilities. Clear lesson goals better equip students to evaluate whether the goals have been met, and therefore offer them a better chance of experiencing success. Teaching that provides explanations that are understood, that keeps track of students' work and when needed helps them initiate and sustain their work, and that uses faulty answers constructively (teacher support) should clearly be connected to perceived learning and successful task-solving. Novel tasks and teacher enthusiasm, should be associated, via increased motivation and motivation type, with task solving success and perceived learning.

6.4 Limitations and further research

The present study has identified important variables for explaining positive emotional experiences during mathematics learning and suggests a direction for teachers who wish to enhance students' emotional experiences. The study is based on students perceptions of their learning situation and own behavior. Although these perceptions are highly relevant in emotion and motivation research, this makes it difficult to advice on exactly how to design a favorable learning situation (since the same situational features probably may be perceived, and thus described, differently by different students). Furthermore, although theory provides some guidance, the correlational results tell little about the mechanisms behind how personal and situational characteristics contribute to the emotions measured in this study. Hence, further research, including 'objective' descriptions of the situations in addition to students perceptions, about how the interaction of different variables affects students' emotions would help to deepen our understanding of how to provide beneficial learning situations. For example, it has been argued that characteristics of the learning situation could have different influences on students of different epistemological beliefs (Domin, 1999; Finster, 1989). That is, even though a certain population of students would benefit from, for example, autonomy supportive teachers, a subgroup of these students might not. In this case, autonomy support might be less beneficial for students who hold dualistic (rather than holistic/relativistic) epistemological beliefs. Such students might have more difficulty handling responsibility for their own learning and constructively using teachers’ autonomy support. A more thorough understanding of the interactions of the variables that are important for students’ emotions would be of much use for teachers who try to teach in a way that takes students’ individual needs into account.

7 References

Ainley, M., & Ainley, J. (2011). Student Engagement with Science in Early Adolescence: The Contribution of Enjoyment to Students' Continuing Interest in Learning about Science. [Reports - Research]. *Contemporary Educational Psychology, 36*(1), 4-12.

Artino, A. R., & Jones, K. D. (2012). Exploring the Complex Relations between Achievement Emotions and Self-Regulated Learning Behaviors in Online Learning. [Reports - Research]. *Internet and Higher Education, 15*(3), 170-175.

Ashby, F. G., Isen, A. M., & Turken, U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review, 106*(3), 529-550.

Berg, C. A. R. (2005). Factors related to attitude change toward learning chemistry among university students. *Chemistry Education Research and Practice, 6*(1), 1-18.

Black, A. E., & Deci, E. L. (2000). The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective. *Science Education, 84*(6), 740-756.

Bodin, M., & Winberg, M. (2012). Role of beliefs and emotions in numerical problem solving in university physics education. *Phys. Rev. ST Phys. Educ. Res., 8*, 010108. doi: 10.1103/PhysRevSTPER.8.010108

Bråten, i., & Strömsö, H. (2006). Predicting achievement goals in two different academic contexts: a longitudinal study. *Scandinavian Journal of Educational Research, 50*(2), 127-148.

Carver, C. S., & Scheier, M. F. (1990). Origins and Functions of Positive and Negative Affect:: A Control-Process View. *Psychological Review, 97*(1), 19-35.

Covington, M. V. (2000). Goal theory, motivation, and school achievement: an integrative review. *Annual Review of Psychology, 51*(1), 171-200.

Csikszentmihályi, M. (1990). *Flow: the psychology of optimal experience*. New York: Harper and Row.

DeBacker, T. K., & Crowson, H. M. (2006). Influences on cognitive engagement: Epistemological beliefs and need for closure. *British Journal of Educational Psychology, 76*(3), 535-551.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behaviour*. New York: Plenum Press.

Deci, E. L., & Ryan, R. M. (1999). Academic Self-Regulation Questionnaire (SRQ-A). *Self-Determination Theory: An Approach to Human Motivation & Personality* Retrieved January 21., 2011

Domin, D. S. (1999). A Review of Laboratory Instruction Styles. *Journal of Chemical Education, 76*(4), 543-547.

Eagly, A. H., & Chaiken, S. (1993). *The psychology of attitudes*. Orlando FL: Harcourt Brace College Publishers.

Elliot, A. J., & Covington, M. V. (2001). Approach and Avoidance Motivation. *Educational Psychology Review, 13*(2), 73-92.

Elliot, A. J., & Murayama, K. (2008). On the Measurement of Achievement Goals: Critique, Illustration, and Application. *Journal of Educational Psychology, 100*(3), 613-628.

Eriksson, L., Johansson, E., Kettaneh-Wold, N., Trygg, J., Wikström, C., & Wold, S. (2006). *Multi and megavariate data analysis. Part I: Basic principles and applications* (Second ed.). Umeå: Umetrics Inc.

Finster, D. C. (1989). Developmental instruction part 1: Perrys model of intellectual development. *Journal of Chemical Education, 66*(8), 659-661.

Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist, 56*(3), 218-226. doi: 10.1037/0003-066x.56.3.218

Fredrickson, B. L., & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought - action repertoires. *Cognition & Emotion, 19*(3), 313-332. doi: 10.1080/02699930441000238

Goetz, T., Hall, N. C., Frenzel, A. C., & Pekrun, R. (2006). A hierarchical conceptualization of enjoyment in students. *Learning and Instruction, 16*, 323-338.

Harackiewicz, J. M., Barron, K. E., Tauer, J. M., & Elliot, A. J. (2002). Predicting Success in College: A Longitudinal Study of Achievement Goals and Ability Measures as Predictors of Interest and Performance From Freshman Year Through Graduation. *Journal of Educational Psychology, 94*(3), 562-575.

Hiebert, J. (2003). What research says about the NCTM standards. In J. Kilpatrick, W. G. Martin & D. Schifter (Eds.), *A research companion to principles and standards for school mathematics* (pp. 5-23). Reston, VA: National Council of Teachers of Mathematics.

Hofer, B. K. (2004). Exploring the dimensions of personal epistemology in differing classroom contexts: Student interpretations during the first year of college. *Contemporary Educational Psychology, 29*, 129-163.

Holland, A. C., & Kensinger, E. A. (2010). Emotion and autobiographical memory. *Phys Life Rev, 7*(1), 88-131. doi: 10.1016/j.plrev.2010.01.006

S1571-0645(10)00007-2 [pii]

Izard, C. E. (2007). Basic Emotions, Natural Kinds, Emotion Schemas, and a New Paradigm. *Perspectives on Psychological Science, 2*(3), 260-280. doi: 10.1111/j.1745-6916.2007.00044.x

Kensinger, E. A. (2009). Remembering the Details: Effects of Emotion. *Emot Rev, 1*(2), 99-113. doi: 10.1177/1754073908100432

Moore, W. S. (1994). Student and faculty epistemology in the college classroom: The Perry schema of intellectual and ethical development. In K. W. Prichard & S. R. McLaran (Eds.), *Handbook of college teaching theory and applications* (pp. 46-67). Westport: Greenwood.

Op 't Eynde, P., & Turner, J. E. (2006). Focusing on the Complexity of Emotion Issues in Academic Learning: A Dynamical Component Systems Approach. [Reports - Research]. *Educational Psychology Review, 18*(4), 361-376.

Pekrun, R. (2006). The Control-Value Theory of Achievement Emotions: Assumptions, Corollaries, and Implications for Educational Research and Practice. *Educational Psychology Review, 18*(4), 315-341.

Pekrun, R., Elliot, A. J., & Maier, M. A. (2006). Achievement goals and discrete achievement emotions: A theorethical model and prospective test. *Journal of Educational Psychology, 98*(3), 583-597.

Pekrun, R., Goetz, T., Daniels, L. M., Stupnisky, R. H., & Perry, R. P. (2010). Boredom in Achievement Settings: Exploring Control-Value Antecedents and Performance Outcomes of a Neglected Emotion. [Reports - Research]. *Journal of Educational Psychology, 102*(3), 531-549.

Pekrun, R., Goetz, T., & Perry, R. P. (2005). Achievement emotions questionnaire: User's manual. Munich: Department of Psychology, University of Munich.

Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Academic Emotions in Students' Self-Regulated Learning and Achievement: A Program of Qualitative and Quantitative Research. *Educational Psychologist, 37*(2), 91-105.

Reisberg, D., & Heuer, F. (2004). Memory for emotional events. . In D. Reisberg & P. Hertel (Eds.), *Memory and emotion.* (Vol. 3-41). New York: Oxford University Press.

Ryan, R. M., & Connell, J. P. (1989). Perceived locus of causality and internalization: Examining reasons for acting in two domains. . *Journal of Personality and Social Psychology* (57), 749-761.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology, 25*(1), 54-67.

Schacter, D. L. (2011). *Psychology* New York, NY Worth Publishers.

Scherer, K. R. (2001). Appraisal Considered as a Process of Multi-Level Sequential Checking In K. R. Scherer, A. Schorr & T. Johnstone (Eds.), *Appraisal Processes in Emotion: Theory, Methods, Research* (pp. 92–120). Oxford: : Oxford University Press.

Scherer, K. R. (2005). What are emotions? And how can they be measured? *Social Science Information, 44*(4), 695-729. doi: 10.1177/0539018405058216

Schunk, D. H., Pintrich, P. R., & Meece, J. L. (2008). *Motivation in education: theory, research and applications* (3 ed.). Upper Saddle River, New Jersey: Pearson Education, Inc.

Schutz, P. A., & DeCuir, J. T. (2002). Inquiry on Emotions in Education. *Educational Psychologist, 37*(2), 125-134.

Umetrics. (2009). SIMCA-P+ (Version 12.0) [Computer software]. Umeå: Umetrics.

Weiner, B. (1985). An attributional theory of achievement motivation and emotion. *Psychological Review, 92*(4), 548-573.

Wigfield, A., & Eccles, J. S. (2000). Expectancy-Value Theory of Achievement Motivation. *Contemporary Educational Psychology, 25*(1), 68-81.

Winberg, T. M., & Berg, C. A. R. (2007). Students' cognitive focus during a chemistry laboratory exercise: Effects of a computer simulated prelab. *Journal of Research in Science Teaching, 44*(8), 1108-1133.

Winberg, T. M., Hellgren, J. M., & Palm, T. (2014). Stimulating positive emotional experiences in mathematics learning: influence of situational and personal factors. *European journal of psychology of education*. doi: 10.1007/s10212-014-0220-y

Windschitl, M., & Andre, T. (1998). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs. *Journal of research in science teaching, 35*(2), 145-160.

Figure Captions

Fig.1 Loading plot of the top-model, predicting students' positive activating emotions (indicated by the star) during a mathematics lesson. Predictor variables (triangles) are students' general thoughts about mathematics and learning as measured in questionnaire one (italicized) and their perceptions of the characteristics of the specific lesson, as measured in questionnaire two