Mixed Emotions:
Network Analyses of Intra-Individual Co-occurrences Within and Across Situations

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Abstract

This study revisits the structure of emotions by employing a co-occurrence network analysis. While previous studies have examined the structure of emotions primarily through *inter-individual* correlations, we investigated how often and which specific positive and negative emotions occur together *within individuals*. Two studies were conducted with high school students, one (N=21,678) using retrospective emotion measures (open-ended questions and 28 rated items) and the other (N = 471) using in-the-moment emotion measures (experience sampling).

As in previous studies, positive and negative emotion ratings were negatively correlated across individuals, and this negative correlation became stronger when measurement error was controlled. Nevertheless, network analyses of both the open-ended responses and of emotion rating scales found frequent co-occurrences between both positive and negative emotions within individuals and within situations. Across all networks, happy, tired, and stressed were among the most frequent emotions that occurred together with emotions of opposite valence. The network analyses presented in this article open new directions to the long-lasting debate about the structure of emotions by revealing co-occurrences that inter-individual correlations would not show.

Keywords: positive and negative emotions, structure of emotions, co-occurrence network analysis, intra-individual variation, experience sampling, mixed methods, PANAS

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1. Introduction

Positive and negative emotions occur together within individuals. For instance, students look forward to school anticipating feelings of joy while interacting with friends; and at the same time they might dread effortful schoolwork and boring classes. Emotion scholars have extensively debated for over 40 years whether positive and negative emotions were mutually exclusive, or if they were independent factors that sometimes occur together (e.g., Cacioppo & Berntson, 1994; Kaufmann, 2009; Russell & Carroll, 1999; Tellegen, Watson, & Clark, 1999). This debate about the structure of emotion has mostly been based on the analysis of correlations between positive and negative emotions *across* individuals. In contrast, it is not well understood how often and which positive and negative emotions are experienced together *within* individuals. Intra-individual analyses are needed to understand these occurrences (see e.g., Bergman & Magnusson, 1997; Molenaar, 2004; Reizle, 2013). Recent studies have started to examine intra-individual patterns of emotions, and found that positive and negative emotions co-occur in some situations and individuals (Goetz et al., 2014; Moeller, Salmela-Aro, Lavonen, & Schneider, 2015; Pekrun, Goetz, Titz, & Perry, 2002).

The present study extends this line of inquiry and applies intra-individual co-occurrence network analyses to examine how often positive and negative emotions were experienced together in a sample of high school students, and which specific pairs of positive and negative emotions occurred most frequently. While correlational analyses only indicate an overall trend of shared variation across individuals, the network analysis shows both rare and frequent co-occurrences between specific emotions within individuals. We compare this new method with the more common analyses of inter-individual correlations to discuss how conclusions about the structure of emotion differ systematically by applied analyses. In a first

study we assessed emotions as retrospective reports of typical experience using open-ended questions and frequency rating scales, while in study 2 we applied in-the-moment emotion ratings using the experience sampling method.

1.1 An old debate about the relationship between positive and negative emotions

Whether positive and negative emotions are independent or opposite poles of a bipolar scale has been discussed for over four decades. Past research has supported the claim that positive and negative emotions are negatively correlated (e.g., Frijda, 1986; Russell & Carroll, 1999; Smith & Ellsworth, 1985; Wundt, 1922), as well as the claim that positive and negative emotions are largely uncorrelated (e.g., Cacioppo & Berntson, 1994; Davidson, 1998; Diener & Emmons, 1985; Gray, 1981; Tellegen, Watson, & Clark, 1999). Recent approaches have tried to reconcile the debate by moving from the original question of whether positive and negative emotions are independent to the question of the circumstances leading to positive and negative affect being independent versus bipolar (Cacioppo, Gardner, & Berntson, 1999; Diener & Emmons, 1985; Diener, Larsen, Levine, & Emmons, 1985; Diener & Iran-Nejad, 1986; Feldman Barrett & Wager, 2006; Kaufmann, 2009; Tellegen, Watson, & Clark, 1999).

These integrative standpoints propose that the structure of positive and negative emotions is not static, but depends on both measures and causes of emotional experiences. For instance, the use of semantic opposites (happy – sad) leads to stronger negative correlations between positive and negative emotions, compared to scales that measure positive and negative emotions with diverse lists of not directly opposed adjectives (Feldman Barrett & Russell, 1988). Moreover, some studies argue that participants carry intuitive beliefs about the structure of emotions and tend to impose a bipolar structure on unipolar scales (Carroll & Russell, 1999). The structure of emotions also looks different on the level of situational states than the level of stable person characteristics (Ketonen, Dietrich, Moeller, Salmela-Aro, & Lonka, 2017; Schmukle, Egloff, & Burns, 2002; Vansteenlandt, Mechelen & Nezlek, 2005; Zelenski & Larsen, 2000). Vansteenlandt and colleagues (2005) found that positive and

negative emotions were negatively correlated within situations (state-level), while they were uncorrelated to very slightly correlated ($.15 \leq r \leq -.24$) across individuals (trait-level).

Furthermore, studies that control for confounding variables which affect both positive and negative emotions, such as approach motivation, dominance, measurement error, and acquiescence, tend to find lower correlations between positive and negative emotions than studies that do not control for these confounds (e.g., Green, Goldman, & Salovey, 1993; Harmon-Jones, Harmon-Jones, Abramson, & Peterson, 2009; Harmon-Jones & Harmon-Jones, 2010).

1.2 Intra-individual approaches to the structure of emotions

Growing evidence indicates that positive and negative emotions co-occur within individuals (e.g., Goetz et al., 2014; D'Mello, Lehman, Pekrun, & Graesser, 2012; Ketonen et al., 2017; Trampe, Quoidbach, & Taquet, 2015). For instance, a student can experience anxiety together with excitement, happiness, and interest in a learning situation (Moeller, Salmela-Aro, et al., 2015; Pekrun et al., 2002). Moreover, anxiety can co-occur with positive emotions and pro-active coping in situations which are perceived as challenging but controllable, while anxiety co-occurs with stress and negative emotions in situations perceived as demanding but uncontrollable (Jones, Meijen, McCarthy, & Sheffield, 2009). Likewise, stress can come accompanied with positive emotions for some individuals, and with negative emotions in others (e.g., Simmons & Nelson, 2007).

1.2.1 How to assess intra-individual co-occurrences of emotions

Since the structure of emotions can differ between persons and cultures (Feldman Barrett & Russell, 1998; Miyamoto, Uchida, & Ellsworth, 2010), we need more studies on the co-occurrences of positive and negative emotions within situations and individuals. Most studies about the structure of emotions have been limited to the analysis of correlations across individuals. Such inter-individual correlations do not necessarily describe the experiences of the studied individuals. For instance, a correlation between two variables can be negative

despite the fact that many of the studied individuals experience high levels of both variables (e.g., Molenaar, 2004; Reizle, 2013; Salmela-Aro, Moeller, Schneider, Spicer, & Lavonen, 2016).

A growing literature examines intra-individual correlations among positive and negative emotions. However, even analyses of intra-individual correlations are limited in that they only describe one trend (e.g., a significant positive correlation of moderate effect size) for a population; they do not provide information about subgroups in that population that might experience different constellations of the studied variables. For instance, Pekrun and colleagues (2002) examined intra-individual correlations between anxiety and interest across repeated assessments and found that this correlation was close to zero. Yet, the intra-individual correlations ranged from $-.80$ to $.80$ across respondents, potentially obscuring distinct groups: (1) individuals who felt interested in anxious situations, and (2) individuals who felt disinterested in anxious situations (see also Moeller, Keiner, & Grassinger, 2015). Such subgroups can be detected with cluster analyses. For example, in one study that conducted a cluster analysis of situational measures of boredom and positive affect, boredom occurred together with high positive affect in some situations, and with low positive affect in others (Goetz et al., 2014). One major disadvantage of cluster analyses, however, is that the method is not practical for examining co-occurrences among a large number of emotion items.

The present study employs a co-occurrence network analysis to examine intra-individual co-occurrences of positive and negative emotions. The advantage of this method is that it can handle large sets of emotion items and is able to detect distinct subgroups of co-occurrences. Co-occurrence networks provide visualizations and statistics that describe if and how often different variables occur together within the same frame of reference, which can be the same person or the same measurement time point (situation), or the same source of information (e.g., geographic location). For instance, co-occurrence network analyses are applied to describe which species occur together in the same geographic environments

(Araújo, Rozenfeld, Rahbek, & Marquet, 2011) and to investigate the changes in historic connotation of words (Wijaya & Yeniterzi, 2011). In psychology, most network analyses are used to study connections between individuals such as social networks (Wang, Iannotti, Luk, & Nansel, 2010). Some studies have used network analysis to visualize the strength of correlations between a set of variables, using networks where lines between two variables are proportional to the size of their correlations or regression weights. These approaches are receiving increasing attention and have been applied to the study of emotions (Bringmann et al., 2016; Constantini et al., 2015), clinical symptoms (McNally et al., 2014); and brain activity networks (Supekar, Menon, Rubin, Musen, & Greicius 2008). These networks examine (partial) correlations among variables and therefore give interesting overviews of the co-variance structure among emotions. However, they do not examine intra-individual co-occurrences as defined above and therefore do not tell *how often* emotions occur together within individuals or situations.

Co-occurrence network analysis used here provides additional information beyond that provided by correlation-based networks: (1) Two variables may frequently co-occur despite their negative correlation, which would only be detected in an intra-individual co-occurrence approach, and (2) Co-occurrence network analysis helps avoid a common misinterpretation of correlations: A strong positive correlation between two variables may lead a researcher to conclude that variable A is “high” when variable B is “high”, even when neither variable A nor variable B are rated as “high” by participants on the original response scale. For example, situational anxiety in everyday school situations is rarely rated above the scale midpoint; Moeller et al., 2015). Nevertheless, there is enough variation in the lower ranges of the response scale for anxiety to be positively correlated with other negative emotions reported in the same situations (Ketonen et al., 2017). Co-occurrence network analysis (but not correlation-based networks) would show how often (or rarely) genuinely high levels of two variables co-occur, as defined by a meaningful cut-off for “high”, see our Study 2 below).

In this paper we apply co-occurrence network analysis to both open-ended responses and rated scales to understand the intra-individual structure of emotions. In a similar approach, Trampe and colleagues (2015) examined intra-individual co-occurrences between emotions using experience sampling method data of about 11,000 participants (age range 14-74). The authors asked participants to report on a binary scale (yes/no) whether participants experienced 18 emotions in a given situation and found that positive and negative emotions occurred together in about 30% of all situations. The current study extends this approach to other measures of emotions, including open-ended responses and emotions rated on Likert-like response scales, in order to capture a larger number of emotions and in order to compare the insights provided by co-occurrence analysis versus correlation analysis. Furthermore, we assess emotions as both retrospective reports of typical experiences (Study 1) and in the moment experiences (using experience sampling method, Study 2).

1.3.2 The present research: Investigating intra-individual co-occurrences of emotions

The present research uses co-occurrence network analyses to describe which emotions are reported together *within* individuals. We examine how often positive and negative emotions co-occur, and which specific emotions are mentioned together. For this purpose, we conducted two studies, one in which we examine emotions that co-occur within the same individuals but not necessarily within the same situations, and a second study in which we examined in-the-moment co-occurrences of academic emotions in school situations.

In Study 1, we first examined which emotions are mentioned together when students are asked to freely name the three feelings they most frequently experience at school. Here, co-occurrence is defined as emotions mentioned together at typically experienced in the open-ended responses of the same individual. Second, also in Study 1, we developed a network analysis approach to examine intra-individual co-occurrences of highly rated emotion items. In this analysis, we define co-occurrence as two highly rated (above scale midpoint) emotions within the same *individual*. This newly developed analysis can show if and how

often students experience high levels of both stress and happiness, or any other pairwise combination of emotions. Third, we show which insights provided by network analyses go beyond what already is known using correlational methods.

In Study 2, we examined in-the-moment intra-individual co-occurrences of emotions within school situations in high school students using experience sampling method data. In this study, co-occurrence was defined as two highly rated (above scale midpoint) emotions occurring together within the same *situation*.

2. Study 1: Analysis of intra-individual co-occurrences of emotion ratings across time

2.1 Research Questions

In Study 1, both open-ended responses and emotion rating scales were used. First, we examined co-occurrences of emotions in the students' answers to the open-ended question "How do you typically feel at school?" (in RQ1 to RQ3).

RQ1: How often do students report positive and negative emotions together in their open-ended responses?

RQ2: What specific emotions are mentioned together, and how often?

RQ3: Which distinct clusters of emotion co-occurrences exist in the network of open-ended responses?

Next, we examined co-occurrences of highly rated emotions in the students' emotion ratings (RQ4 to RQ 6).

RQ4: How often do students report high ratings of positive and negative emotions together?

RQ5: Which specific highly rated emotions occur together within individuals, and how often?

RQ6: Which distinct clusters of such emotion co-occurrences exist in the network of highly rated emotions?

RQ7: How do inter-individual correlations between positive and negative emotions compare to the intra-individual co-occurrences observed in the network analysis? We expected to find low negative correlations between the subscales for positive and negative emotions of the PANAS (see Watson & Clark, 1999). In line with previous studies, we expected that these correlations would become substantially negative if the measurement error is taken into account in structural equation models (see Green et al., 1993). In addition, we examined the correlations between the most frequently co-occurring pairs of positive and negative emotions among the top ten most frequent pairs of co-occurring emotions.

2.2 Methods

2.2.1 Data collection procedures

The data were collected in an online survey. Participants were recruited through schools and a social media campaign (e.g., Twitter and Facebook posts, youth serving organizations). The link was accessed approximately 46,000 times. 21,678 students met the criteria for being included in the study, which were (1) U.S. residents (filtered by their IP address); (2) students in grades 9 through 12; (3) between 13 and 19 years old; (4) they provided at least six valid answers; and (5) they did not write nonsensical answers in their open responses that made us question their motivation to provide valid information (e.g., we excluded students who wrote “ggfdhgf”, “lizard” or “Less of a poophead” instead of emotions in their open responses).

2.2.2 Sample

The sample was diverse in terms of gender, ethnic background, age/school grade and socioeconomic status, school types and geographic location. There were 31.7% male participants, 64.9% female and 3.4% reported “other” gender identities. The sample was 55.9% White/Caucasian, 12.7% Hispanic, 12.3% Black/African-American, 8.7% Asian/Asian-American, 5.7% Biracial or Multiracial, and 4.6% reported other identities. Data was available from all 50 states and public and private schools were represented to a proportion similar to those in the total population (83.4% public schools, 12.8% private). The students were on average 15.9 years old ($SD = 1.11$), with 27.8% 9th graders, 25.5% 10th graders, 24.9% 11th graders and 21.7% 12th graders. The mean subjective socio-economic status rating was 6.46 ($SD = 1.96$); measured with a scale of 0 (worst off) to 10 (best off), based on Ostrove, Adler, Kuppermann, and Washington (2000).

2.2.3 Measures

Open-ended question

Students were asked “How do you typically feel when you are in school? List up to three feelings” followed by three blank fields. Each open answer was coded, and in total 480 different emotions were identified. Most students wrote one emotion per field, such as stressed, stress, or stressed out. Such similar terms were collapsed into one emotion label (in this case: stressed). Some students used longer answers, such as “I feel happy” and “Most of the time I feel happy” and these answers were coded into the corresponding emotion label (happy). Answers that included specific qualifying information, such as “happy with friends” were not collapsed under the general label happy, but kept separate. For each emotion label, valence was classified as negative, positive, or neutral (e.g., “indifferent”, and “neutral”) by two researchers (91.1% of agreement between the raters; all disagreements were resolved by discussion).

Emotion rating scales

Students were asked to rate how often they experienced each of 28 emotions on a scale from 0 (*never*) to 100 (*always*).

PANAS for children, short version. General positive and negative emotions were assessed using the short version for children of the Positive Negative Affect Schedule (PANAS; Ebesutani et al., 2012). This measure consists of two subscales, one tapping positive affect (items: joyful, cheerful, happy, lively, and proud; $\alpha = .90$) and another tapping negative affect (items: miserable, mad, afraid, scared, and sad; $\alpha = .84$).

Social emotions. We assessed emotions that reflect how students feel in social interactions with others. The scale of positive social emotions consisted of the items accepted, respected, connected, and grateful ($\alpha = .80$). The scale of negative social emotions consisted of the items lonely and ashamed (Spearman-Brown Coefficient = .65).

Academic emotions. Third, we assessed emotions that were not included in the previously described measures but were identified to be relevant by prior studies on academic emotions (e.g., Goetz et al., 2014; Pekrun, 2006). The positive academic emotions included feeling interested, hopeful, fun, confident, and relieved ($\alpha = .82$). The negative academic emotions included feeling hopeless, stressed, angry, nervous, bored, frustrated, and discouraged ($\alpha = .82$).

2.3 Analyses and Results

2.2.1 Intra-individual co-occurrences of emotions in open-ended answers

2.2.1.1 How often do students report positive and negative emotions together in their open-ended responses (RQ1)

Students were asked to list three emotions they frequently experienced at school. Positive and negative emotions could occur together in four potential patterns: (1) two positive and one negative emotion; (2) one positive and two negative emotion; (3) one positive and one negative emotion, and one neutral emotion; (4) one positive, one negative, and one missing emotion. Positive and negative emotions were mentioned together by 34.1% of all students (see Table 1). The most frequent constellation of mixed positive and negative emotions consisted of two negative and one positive emotion (20.4%). It should be noted that we examine co-occurrences of emotions within individuals, but not within specific situations, since we did not apply situation-specific measures. Thus, we can only conclude that 34.1% of the individuals who reported frequent positive emotions at school also reported frequent negative emotions at school. We cannot say whether students experienced these sequentially one after another, or at the same time.

Table 1

Frequencies of valence constellations in the three open answers

Constellation of valences of mentioned emotions	Co-occurrence of positive and negative	Relative frequency %
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	valences	
3 negative		31.1
2 negative, 1 positive	X	20.4
2 negative, 1 missing		14.3
2 positive, 1 negative	X	6.4
1 positive, 1 negative, 1 missing	X	5.9
3 words missing		4.9
1 negative, 2 missing		4.9
1 positive, 2 missing		3.0
3 positive		2.3
2 positive, 1 missing		2.2
2 negative 1 neutral		1.7
1 positive 1 negative 1 neutral	X	1.4
1 negative, 1 neutral, 1 missing		0.7
1 positive, 1 neutral, 1 missing		0.3
2 positive, 1 neutral		0.3
1 neutral, 2 missing		0.2
1 negative, 2 neutral		0.0
1 positive, 2 neutral		0.0
2 neutral, 1 missing		0.0
3 neutral		0.0

2.2.1.2 What specific emotions are mentioned together, and how often? (RQ2)

Because students reported a maximum of three emotions, there were up to three possible emotion co-occurrences per student. We conducted a co-occurrence network analysis using gephi, version 0.8.1-beta (Bastian, Heymann, & Jacomy, 2009). The list of all emotions was entered as a nodes table and the co-occurrences among the first, second, and third answer for all students were entered as an edges table.

The complete network graph can be seen in Figure S-1 (see supplemental online materials). In this graph, each observed emotion with at least one co-occurrence was plotted and represented by a bubble and a word tag. Such bubbles representing the words in the network are called nodes. Co-occurrences of words were visualized with gephi's ForceAtlas2 algorithm (Jacomy, Venturini, Heymann, & Bastian, 2014), in which nodes by default repel each other (move away from each other), while connected (co-occurring) nodes attract each other (get closer). Thus, nodes located close to each other tend to be directly or indirectly connected, meaning they are either mentioned together, have common neighbors, or few interconnecting nodes between them. In contrast, nodes that are located far away of each other tend to be less closely connected, meaning they are rarely mentioned together and do not share many directly or indirectly connected neighbors. The number of times an emotion was connected to different other emotions (the node degree) was proportional to the size of the word's bubble and word tag, meaning the more connected a word was with other words, the larger it appeared in the network. Co-occurrences of two emotions were represented by connecting lines. The number of times each connection was observed (the edge weight) was proportional to the thickness of that line.

The network was undirected, meaning it made no difference whether an emotion was written in the first, second, or third response field. In the graph of the complete network, emotions of positive valence were printed red, negative emotions blue, and neutral grey. The connecting lines between the emotions (the edges) were blue if connecting two negative emotions, red if connecting two positive emotions and purple if connecting a positive with a negative emotion (see Figure S-1 in the online materials).

The complete network of connections consisted of 480 nodes (i.e., emotion words) and 7,874 edges (i.e., distinct constellations of two words jointly mentioned by the same individual). The visual inspection of the network shows that positive emotion words clump together on one side of the network (lower right corner in Figure S-1) and negative emotion words clump together on the other side (upper left corner). The top ten emotions with the highest number of connections with distinct other emotions (i.e., nodes with the highest degrees) were: tired (node degree 393), stressed (node degree 372), bored (360), happy (353), anxious (293), annoyed (262), alone (237), sad (223), depressed (205) and frustrated (node degree 185).

Table 2 shows the ten most frequently co-occurring pairs of emotions. The most frequent combinations of words mentioned together were (1) tired-stressed (2,673 co-occurrences, reported by 12.3% of all individuals), followed by tired-bored (1,620 co-occurrences, 12.1% of all individuals) and tired-happy (1,570 co-occurrences, 7.2% of all individuals).

Table 2

Top ten most frequent connections (edges) between emotion words

Rank	Node 1	Node 2	Edge weight	% of all edges	% of all persons
1	Tired	Stressed	2,673	4.9	12.3
2	Tired	Bored	2,620	4.8	12.1
3	Tired	Happy	1,570	2.9	7.2
4	Stressed	Happy	1,165	2.1	5.4
5	Stressed	Bored	1,035	1.9	4.8
6	Bored	Happy	950	1.7	4.4
7	Annoyed	Tired	930	1.7	4.3
8	Anxious	Stressed	827	1.5	3.8
9	Anxious	Tired	773	1.4	3.6
10	Annoyed	Bored	635	1.2	2.9

Note. The edge weight indicates how often two words were mentioned together

Despite this tendency of words of the same valence to clump together, there were many co-occurrences between positive and negative emotions, particularly in the center of the network. These co-occurrences between positive and negative emotions are visualized in Figure 1. To give a better overview, this figure leaves out all edges between emotions of the same valence and only shows the 50 most frequently reported co-occurring positive and negative emotions (i.e., 50 mixed-valence edges with the highest weights). A figure of all mixed-valence edges can be found in the supplemental online materials (Figure S-2). The ten emotions that most frequently co-occurred with emotions of the opposite valence were happy (co-occurred with 184 different negative emotions), tired (co-occurred with 134 positive emotions), stressed (131 co-occurrences with positive emotions), bored (110 co-occurrences with positive emotions), anxious (92 positive emotions), annoyed (83 co-occurrences with positive emotions), excited (linked with 81 negative emotions), alone (linked with 67 positive emotions), okay (linked with 62 negative emotions), and nervous (linked with 58 positive emotions).

2.2.1.3 What distinct clusters of emotion co-occurrences exist in the network of open-ended responses? (RQ3)

To examine whether there were different types of co-occurrences between freely recalled emotion terms, we identified communities of connections in the network by running the in-build ‘modularity’ option in gephi (for details, see Blondel, Guillaume, Lambiotte, & Lefebvre, 2010). This procedure identifies eventual communities of sub-networks of emotions that are more frequently connected among each other than they are connected with emotions outside of that sub-network.

There were four sub-networks/clusters in the network (three large and one very small). As Table 3 shows, the largest sub-network consisted of predominantly (88.2%) negative emotions and included only few positive (7.5%) and neutral (4.3%) terms. The second largest sub-network consisted of high proportions of both negative (50.3%) and positive emotions (38.1%), we call it the mixed-valences cluster. The third sub-network consisted of predominantly positive emotions (71.6%). The fourth sub-network was very small and only consisted of two words (wishful and vacant) mentioned by only one person, and is therefore not interpreted.

Table 3

Open-ended responses: Frequencies of positive, negative, and neutral emotions in the three sub-networks

Emotions in the network	Mainly negative cluster (38.96% of all edges)	Mixed valences cluster (39.83% of all edges)	Mainly positive cluster (21.25% of all edges)
Negative	88.24%	50.26%	16.67%
Positive	7.49%	38.10%	71.57%
Neutral/Unclear	4.28%	11.64%	11.76%

Emotions with most connections to distinct other emotions in the ‘negative emotion cluster’ included feeling anxious, alone, sad, depressed, and nervous (see Table 4). In the ‘mixed valences cluster’, the emotions with most connections were tired, bored, stressed, happy, annoyed, and excited. This cluster represents the center of the overall network, meaning emotions with most connections (i.e., the nodes with the highest degrees; see Figure S-1 and Table 2). In the third, ‘positive emotion cluster’, the emotions with most connections were safe, good, okay, fun, and great (see Table 4).

Table 4

Top ten emotions in the three sub-networks and number of their connections

Mainly negative cluster		Mixed-valences cluster		Mainly positive cluster	
Top ten words	Degree within cluster	Top ten Words	Degree within cluster	Top ten words	Degree within cluster
Anxious	134	Tired	167	Safe	54
Alone	129	Bored	161	Good	52
Sad	119	Stressed	159	Okay	33
Depressed	110	Happy	146	Fun	29
Nervous	82	Annoyed	118	Great	29
Angry	79	Excited	85	Confident	27
Judged	77	Frustrated	83	Comfortable	27
Scared	69	Exhausted	78	Smart	27
Uncomfortable	57	Overwhelmed	72	Fine	24
Insecure	55	Content	68	Loved	23

2.2.2 Analysis of intra-individual co-occurrences of emotion ratings

The above reported network analysis was based on the written answers to an open-ended question. Such open-ended questions are not the most common emotion measures; more common is the approach of measuring emotions with rating scales. Therefore, we developed a network analysis approach for examining co-occurrences of highly rated emotion items as measured in common rating scales such as the PANAS. To our

knowledge, this is the first study to use network analysis for the analysis of co-occurring high scores in rating scales.

3.2.1 How often do individuals report high ratings of positive and negative emotions together? (RQ4)

We performed the co-occurrence network analysis of 28 rated emotion items.

Previously, co-occurrence meant that two emotions were recalled together by one individual (i.e., listing feeling happy and stressed). This definition could not be applied to rated items, because all items were rated by each student. Instead, we defined that two emotions co-occur if they are both rated highly by the same student (i.e., above the scale midpoint, equal or higher than 50 on a 0/never -100/always scale). The rationale for picking this cut-off was that (1) this scale midpoint intuitively distinguishes low from high ratings, and (2) every emotion that is experienced more than 50% of the time necessarily overlaps at some times with any other emotion that is experienced more than 50% of the time.

First, we examined how many students reported high levels of at least one positive and at least one negative emotion and found that this was true for 84.9% of all individuals. That indicates that some positive and negative emotions occur often together within individuals. In contrast, 9.1% of all individuals reported high levels of only negative emotions but not of any positive emotion, 3.2% reported high levels of only positive emotions but not of any negative emotion, and 2.8% reported only below scale-midpoint levels of both positive and negative emotions.

3.2.1 Which specific highly rated emotions occur together within individuals, and how often? (RQ5)

For the co-occurrence network analysis of rated emotions, we created a dataset that contained a list of all intra-individual pairs of highly rated emotions in the dataset (total of 2,047,165 emotion co-occurrences across all individuals). The network analysis of emotion ratings was conducted with the same program and algorithm as the previous network analysis of emotion words, see above. The 28 items can form 378 different pairs of co-occurring emotions, meaning the network consisted of 28 nodes and 378 different edges. Nodes again are represented by bubbles in the network, and edges by lines between the bubbles. Each of these edges (co-occurrences) can be reported multiple times across individuals. For instance, 17,258 students reported a co-occurrence (edge) of the items stressed and confident. This number of reports per edge is called the edge weight, and is proportional to the thickness of the line that represents the edge.

The complete graph of the resulting network can be seen in Figure S-3 in the supplemental online materials. Positive emotions clumped together mostly in the right corner and negative emotions mostly in the left corner, with some overlaps between these poles. The ten most frequent co-occurrences of highly rated emotions are reported in Table 5. Among these ten most frequent co-occurrences, seven pairs were co-occurrences among negative emotions. However, three co-occurrences were between positive and negative emotions: accepted-stressed, interested-stressed, and happy-stressed.

Table 5

Top ten most frequent connections (edges) between emotion ratings in the complete network

Rank	Node 1	Node 2	Edge weight	% of all edges	% of all persons
1	Bored	Stressed	14,639	0.72	67.53
2	Frustrated	Stressed	14,423	0.70	66.53
3	Bored	Frustrated	12,834	0.69	59.20
4	Nervous	Stressed	12,646	0.62	58.34
5	Frustrated	Nervous	11,088	0.54	51.15
6	Bored	Nervous	10,931	0.53	50.42
7	Accepted	Stressed	10,139	0.50	46.77
8	Interested	Stressed	9,529	0.47	43.96
9	Discouraged	Stressed	9,300	0.45	42.90
10	Happy	Stressed	9,287	0.45	42.84

Note. The edge weight indicates how often high ratings of two emotions were reported together within individuals.

Next, we found that 41.0% of the 2,047,165 observed co-occurrences were pairs of positive and negative emotions. A complete graph of all mixed-valence co-occurrences is shown in Figure 2. The ten most frequent mixed-valence pairs of co-occurring positive and negative emotions were: accepted-stressed (reported by 46.77% of all individuals), interested-stressed (43.96% of individuals), happy-stressed (42.84%), respected-stressed (42.67%), grateful-stressed (42.11%), accepted-bored (41.80%), confident-stressed (39.81%), proud-stressed (38.71%), happy-bored (37.87%), and respected-bored (37.65%). In other words, it happens quite often that students report high ratings for both positive and negative emotions.

3.2.2 Which distinct clusters of such emotion co-occurrences exist in the network of highly rated emotions? (RQ6)

As in the network analysis of open-ended emotion descriptions, we examined whether it was possible to identify distinct sub-networks, or clusters, within the overall

network. This analysis was again conducted using the modularity option in gephi. Two clusters were found, each comprising 50% of the nodes and distinguishing between positive emotion items in one cluster, and negative emotion items in the other cluster. This finding indicates that high ratings of one emotion tend to occur together with other highly rated emotions of the same valence. This analysis of sub-networks is strongly influenced by the edge weights, meaning the number of times a certain link occurred in the dataset.

The current analysis of sub-networks is based on different data than those for open-ended responses. The emotions reported in the open-ended responses varied strongly in their number of connections to other emotions. For instance, the emotion term stressed was connected to a large number of other emotions, while the emotion term apathetic was connected to only one other emotion (tired). In contrast, there was no such variation between node degrees in the network of rated emotions. Here, all highly rated emotions occurred together with all other emotions at least a couple of times. Therefore, the node degree is the same for all emotions. Since node degrees are similar for all emotions, the only varying network statistic that can influence the identification of sub-networks is the number of times each link between two emotions occurred in the dataset (the edge weight).

3.2.3 How do inter-individual correlations between positive and negative emotions compare to the intra-individual co-occurrences observed in the network analysis? (RQ7)

In order to point out the unique insight added by the co-occurrence network analyses, we compared it to more common analyses of inter-individual correlations

among emotion ratings. We analyzed correlations between positive and negative emotion rating scales (positive and negative PANAS, social, and academic emotions), as well as correlations between the mixed-valence emotion pairs that co-occurred most frequently in the network analysis (accepted-stressed, interested-stressed, and happy-stressed, see Table 5). In line with previous findings, we expected low to moderate negative correlations between positive and negative emotions. Furthermore, we estimated the measurement error-cleared correlation between the latent variables of positive and negative emotions with structural equation model in Mplus, to test whether this correlation would be substantially stronger and negative as reported by Green et al. (1993).

The correlations between the positive and negative scales on the PANAS, social emotions, and academic emotions scales were $r = -.38$, $r = -.43$, and $r = -.38$, respectively, demonstrating weak to moderate associations (for all intercorrelations, see Table S-6 in the online appendix), which is in line with previous findings (e.g., Diener et al., 1985; Gaudreau, Sanchez, & Blondin, 2006; Crawford & Henry, 2004). Also in line with previous findings (Green et al., 1993), the correlation between positive and negative affect became stronger when measurement errors were modelled explicitly in structural equation models. The correlation between the latent positive and negative variables was $r = -.52$ for the PANAS [$\chi^2(df) = 2224.851(33)$, $p = .000$; TLI = .981; CFI = .974; RMSEA = .091; SRMR = .056; social emotions: $r = -.48$; $\chi^2(df) = 9393.258(53)$, $p = .000$; TLI = .892; CFI = .866; RMSEA = .056; SRMR = .042; academic emotions: $r = -.63$; $\chi^2(df) = 1545.305(8)$, $p = .000$; TLI = .960; CFI = .925; RMSEA = .096; SRMR = .036].

Finally, we examined the correlations between the pairs of positive and negative emotions that most often co-occurred in the dataset (see Table 5). We found negative, but rather small correlations between all of these three pairs of emotions (accepted-stressed: $r = -.20$; interested-stressed: $r = -.14$; happy-stressed: $r = -.27$). Thus, in the same dataset where network analyses revealed substantial co-occurrences between positive and negative emotions, the same emotions were negatively correlated. That implies that co-occurrence network analysis reveals a structure that is easily overlooked if only correlations are examined.

2.4 Discussion

Study 1 investigated the structure of retrospectively recalled positive and negative emotions in high school students. While most previous studies examined the relatedness versus independence of emotions across individuals using correlational analyses (e.g., Gaudreau et al., 2006; Russell & Carroll, 1999; Tuccitto, Giacobbi, & Leite, 2009; Watson & Clark, 1997), our study examined the intra-individual co-occurrence of emotions using co-occurrence network analyses. We examined how often positive and negative emotions were reported together by individuals, and which specific emotions occurred together within the same individuals. First, we applied network analysis to examine co-occurrences among emotions assessed with open-ended questions. Second, we developed a new network analysis approach to study intra-individual co-occurrences among emotions measured with the more common Likert-like response scales.

Previous network approaches (Bringmann et al., 2016; Lee Pe et al., 2015) have examined partial correlations among emotions but to our knowledge only one study has previously addressed the question of *how often* positive and negative emotions occur

together within individuals (Trample et al., 2005). The here presented co-occurrence network analysis can reveal information that the previously applied correlation-based network approaches may have obfuscated. For example, a negative or zero correlation between two emotions may hide the fact that in some individuals the two variables may be positively associated while in others they may be negatively associated (Moeller et al., 2015; Pekrun et al., 2002). The frequency of co-occurrences would remain unknown if only correlations were examined.

Another difference between co-occurrence and correlation-based analyses is that co-occurrences refer to an absolute frame of reference (i.e., two discrete emotions being mentioned together, or high ratings of two emotions occurring together as measured in terms of scores on the original response scale). This can be meaningful in studies that are interested in the frequency of certain experiences occurring together. For example, a clinician studying comorbidity might be more interested in the absolute score of an answer (above a clinical cut-off) than in the relative rank of an answer in comparison to the sample distribution. Two symptoms may be strongly positively correlated and yet rated low across individuals, which would imply that they rarely reach a clinical cut-off. A strong positive correlation would not imply a comorbidity in this case.

Positive and negative emotions occurred together both in the open-ended responses and the rating scales (see Figures 1 and 2). One out of three individuals reported positive and negative emotions together in their open-ended responses (see RQ1). Even more individuals (84.9%) reported high ratings of at least one positive emotion together with at least one negative emotion; of all observed pairs of co-occurring high emotion ratings, 41.0% were combinations of positive and negative emotions (see

RQ4). This difference in frequencies is likely due to the fact that the open-ended questions only asked for the three most frequent feelings at school and students could draw on any emotion term in the English language, while the emotion ratings constrained participants to endorse a smaller set of specific emotions.

The network of emotion co-occurrences in the open-ended responses included three sub-networks, one consisting of mostly negative emotions, one consisting of mixed positive and negative emotions, and one consisting of mostly negative emotions (RQ3). The negative emotions stressed, tired, and bored frequently co-occurred with positive emotions, such as feeling happy (RQ2). While it was not possible to identify a sub-network of mixed-valence among rated emotions, we did find that high ratings of some negative emotions, such as stress, frequently occurred together with high ratings of positive emotions, such as feeling accepted, interested, and happy (RQ5). This corroborates similar findings from the first network of open-ended responses.

The mixed-valence sub-network was found in the network of open-ended responses (RQ3), but not in the network of highly rated items (RQ6). As discussed above, this does not imply that there were no co-occurrences between positive and negative emotions among rated items (see Figure 2). Rather, this finding means that the rated emotions of similar valence were more strongly interconnected with one another than they were with emotions of opposite valence. Furthermore, the identification of sub-networks is influenced by the method we developed to define co-occurrences among rated emotions. We defined that two emotions co-occurred if both were rated above the mid-point of the frequency scale. This was a conservative criterion for co-occurrence. If two emotions are rated as occurring more than 50% of the time, they by necessity overlap

at last some of the time (i.e., co-occur). However, co-occurrences are also possible below this cut-off. For instance, if a person feels stressed only 30% of the time, but feels at the same time interested in what they are learning, then stress and interest co-occur. These co-occurrences would not be detected with the cut-off employed in this study. The number and frequency of connections of one emotion to others is related to the overall frequency of times this emotion was reported. Therefore, a different cut-off would shift the frequencies of co-occurrences and likely increase the number of detectable sub-networks.

In this study, only the information about a pairwise co-occurrence is intra-individual, but the networks of those pairs are plotted across individuals. If readers see a line between the emotions happy and stressed, they know that these emotions occurred together within the same individuals. However, there is no way to know whether the emotion pair happy and stressed occurred in the same individuals as the emotion pair happy and bored. The overall network only gives an inter-individual summative overview of the intra-individual pairwise co-occurrences. An advantage of this representation is that the network analysis gives a quick overview of both rare and frequent pairwise co-occurrences. In particular, the less frequent co-occurrences would not be visible in other analyses methods.

It needs to be noted that we use the term co-occurrence to refer to different emotions that occur together *within individuals*, not within situations. This contributes a new perspective to the previously mostly inter-individual research on the structure of emotions. However, we could not examine whether the emotions that co-occur within individuals do so sequentially (one after another), or at the same time. Situation-specific

measures of positive and negative emotions are needed to study co-occurrences in this more narrow meaning – different emotions experienced at the same time. It has been argued that asking participants in retrospective questions to mentally aggregate their experiences over time may lead to memory biases and self-belief biases, and therefore be less valid than in-the-moment measures of emotions (see e.g., Goetz et al., 2013; Robinson & Clore, 2002; Takarangi et al., 2006). To address this limitation of the present study, Study 2 used in-the-moment measures of emotions.

3. Study 2: Analysis of in-the-moment co-occurrences of highly rated emotions

Study 2 examined in-the-moment co-occurrences of emotions. This was necessary because the structure of emotion may be different on the level of situations than on the level of individuals (e.g., Ketonen et al., 2017; Vansteenlandt et al., 2005). For this purpose we employed the experience sampling method to collect emotion ratings from students throughout their school days.

3.1 Research Questions

RQ8: How often do students report high ratings of positive and negative emotions together within the same situations? Based on results of Study 1 and previous findings by Trampe et al. (2015), we expected that positive and negative emotions would occur frequently together, within individuals and situations.

RQ9: Which specific highly rated emotions occur together within situations, and how often? Based on the results of Study 1, we expected that the feelings of tiredness, happiness, stress and boredom would often occur together with emotions of opposite valence.

RQ10: How do intra-individual (situation-level) and inter-individual (person-level) correlations among positive and negative emotions compare to the in-the-moment

co-occurrences observed in the network analysis? We expected to find low negative correlations between positive and negative emotions on both the level of situations and the level of individuals.

3.2 Methods

3.2.1 Data collection procedures

In-the-moment experiences of emotions were assessed using experience sampling method (ESM). We used the app of the LifeData Corp (2016), which runs on Android and iPhone smart phones. Over the course of four weeks, students filled out short surveys on their own smartphones at three time points during school lessons. All in-school ESM signals were timed to occur five minutes before the end of a class, to keep the interruptions in the classroom low. The data comprised 18,610 ESM responses / situations. The average number of completed ESM surveys per person was 39.43.

3.2.1 Sample

472 students from six public high schools in Connecticut were participated in the ESM study. The students were on average 15.8 years old (71.2% female). There were 28.4% 9th graders, 29.8% 10th graders, 28.7% 11th graders, and 13.1% 12th graders. Schools were selected to represent diverse social-economic backgrounds: 13.8% of our participants were from the four low income schools al of which had more than 96% of students eligible for free lunch. The other 86.2% of our participants went to the two high income schools in which only 5-6% of students were eligible for free lunch.

3.2.1 Measures

Emotions were assessed with 13 single items (enthusiastic, happy, interested, curious, calm, relaxed, frustrated, anxious, afraid, tired, sad, bored, and stressed) that were rated on a response scale of 1 (*not at all*) to 4 (*very much*).

3.3 Analyses and Results

The situational emotion ratings were dichotomized at the scale midpoint as in Study 1. For this analysis, we created a dataset that contained a list of all in-the-moment pairs of highly rated emotions in the dataset (total of 133,675 situational emotion co-occurrences). The network analysis of emotion ratings was conducted with the same program and algorithm as in Study 1. The 13 emotion items formed 78 different pairs of co-occurring emotions, meaning the network consisted of 13 nodes and 78 different edges. Nodes again are represented by bubbles in the network, and edges by lines between the bubbles. Each of these edges (co-occurrences) can be reported multiple times across situations by each individual and across individuals. The edge weight represented the number of times two highly rated emotions occurred together within a situation.

In addition, the correlations among emotions were examined. Since the data were nested with situations within individuals, a multilevel analysis was conducted in Mplus 7, Version 1.31 (Muthén & Muthén, 2012-2015), using the TYPE = TWOLEVEL command. The variation between situations was modelled on the within-level ('situation-level'), and the inter-individual variation of the stable emotion components was modelled on the between-level ('person-level').

The complete graph of the resulting network can be seen in Figure S-4 in the supplemental online materials. Positive emotions clumped together mostly in the lower

left corner and negative emotions mostly in the upper right corner. The ten most frequent co-occurrences of highly rated emotions are reported in Table 6. Among these ten most frequent co-occurrences, four pairs were co-occurrences among positive emotions, four were co-occurrences among negative emotions, and two were mixed-valence pairs of a negative and a positive emotion (calm-tired, happy-tired).

Table 6

Top ten most frequent in-the-moment co-occurrences (edges) between emotion ratings in the experience sampling method data

Rank	Node 1	Node 2	Edge weight	% of all edges	% of all situations	Situation-level correlation	Person-level correlation
1	Happy	Interested	5,792	4.33	31.12	.35*	.61*
2	Tired	Stressed	4,856	3.63	26.09	.27*	.69*
3	Calm	Relaxed	4,633	3.47	24.90	.53*	.97*
4	Tired	Bored	4,407	3.30	23.68	.29*	.61*
5	Happy	Calm	4,181	3.13	22.47	.39*	.63*
6	Happy	Relaxed	4,094	3.06	22.00	.43*	.69*
7	Calm	Tired	3,608	2.70	19.39	-.05*	-.27*
8	Happy	Tired	3,289	2.46	17.67	-.15*	-.26*
9	Bored	Stressed	3,277	2.45	17.61	.20*	.43*
10	Anxious	Stressed	3,253	2.43	17.48	.44*	.72*

Note. The edge weight indicates how often high ratings of two emotions were reported together within the same situation by the same individual. All correlations were significant on the $p \leq .05$ level.

3.3.1: How often do students report high ratings of positive and negative emotions together within the same situations? (RQ8)

In the experience sampling data, 37.04% of the 133,675 observed in-the-moment co-occurrences were pairs of positive and negative emotions, 32.05% were pairs of negative emotions, and 37.04% were pairs of positive emotions. A complete graph of all mixed-valence co-occurrences is shown in Figure 3.

3.3.2: Which specific highly rated emotions occur together within situations, and how often?(RQ 9)

The ten most frequent mixed-valence pairs of co-occurring positive and negative emotions were: calm – tired, happy – tired, relaxed – tired, calm – bored, relaxed – bored, happy – bored, happy – stressed, calm – stressed, interested – tired, and relaxed - stressed. These ten pairs of mixed emotions occurred in 9.2% to 19.4% of all situations; see Table 7.

3.3.3 How do situation-level and person-level correlations among positive and negative emotions compare to the in-the-moment co-occurrences observed in the network analysis? (RQ10)

Although mixed emotions occurred frequently within situations, the aforementioned pairs of negative and positive emotions were negatively correlated within individuals ($-.35^* \leq r_{within} \leq -.05^*$) and across individuals ($-.57^* \leq r_{between} \leq -.14^*$; all of which were significant at the .05 level; see Table 7).

Table 7

Top ten most frequent in-the-moment co-occurrences of mixed-valence emotion pairs in the experience sampling method data

Rank out of 78	Node 1	Node 2	Edge weight	% of all edges	% of situations	Situation-level correlation	Person-level correlation
7	Calm	Tired	3,608	2.70	19.39	-.05*	-.27*
8	Happy	Tired	3,289	2.46	17.67	-.15*	-.26*
11	Relaxed	Tired	3,192	2.39	17.15	-.10*	-.31*
15	Calm	Bored	2,677	2.00	14.38	-.06*	-.14*
21	Relaxed	Bored	2,293	1.72	12.32	-.11*	-.22*
24	Happy	Bored	2,047	1.53	11.00	-.23*	-.30*
25	Happy	Stressed	2,043	1.53	10.98	-.31*	-.35*
26	Calm	Stressed	2,022	1.51	10.87	-.32*	-.54*
28	Interested	Tired	1,973	1.48	10.60	-.15*	-.29*
31	Relaxed	Stressed	1,705	1.28	9.16	-.35*	-.57*

Note. The within-level represents the variation across situations, within individuals; the between-level represents the variation across individuals. All correlations were significant on the $p \leq .05$ level.

3.4 Discussion

Study 2 showed that positive and negative emotions co-occur frequently within the same situations, corroborating and extending the findings from Study 1. Importantly, neither intra-individual nor inter-individual correlations would have revealed this information, since positive and negative emotions were negatively correlated both on the level of situations, as on the level of individuals (see Table 7). It is therefore insightful to combine correlation-based analysis of the structure of emotions with examinations of the co-occurrence structure.

The most frequently co-occurring mixed-valence emotion pairs tended to be correlated rather low, on the situational level (e.g., calm-bored and calm-tired, within-level correlations -.05 and -.06). That low situation-level correlations can hide substantial co-occurrences of seemingly opposite affective experiences within learning situations has been shown before in a study by Pekrun and colleagues (2002). Together, these findings indicate that the structure of emotions differs between individuals and that the *average* correlation of two variables even on the situational within-level does not fully describe the co-occurrences that can be observed in a sample, which corroborates previous findings (e.g., Pekrun et al., 2002; Salmela-Aro et al., 2016). This is important, given that correlations are sometimes misleadingly labelled “co-occurrences” in the emotion literature (e.g., Vansteenlandt et al., 2005). Revealing the overlooked co-occurrences is one of the advantages of the here employed network analysis over previous network studies which have examined (partial) correlations among situational emotion measures (e.g., Bringmann et al., 2016; Lee Pe et al., 2015).

As study 1 before, study 2 suggests that the negative experiences of feeling tired, bored, and stressed are ambiguous in the sense that they frequently co-occur with positive as well as with negative emotions. This is supported by previous research, such as the study by Goetz and colleagues (2015) who described clusters of situations in which at least moderate levels of boredom occurred together with positive affect. Likewise, stress has been associated with positive emotions and motivation in situations in which students feel challenged but also feel

that they have the skills to keep up with current challenges (e.g., Schneider et al., 2016). That tiredness is associated with both positive and negative emotions may not be surprising given that it is not associated with a particular valence but rather labelled an “other affective states: fatigue” in the PANAS-X (Watson & Clark, 1994). Tiredness only becomes an aversive experience when individuals are prevented from sleeping, particularly if they then encounter emotional challenges (Goldstein et al., 2013), but tiredness may nevertheless occur together with happiness and even interest, as this study showed.

While it might not surprise that mixed emotions of the same activation level occur together (such as the low arousal pairs relaxed – tired, calm – tired, calm – bored), it may come as a surprise that low and high arousal emotions of opposite valence also occur together, like relaxation or calmness occur together with stress in 9-11% of all situations. This may indicate that adolescents use the term stress in ambiguous ways.

4. General Discussion

In two studies we examined the co-occurrence of positive and negative emotions. Study 1 assessed retrospective reports of emotions both in open-ended responses and rating scales and Study 2 employed the experience sampling method to assess in the moment experiences. Across both studies, we found that positive and negative emotions were experienced together within the same individuals and even the same situations.

The general findings about the structure of emotions stressed in our network analyses have been well known on a smaller scale in the study of specific emotions. For example, anxiety and interest co-occur in classroom settings (Moeller, Salmela-Aro, et al., 2015; Pekrun et al., 2002). Similarly, a number of studies found both positive correlates and positive outcomes of (moderate) stress (e.g., Folkman, 2008; Folkman & Moskowitz, 2000; Hardy & Parfitt, 1991; Simmons & Nelson, 2007). Although this research mostly did not examine co-occurrence of emotions, we can speculate that the differences in outcomes can in part be due to other positive or negative emotions accompanying stress. The present studies show that

positive emotions co-occur with stress and describe what specific emotions occur together with stress. For instance, stress co-occurs most often with happiness in the open-ended responses, but also with feeling excited, focused, interested, and motivated.

To demonstrate the unique information added by co-occurrence network analyses, we compared them with correlation analyses (RQ7, RQ10). As expected, positive and negative emotions were negatively correlated, with small to moderate effect sizes similar to those in previous studies (see Watson & Clark, 1997; Ketonen et al., 2017). These correlations became stronger in structural equation models that controlled for measurement error (Green et al., 1993). Although the inter-individual correlations suggested that relatively high ratings in negative emotions tend to come with low ratings in positive emotions, and vice versa, the network analyses indicated that positive and negative emotions were experienced together by many individuals. For example, in Study 1 there was a negative correlation between feeling stressed and accepted ($r = -.20$), but almost half of the participants (46.8%) highly rated both of these emotions. Inter-individual correlations only offer information about rank co-variation between variables, but do not inform whether high absolute scores of two variables co-occur. We therefore argue that the network analysis of intra-individual co-occurrences is more informative than inter-individual correlations if the research question asks if and how often individuals who mention or highly rate one emotion will also do so for another emotion.

Taken together, we conclude that network analysis can reveal co-occurrences of positive and negative emotions that are often overlooked in conventional correlation analyses. We replicated these findings in two different samples of high school students and with both trait-like and state-like measures. Positive and negative emotions co-occurred in individuals and within situations, while at the same time being negatively correlated. These often overlooked intra-situational or intra-individual co-occurrences can also be detected with other methods such as cluster analyses, but unlike these, network analysis can examine the co-occurrences among many different variables at a time. The added insight offered by co-

occurrence network analyses regards the questions of *how often* positive and negative emotions are experienced together within individuals, and which specific emotions are most likely to co-occur within persons. Our findings imply that the structure of positive and negative emotions differs between individuals, which supports previous findings by Ketonen et al. (2017), Schmukle et al. (2002) and Vansteenlandt et al. (2005). While one third of all participants reported both positive and negative emotions in their open answers, others reported predominantly negative or positive emotions (RQ1, RQ5). Future studies should examine which characteristics of individuals, contexts, and situations account for individual differences in the structure of emotions.

Our findings raise the question of the consequences of experiencing positive and negative emotions together. Although much previous research has emphasized the positive outcomes of positive emotions (Fredrickson, 2001; Reschly, Huebner, Appleton, & Antaramian, 2008), recent research pointed out that positive emotions can lead to negative outcomes (Gruber, Mauss, & Tamir, 2011; Gruber & Moskowitz, 2014). For instance, in the absence of specific action plans, positive and happy fantasies about desired goals had detrimental effects on the likelihood to actually achieve the fantasized goal (e.g., Oettingen & Mayer, 2002). Likewise, stress and exhaustion in some individuals and situations is associated with high motivation (Moeller, Keiner, et al., 2015; Moeller, Salmela-Aro, et al., 2015; Pekrun et al., 2002; Salmela-Aro et al., 2016). This suggests that students who often experience positive emotions are not necessarily those about whom teachers and parents do not need to worry. They can experience negative emotions at the same time as positive emotions, and the effects of these mixed-valence patterns of emotions on learning are not well known.

The method of co-occurrence network analysis complements more common correlation-based approaches, but also has some limitations. First, network analysis is a mainly exploratory approach. In most cases, such an analysis will result in some net graph

that can be explained or interpreted a posteriori. However, it is possible to formulate in advance specific hypotheses about, for instance, the existence or non-existence or frequency of co-occurrences between specific variables, and to see then if these expected co-occurrences are found in the expected numbers in the observed network. Some research might benefit from such exploratory approaches, and it is often possible to combine network analyses and stricter approaches of hypotheses testing in joint studies. Our findings of frequently co-occurring mixed emotions were replicated across two different samples and three different emotion measures and also corroborated previous findings (Trampe et al., 2015). Moreover, finding that tiredness, stress, boredom and happiness were particularly likely to occur with emotions of opposite valence was replicated across both studies.

Studying the structure of emotions requires well differentiated emotion measures, because characteristics of the emotion measures influence the structures that can be identified (Feldman Barrett & Russell, 1998). Emotion item sets are often limited in the number and aspects of assessed emotions and therefore can lead to findings that do not replicate with different item sets (Feldman Barrett & Russell, 1998). To get a more complete picture, we used an open-ended question in addition to rated emotion items. However, even in this case the identified structure can be influenced by the extent of participants' emotion vocabulary and their ability to describe the granularity of emotions. For instance, among the top ten terms in the sub-network of positive emotions were at least five very vague ones (good, great, okay, fun, fine, see Table 4). It might be that these rather vague terms are used because high school students do not have vocabularies large enough to describe more granular emotions. This in turn might inflate the number of connections of such vague terms to other emotions. For instance, 'fine' can describe a passive-aggressive rejection of help (when feeling upset), or a lighthearted feeling that everything is well (contentment).

Co-occurrence network analysis requires binary data and thus it was necessary to define a cut-off and dichotomize emotion ratings. Such dichotomization can be seen as

information loss. However, whether dichotomization equals information loss depends on the research question. For instance, if the research question asked what other emotions individuals experience in anxiety-provoking situations, it can be useful to dichotomize the anxiety variable at the scale point that distinguishes between item rejection and item endorsement. Correlation-based analyses would not answer that research question, because two variables can be highly correlated even if they both have low endorsement. For instance, situational anxiety and perception of challenge are positively correlated, but endorsement of both variables has been found to be low (at or below the mid-point of the rating scale) that we cannot conclude that highly anxious situations come accompanied with high challenges in a task (Schneider et al., 2016). Since the research on intra-individual co-occurrences is relatively new, there is not yet a consensual definition of what co-occurrence means. Indeed, there could be different valid definitions, depending on the nature of the questions being examined and data available.

In this article we defined co-occurrences as (1) two emotions being mentioned together in open-ended responses of the same individual in retrospective recall, (2) two highly rated emotions reported by the same individual in retrospective recall, and (3) two highly rated emotions reported by the same individual within the same situation. The third definition might be the strictest, but this strict frame of reference is not necessarily needed for every research question. Considering the strong focus on *inter*-individual analyses in previous studies on the structure of emotions, our *intra*-individual approach in Study 1 added new insights even without the in-the-moment measures of Study 2 (for a discussion of intra-versus inter-individual analyses, see also Bergman & Magnusson, 1997; Molenaar, 2004; Reizle, 2013). Importantly, an intra-individual and situation-specific approach such as experience sampling does not necessarily imply that ‘co-occurrences’ are studied: Although situation-level correlations have been labelled “co-occurrences” (e.g., Vansteenlandt et al., 2005), they do not tell how often two emotions occur together within the same situations. Because situation-

level correlations of ESM data are averaged across situations and individuals in classic multilevel analyses, they may overlook that there are different types of situations and individuals with different patterns of emotional co-occurrence (see e.g., Pekrun et al., 2002, and our study 2). For example, the situation-level correlation may be zero, thus suggesting that two emotions (e.g., anxiety and interest) do not co-occur within situations, despite of frequent in-the-moment co-occurrences of the same variables in that same sample (e.g., Pekrun et al., 2002).

Our findings may have practical implications for teachers, parents, and counsellors who assess and respond to emotional experiences of individual students. Knowing that negative emotions are not necessarily low when positive emotions are high implies that raising a student's positive emotions might not eliminate their negative emotions, such as stress, boredom, or loneliness. We believe that understanding the individual constellations (profiles) of specific emotions a student experiences is key to understanding their need for support.

Future research should examine contextual and personality factors that contribute to different emotion patterns. A next step should be to identify characteristics of situations and individuals that determine which emotions co-occur within specific situations or in certain contexts. Our measures were collected in the context of high schools, and it would be interesting to see in future studies whether the context influences the structure of emotions in network analyses. Correlation-based research has indicated that the structure of emotions is influenced by personal and contextual characteristics such as individual traits, culture, and characteristics of situations and days (Feldman Barrett & Russell, 1998; Miyamoto et al., 2010; Ketonen et al., 2017; Vansteenlandt et al., 2005). Systematic comparisons of our network approach in different contexts would help to understand how context characteristics determine the relations between specific emotion contents. For instance, we could imagine that highly challenging contexts such as the Olympic games for athletes or a grant proposal

deadline for researchers increase the experience of negative emotions even for individuals who love and feel positive about their work. The fact that we only studied high school students may limit the generalizability of our findings. However, that Trampe et al. (2015) found similarly frequent co-occurrences between mixed-valence emotions in their more diverse sample suggests that our findings might be relevant beyond the school context.

We believe that network approaches will help us to understand which structures of emotions occur under which circumstances and for which individuals. The next generation of research on the structure of emotions will have to address which specific emotions co-occur in which situations and which individuals are more likely to experience constellations of positive and negative emotions, over time or within specific situations. The scope of possible applications is broad, and we hope that this study can open new horizons for the research on intra-individual variation.

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6. Appendix

Table S-6

Inter-correlations between positive and negative emotion scales (bold)

	PANAS Positive	Social positive	Academic positive	PANAS negative	Social negative	Academic negative
PANAS positive		.75**	.85**	-.38**	-.34**	-.41**
Social positive			.75**	-.40**	-.43**	-.40**
Academic positive				-.35**	-.31**	-.38**
PANAS negative					.69**	.80**
Social negative						.63**
Academic negative						

Note. ** $p \leq .001$.

7. Figures

Figure 1: The 50 most frequent co-occurrences between positive (white) and negative (grey) emotions in open answers. The thickness of each line is proportional to the number of individuals who reported the co-occurrence. The node location was cut-out of the complete network of all words.

Figure 2: Mixed-valence co-occurrences between positive (white), and negative (grey) emotions in the network of emotion ratings. The thickness of each line is proportional to the number of individuals who reported the co-occurrence.

Figure 3: Mixed-valence co-occurrences between positive (white), and negative (grey) emotions in the network of situational emotion ratings (ESM). The thickness of each line is proportional to the number of individuals who reported the co-occurrence.

8. Supplemental Online Materials

see: osf.io/4sgkb