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Empirical study

Stress and emotions during experiments in biology classes: Does the work setting matter?

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ABSTRACT

Experiments are a complex teaching method carrying a high cognitive load and the risk of failure, which both may induce stress among students. However, it remains unclear if the work setting modulates physiological, subjective, and/or emotional stress responses during experiments. In a randomized experimental field study school students ($N = 104$) either watched a biology experiment on video (passive condition), conducted the experiment on their own (active condition) or in small groups (interactive condition). Meanwhile, their subjective stress perception, heart rate variability (HRV), salivary cortisol concentration, and achievement emotions were assessed. In the active condition we observed the strongest subjective and HRV stress responses, followed by the interactive condition. Students of the passive condition displayed the weakest stress reactions. Students of the other two conditions showed a weakened diurnal cortisol decrease, indicating more stress. Across conditions, enjoyment dropped and boredom increased, most pronounced in the passive condition. Moreover, there were some associations between subjective, emotional and physiological stress responses. The findings suggest that conducting experiments alone carries the risk of self-attributed failure signified by elevated stress. In contrast, conducting an experiment in a group is less stressful, as others may constitute a source of support. Watching others conduct an experiment carries a low risk of failure and, thus, the lowest stress responses, but comes with the cost of minimized enjoyment and maximized boredom.

1. Introduction

Experiments are an important learning method in science education, as they enable students to acquire scientific knowledge, develop scientific reasoning skills (Engelmann & Fischer, 2014), obtain insights into scientific methods, and develop problem-solving competencies (Barzel, Reinhoffer, & Schrenk, 2012; for a review, see e.g., Hofstein & Lunetta, 2003). Despite their benefits, many students express dislike about experiments up-front, especially during adolescence, but tend to become interested once they have mastered hands-on experiments themselves (Carmona Miranda, 2012; Dohn, Fago, Overgaard, Madsen, & Malte, 2016). A reason for the disapproval could be the fact that experimental work settings constitute complex learning environments that carry the risk of failure and negative performance evaluations and may, thus, elicit bodily-affective responses, in particular the experience of stress, discrete emotional states and accompanying physiological responses (Alsop & Watts, 2003; Engelmann & Fischer, 2014; Hofstein & Lunetta, 2003; Pekrun & Stephens, 2012). The consequences may be costly, as aversive emotions may predict lower engagement and performance in science subjects (Randler, Hummel, & Wüst-Ackermann, 2013; Wigfield, Tonks, & Klauda, 2009), and may prevent students from pursuing studies or a career in science (Chow, Eccles, & Salmela-Aro, 2012; Osborne & Dillon, 2008).

Research within the context of regular classroom settings suggests that the experience of discrete emotional states, and thus

Abbreviations: AEQ, Achievement Emotions Questionnaire; ANOVA, Analysis of Variance; AUCg, area under the curve with respect to ground; AUCi, area under the curve with respect to increase; ANS, autonomic nervous system; BMI, body mass index; CVT, Control-Value Theory; DNA, deoxyribonucleic acid; HRV, heart rate variability; HPA-axis, hypothalamus pituitary adrenal axis; LF/HF, low frequency/high frequency; OC, oral contraceptives; rmsSD, root mean square of successive differences; VAS, Visual Analogue Scale.

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their effects on performance, depend on a number of situational characteristics (e.g., Pekrun, 2006; Pekrun & Stephens, 2012). For the context of science education, there is evidence that the features of the learning environment (e.g., control over learning activities) and the interaction with teachers and peers (e.g., participation in class) trigger different emotions, which in turn affect the use of learning strategies, achievement motivation, class engagement, and academic performance (e.g., Bellocchi, Quigley, & Otrel-Cass, 2017; Sinatra, Broughton, & Lombardi, 2014). Only few studies have investigated emotions when students perform experiments themselves, mostly focusing on negative emotions like anxiety in physics (Gungor, Eryilmaz, & Fakioglu, 2007) or disgust in biology (Randler et al., 2013). A recent study examined both negative and positive emotions: When students conducted experiments, they experienced high enjoyment and low boredom, and reported increasing situational competence in handling the topic (Itzek-Greulich et al., in press). However, it remains largely unknown which characteristics of the work setting, especially if independent from a specific content, are crucial in shaping the students' bodily-affective responses (cf. Alsop & Watts, 2003; Pekrun, 2006). First, the available studies mostly addressed negative emotions, neglecting the role of positive affect. Second, existing research on situational antecedents of emotions has seldom relied on a taxonomy of work settings which specifies the constellation of relevant situational features. Third, previous studies have rarely used a randomized experimental design.

Using Control-Value Theory of achievement emotions in learning settings (CVT; Pekrun, 2006) and Chi' taxonomy of work settings (Chi, 2009; Menekse, Stump, Krause, & Chi, 2013), the current study investigated perceived stress, positive as well as negative emotions, and accompanying physiological correlates in high school students who conducted a biology experiment under three constructive conditions, which were enriched either with passive, active, or interactive elements. All conditions included the same inquiry-based elements requiring the students to formulate hypotheses, record the results, and reflect upon them. The experiment concentrated on the domain of biology for two reasons: Many high school graduates suffer from fragmented knowledge, and thus struggle in introductory biology courses at college (Harackiewicz et al., 2014). On the other hand, domain-specific knowledge in biology can easily be built up, as previous research identified a link between affective factors and learning especially when students are confronted with inquiry-based approaches like experiments (Dohn et al., 2016). The findings of our study may help to design hands-on experiments that induce low to moderate levels of (activating) stress and positive emotions like enjoyment, but reduce negative emotions like boredom which may have positive effects on students' performance and their attitudes towards science.

1.1. Perceived stress and emotions in academic settings

In learning settings, students may encounter different levels of perceived stress and bodily-affective responses (Alsop & Watts, 2003; Pekrun, 2006; Pekrun & Stephens, 2012). Appraisal emotion theories define stress as a temporary psychological state accompanied by intense arousal which emerges if a situation or a task is appraised as challenging or threatening (Lazarus, 1991). When individuals consider a stressful situation to exceed their coping capabilities, threat appraisals occur. In response, debilitating stress and aversive negative emotions like anxiety may arise. If the person appraises the stressor as challenging the demands are perceived as manageable. Hence, activating levels of stress are evoked which are often accompanied by positive emotions like enjoyment.

Introducing CVT, Pekrun and colleagues (Pekrun, 2006; Pekrun & Stephens, 2012) refined these propositions for the context of learning settings. According to CVT, students appraise potentially stress-inducing characteristics of the educational environment on two appraisal dimensions: (1) subjective control over achievement activities and outcomes and (2) the value attached to them. Achievement activities refer to all behaviors that enable students to deliver academic performance. Examples comprise dealing with external demands and performance evaluations (e.g., when giving a presentation), self-regulation (e.g., during learning), or social interactions with peers (e.g., in study groups) and teachers (e.g., during class). The experience of control is determined by prospective mastery expectations like self-efficacy beliefs as well as retrospective attributions. Value appraisals, on the other hand, signify whether students rate these activities and outcomes as positive or negative and the extent to which they are considered as personally relevant.

Depending on the situational characteristics, and subsequent control and value appraisals, discrete positive (e.g., hope or enjoyment) and/or negative emotions (e.g., anxiety or boredom) may co-occur. Emotions are conceptualized as a coordinated set of affective, cognitive, physiological, and behavioral components (Pekrun & Stephens, 2012). Achievement emotions are defined as emotions that arise in relation to achievement activities and/or subsequent outcomes. When students conduct experiments, predominantly activity-related achievement emotions are expected to occur, with enjoyment (positive, high activation) and boredom (negative, low activation) being the most significant. On the other hand, anxiety represents the most important outcome-related achievement emotion (Itzek-Greulich et al., in press; Muis et al., 2015; Pekrun & Stephens, 2012).

1.2. Physiological stress correlates in academic settings

Besides triggering emotions and subjective stress, academic settings may also elicit physiological stress responses that can be measured through increases in the cortisol concentration and changes in heart rate variability (HRV) measurements (e.g., Hjortskov et al., 2004; Minkley & Kirchner, 2012). When someone faces a stressor, the secretion of cortisol is activated via the hypothalamus pituitary adrenal axis (HPA-axis), leading to a cortisol increase in the saliva, which peaks about 20 min later. Also, an attenuation of the natural diurnal cortisol decrease, which is characterized by a relatively stable peak concentration about 30 min after awakening and a continuous decrease thereafter, can be interpreted as a stress response (Foley & Kirschbaum, 2010; Hellhammer, Wüst, & Kudielka, 2009; Kirschbaum, Tietze, Skoluda, & Dettenborn, 2009). The majority of research has focused on acute stress during examinations, which were identified as social-evaluative stressors that lead to an increase in the cortisol concentration, at least directly before the examination (e.g., Dickerson & Kemeny, 2004; Spangler, Pekrun, Kramer, & Hofmann, 2002). Although, such an acute hormonal stress response can lead to allostasis and adaption (McEwen, 1998), chronic elevated cortisol concentrations can cause serious health problems (McEwen, 1998; Noll & Kirschbaum, 2006; Rensing, Koch, Rippe, & Rippe, 2006) and impair memory retrieval (Wolf, 2009), which may influence academic performance.

Besides, the autonomic nervous system (ANS) is activated if someone is confronted with a stressor. In contrast to the HPA-axis, the ANS ensures a much more rapid adaptation to stressful situations as it is based on nervous signaling instead of a hormonal cascade (Baert, Casier, & De Raedt, 2012; Kemeny, 2003). The ANS can be subdivided into two subsystems: Under stress, the sympathetic nervous system enables the organism to adapt rapidly to demanding situations, while the parasympathetic nervous system