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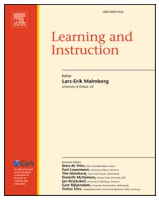
Learning and Instruction 80 (2022) 101628

Contents lists available at ScienceDirect

Learning and Instruction

journal homepage: www.elsevier.com/locate/learninstruc



The differences and similarities between curiosity and interest: Meta-analysis and network analyses

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ARTICLE INFO

Keywords:
Curiosity
Interest
Epistemic emotion
Experience sampling method
Network analysis

ABSTRACT

Three studies on the relationship between curiosity and interest are reported. The first study was a meta-analysis that examined the Pearson correlations between scales assessing curiosity and interest. Based on 24 studies (31 effect sizes), we found that the curiosity scales correlated with the interest scales at a moderate level ($r = 0.53$), but they had extremely high heterogeneity. The second and third studies applied network analyses (i.e., co-occurrence analysis and correlation-based analysis) to data that was collected using experience sampling method. Across the studies, we found that while the feelings of curiosity reflected feelings of inquisitiveness, the feelings of interest were aligned with positive affect such as enjoyment and happiness. Importantly, an asymmetrical pattern also was found in curiosity-interest co-occurrences: when feelings of curiosity occurred, the co-occurrence of feelings of interest was highly likely, but not so vice versa. Overall, our findings suggest that feelings of curiosity are special cases of feelings of interest that pertain to knowledge acquisition. Theoretical and practical implications of these findings are discussed.

1. Introduction

Curiosity, the human motive to seek information or knowledge (Grossnickle, 2016; Kidd & Hayden, 2015), has gained increasing attention. Most researchers work with Lowenstein's (1994) definition describing curiosity as information search aimed at closing a knowledge gap. Interest, on the other hand, refers to information search that is more general and ongoing (Hidi & Renninger, 2006, 2020). The relationship between curiosity and interest, particularly whether they are distinct, has been the subject of numerous discussions (see Peterson & Hidi, 2019 special issue). Both variables have been shown to be associated with learning (Hidi, 2001; Kang et al., 2009; Shah, Weeks, Richards, & Kaciroti, 2018), motivation (Tang & Salmela-Aro, 2021; Vogl, Pekrun, Murayama, & Loderer, 2020), and cognitive development (Malanchini, Engelhardt, Grotzinger, Harden, & Tucker-Drob, 2019; Renninger, Hidi, & Krapp, 1992). For this reason, curiosity is often conflated with interest in the research literature (Hidi & Renninger, 2019; Shin & Kim, 2019).

Is curiosity synonymous with interest (Schmidt & Rotgans, 2020; Silvia, 2008), or *are they two distinct constructs* (Grossnickle, 2016; Renninger & Hidi, 2015a)? Answering these questions is important to avoid a jingle-jangle fallacy. In addition, understanding the distinction between these two constructs has the potential to significantly impact educational practice, as effective interventions for each may be different if they are indeed distinct. Since many of the discussions so far have been mainly based on theoretical considerations, direct empirical examinations of the potential distinction between curiosity and interest are needed (see calls by Alexander, 2019; Hidi & Renninger, 2019; Pekrun, 2019).

In the present research, three studies were conducted. First, we performed a meta-analysis to examine the magnitude of the correlations between curiosity and interest. We examined the correlation between curiosity and interest, and more importantly, the heterogeneity of correlations depending on the scales used. Subsequently, we focused on the subjective feelings associated with curiosity and interest. We conducted two empirical studies (one focused on daily life, and the school day generally, and the other in the academic context of school classrooms)

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https://doi.org/10.1016/j.learninstruc.2022.101628
Received 25 May 2021; Received in revised form 10 April 2022; Accepted 6 May 2022
Available online 19 May 2022

that examined the relationship of the two constructs with network analyses of data collected using experience sampling method. This is a novel approach for comparing subjective feelings of curiosity and of interest. It was designed to allow consideration of similarities and differences among the constructs in relation to emotions and motivations during learning.

1.1. Curiosity and interest: similarities and differences

Renninger and Hidi (2015b) pointed out that the terms curiosity and interest have long been used interchangeably (e.g., Hall & Smith, 1903), and have been investigated as two distinct lines of research. Curiosity was first studied as human drive or motive (Berlyne, 1960, 1966); following this, it was examined either as a personality trait (Litman & Jimerson, 2004), or as a psychological state triggered by a knowledge/information gap (see reviews by Kidd & Hayden, 2015; Loewenstein, 1994). Interest, in contrast, was first examined and discussed as a motivational variable (Dewey, 1913; Schiefele, Hausser, & Schneider, 1979). Subsequently, it was discussed as both a psychological state that is characterized by increased attention, concentration and affect, as well as the motivation to reengage with content (Hidi, 1990; Renninger et al., 1992; Renninger & Wozniak, 1985). In the same period, Schiefele (1991) and his colleagues (e.g., Schiefele & Krapp, 1996) considered interest from a feeling perspective.

Recently, the finding that curiosity promotes learning and memory (Brod & Breitwieser, 2019; Kang et al., 2009; Shah et al., 2018) led researchers to also consider it as a motivational variable that is malleable (Grossnickle, 2016). To date, researchers have studied curiosity as an epistemic emotion (i.e., emotions that relate to knowledge construction; e.g., Nerantzaki & Efklides, 2019; Pekrun, Vogl, Muis, & Sinatra, 2017), a motivational disposition (e.g., Jirout & Klahr, 2012; Kahan, Landrum, Carpenter, Helft, & Jamieson, 2017), and as a task induced motivational state (e.g., Kang et al., 2009; Loewenstein, 1994). In these studies, together with those undertaken from a personality perspective (von Stumm, Hell, & Chamorro-Premuzic, 2011), researchers have investigated curiosity as a motivational variable at the state-as well as at the trait-level.

Meanwhile, researchers who examined the development of interest (e.g., Hidi & Renninger, 2006; Renninger & Hidi, 2022 2016) have also investigated interest at both the state/situational- and trait/dispositional-levels (e.g., Renninger, Bachrach, & Hidi, 2019). They also considered the transition between situational and dispositional (individual) interest (e.g., Hecht, Knutson, & Crowley, 2019). Hidi and Renninger's (2006) four-phase model of interest describes phases in a developmental process in which situational interest is first triggered, then maintained, and subsequently may evolve into an emerging, and eventually into a well-developed individual interest. There are ample empirical studies that provide validation for these developmental phases (e.g., Jansen, Lüdtke, & Schroeders, 2016; Knogler, Harackiewicz, Gegenfurtner, & Lewalter, 2015; Rotgans & Schmidt, 2018). All in all, the parallel lines of research between curiosity and interest, appear to have overlaps, posing a question about the differences between curiosity and interest (Alexander, 2019; Pekrun, 2019).

Some scholars have specified the distinctions between curiosity and interest (Grossnickle, 2016; Hidi & Renninger, 2019; Markey & Loewenstein, 2014; Renninger & Hidi, 2015a; Shin & Kim, 2019). Grossnickle's (2016) was the first comprehensive review. In addition to providing an overview of definitions and measures of the two constructs, she discussed and highlighted three differences between curiosity and interest that appear in the theoretical literature. The first was the role of knowledge. In general, curiosity has been considered to be a gap in knowledge, which is best induced when there is some, but not too much, knowledge. However, interest may be experienced with various levels (low and high) of prior knowledge. The second difference referred to goals and outcomes. Curiosity is argued to reduce uncertainty and fill a knowledge gap, whereas interest describing the acquisition of knowledge more generally which is enjoyable. Finally, Grossnickle described the differences in the stability and malleability of curiosity and interest. She explained that curiosity, in particular trait curiosity, has been assumed to be stable, as a part of an individual's personality traits. Though the state-level curiosity is affected by external/environmental factors, it is also a manifestation of trait curiosity, as a person with high trait curiosity tends to show state curiosity often. In contrast, interest is largely malleable and can still be altered even when it is at the dispositional level (e.g., individual interest).

Subsequently, Shin and Kim (2019) discussed five aspects of the curiosity and interest relation that have overlaps with and also extend Grossnickle's (2016) points. They pointed out that state curiosity can be distinguished from situational interest. Their first point compared the variables theoretically: while situational interest was described as being rooted in hedonic experience and emotion, curiosity was perceived as involving unpleasant feelings. Second, they posited that there were different biological bases for curiosity and interest (Berridge & Kringelbach, 2015). Curiosity was seen as corresponding to the "wanting" subcortical system that involves midbrain dopamine pathways. Situational interest, on the other hand, was perceived as being related to the "liking" system that is responsible for opioid activity in valuation brain regions (e.g., nucleus accumbens).[1] Moreover, Shin and Kim (2019) distinguished the two constructs based on their antecedents, correlates, and outcomes. Triggers for curiosity include incomplete information, associated with aversive feelings, and the seeking of information to dissolve the aversive state. In contrast, interest is seen as being triggered by well-organized information that is associated with positive affect and enjoyment.

1.2. Current status on the empirical investigations about curiosity-interest distinction

Despite ongoing theoretical discussions, empirical investigations addressing the similarities and differences between curiosity and interest are scarce (Hidi & Renninger, 2019; Pekrun, 2019). In fact, the distinction between curiosity and interest has been rarely studied as an explicit research goal (Peterson & Hidi, 2019). One reason is that understanding the relation between curiosity and interest depends on how researchers conceptualize and assess the two variables (Murayama, FitzGibbon, & Sakaki, 2019). Typically, empirical research that aims to distinguish or to show the closeness between two constructs relies on a factor-analytic approach: by examining the correlations between them (e.g., Schmidt & Rotgans, 2020), their differences in predicting outcomes (e.g., Marsh et al., 2019), their convergence in factor models (e.g., Muenks, Wigfield, Yang, & O'Neal, 2017). However, all of these approaches require at least some consensus on either the definitions or on widely used assessments of the constructs. In the case of curiosity and interest, this is presently difficult. Although there are some scales that have assessed curiosity and interest separately (e.g., Boscolo, Ariasi, Del Favero, & Ballarin, 2011; Litman, 2008), the overlapping items in these scales is a concern (Shin & Kim, 2019). It appears that examining simple correlations between the scores of curiosity and interest scales can provide at least a preliminary understanding of available information on the associations between the two constructs. However, the correlations on the basis of those scales are insufficient to tell the fundamental differences between curiosity and interest (see discussion in Donnellan, Aslan, Fastrich, & Murayama, 2022).

A similar point has been illustrated by Schmidt and Rotgans (2020) who reviewed existing measures, labeled either as measuring epistemic curiosity or situational interest, and then rank ordered the frequency

[1] We further note that this distinction has been questioned in subsequent publications, as the biological roots of the two constructs overlap (see discussion in Renninger & Hidi, 2022).

that the items of each were employed. Following this, using the four most frequent items, they developed a measure to assess differences between the two constructs and concluded that that there was no distinction. Although the study was well designed and the method was thorough, the measures employed may have been conflated. For example, the item "I feel the desire to learn more about this topic" is an item used for identifying curiosity, but it could also be used to assess interest (e.g., Hidi & Renninger, 2006). In short, their conclusion was highly contingent upon their measurement.

The issue of measurement is fundamental. In fact, unless we have an agreed-upon consensus about how curiosity and interest are defined, we cannot consider the validity of the distinctions (Murayama et al., 2019). Alternative ways to evaluate the similarities and differences between curiosity and interest include focusing on their operationalization such as individuals' interpretations (e.g., Donnellan et al., 2022), or considering the *subjective feelings/experience of* the two constructs in the moment. The subjective feelings of a construct can serve as the first gate to the mental state (Pekrun, 2020), and its assessment is relatively straightforward and uncontroversial: We can simply ask participants' about their feelings of curiosity and their feelings of interest at a specific moment.

1.3. The present set of studies

The present research has two goals. First, using existing self-reported measures we aim to demonstrate that the statistical relationship between curiosity and interest varies because it critically depends on how the scales are constructed. We show this by conducting a meta-analysis (Study 1) that was designed to gather metric data and pooling correlations of the scales that have been used to assess curiosity and interest. We report the general correlation between curiosity and interest, and examine whether and how the correlations between the scales that are used to measure curiosity and interest vary depending on how the constructs are conceptualized.

Second, we empirically assess the potential similarity and distinction of these constructs by focusing on respondents' subjective feelings of curiosity and of interest. We use the experience sampling method (ESM) in two different settings (daily life in-and-outside of school, and the classroom) to consider the correlates of these subjective feelings. By measuring variables multiple times over a relatively short period of time (e.g., 5–6 times per day over two weeks or 1–3 times per lesson), ESM provides a snapshot of variables in the moment and also a more reliable way in which to measure situational variables such as momentary subjective feelings (Berkel, Ferreira, & Kostakos, 2017; Hektner, Schmidt, & Csikszentmihalyi, 2007). Importantly, we took a psychological network approach (Epskamp, Rhemtulla, & Borsboom, 2017) to analyze the correlates of the feelings of curiosity and feelings of interest in a more comprehensive and holistic manner. More specifically, these analyses allowed us to assess the relationship between the feelings of curiosity and feelings of interest by taking into account other related emotions and motivations. This method enabled us to examine the complex dynamic relationship of the multiple variables and thus was suitable for examining the various momentary feelings that co-occur in learning processes.

2. Study 1: meta-analysis of curiosity and interest

We conducted a meta-analysis to analyze what existing questionnaire-based studies show about the relation between curiosity and interest. Pearson correlations are often used to weigh the closeness between variables, as the strength of correlations can serve as a proxy to indicate the interdependency of variables. However, there is a large variety in the measurements of curiosity and interest (Grossnickle, 2016; Schmidt & Rotgans, 2020; Shin & Kim, 2019). The meta-analysis assesses the heterogeneity of the correlations of the scales, and how they are dependent on the nature of the scales, rather than other extraneous factors. Information about measurement level of the constructs (e.g., trait/stable level, situational/task level) was collected as a key moderator, given its important role for understanding the differences between curiosity and interest.

2.1. Method

2.1.1. Literature search to identify studies for inclusion

An overview of our search and screening procedures is presented in Fig. S1. Titles and abstracts were examined for the following terms: curiosity AND interest. We searched Web of Science, PsycInfo, ERIC, Scopus and ProQuest for articles published in peer-reviewed journals, conferences, or dissertations prior to April 2020. We also searched Google Scholar and kept the first 1000 search results as our supplementary databases based on the prior suggestions (Haddaway, Collins, Coughlin, & Kirk, 2015). The initial search yielded 3701 publications. All the search results can be traced from https://osf.io/8rj26/. After excluding 738 duplicate publications, the first author and a research assistant closely reviewed the remaining 2963 abstracts using specific study inclusion criteria.

2.1.2. Criteria for inclusion and coder reliability

The primary metric of interest in this study was the Pearson correlation coefficient between measures of curiosity and interest. Studies were included if they 1) had at least one quantitative measure of curiosity and at least one quantitative measure of interest; and 2) reported at least one correlation (*r*) between any measure of curiosity and any measure of interest, or appeared to have such correlations. Experimental and quasi-experimental studies were included as long as at least one correlation between curiosity and interest was reported either at the pretreatment time-point or at the post-treatment time-point. Case studies (sample size of one), qualitative, and single-case designs were excluded from the current meta-analysis. After a screening of the 2963 publications abstracts based on the above-mentioned criteria, a total of 67 publications appeared to meet inclusion criteria. A full-text review was conducted of these articles and a further 43 publications were excluded as they did not meet the inclusion criteria. Most commonly, articles were excluded because they did not report correlations between measures of curiosity and interest or the authors could not be reached for further clarification. Not all publications provided sufficient information related to the variables of interest. In case of insufficient information, we contacted the corresponding author of the paper with a request for the correlation coefficient. In the end, our final sample included 24 studies, 31 effect sizes, and a total of 4817 participants (ns ranging from 15 to 646). The full citation list for all included articles can be found in the online supplemental materials.

All papers were coded by the first author and a research assistant, and all disagreements were resolved through internal discussion. The following data were collected from each study and used as study moderators (except publication status given the small number of unpublished studies): Pearson's r correlation between the curiosity and interest, sample size, the year of the study, the age group (either adult sample including university students or youth sample), the level of measurements for both curiosity and interest (either at trait/stable level, at situational/task level, or at cross level), if the article was published in a peer-reviewed journal, and the focus of study (achievement focus or non-achievement focus). In addition, for studies that were examining curiosity from a multidimensional perspective (e.g., interest- and deprivation-type curiosity; Mussel, 2013), we also coded effect size separately for each dimension. However, the number of studies reporting effect sizes for different dimensions was small ($k = 5$), thus we have only preliminary results for these studies, and could not perform further moderation analyses. Across the total variable matrix, the mean inter-rater agreement was 93.25%. The interrater agreement was 99.9% for sample size, 100% for age group, 99.1% for measurement level, 78% for study focus, 83.2% for publication group, and 99.3% for effect sizes.

2.1.3. Analyses

The analyses were conducted in R using the statistical packages meta (v4.12–0), and MAc (v1.1.1). For studies that examined curiosity and interest in multiple situations/tasks (e.g., Nerantzaki & Efklides, 2019; Sung & Yih, 2016), we either aggregated the correlation based on Hunter and Schmidt's (2004) approach or requested the authors to compute the aggregated effect size to avoid effect size dependency problem. To examine the moderator/subgroup effect, a mixed-effects model (i.e., random-effects model within subgroups, fixed-effects model between subgroups) was performed (Borenstein & Higgins, 2013). All analyses codes and results can be found in https://osf.io/8rj26/.

Heterogeneity of the correlations (i.e., between-study variation) was indexed by I^2, which represent the ratio (0%–100%) of true heterogeneity to total variance across the observed effect estimates. According to Higgins, Thompson, Deeks, and Altman (2003), I^2 of 25%, 50%, and 75% can be deemed as having low, moderate, and high between-study heterogeneity, although this also depends on the context of studies.

Test for Publication Bias. Publication bias was tested by examining the asymmetry of effect sizes using the method proposed by Egger, Smith, Schneider, and Minder (1997). Results indicated that the standard errors of correlations did not significantly predict correlations among studies, t (29) = 0.68, $p = .50$. Therefore, there is little evidence for publication bias in the data.

2.2. Results

Based on our inclusion criteria, 24 studies with 31 independent samples, involving over 4817 participants and 31 correlations between curiosity and interest were included in the final analysis. A summary of the results is presented in Table 1. Overall, the relation between curiosity and interest was moderate-to-high and significant, $r = 0.53$, $p < .001$, 95% CI [0.38, 0.66]. However, there is a very large heterogeneity among the correlations, $I^2 = 96.9\%$, $Q\,(30) = 954.51$, $p < .001$; r ranges from −0.32 to 0.98.

Next, the relation between curiosity and interest was examined by each moderator (see Table 1). There were no moderator effects by age group ($Q\,(1) = 0.00$, $p = .96$), or the scope of study (either achievement-focus or not; $Q\,(1) = 0.28$, $p = .59$). We found the moderator effect of measurement level of construct ($Q\,(2) = 12.88$, $p < .01$; see Fig. S2 and Table S1 for the measures used in studies of this meta-analysis). When both curiosity and interest were measured at the trait/stable level, the correlations were moderate-to-high, $r = 0.63$, 95% CI [0.45, 0.76], r ranges from 0.30 to 0.97. Moreover, the correlation was moderate-to-high when curiosity and interest were measured at the situational/task level, $r = 0.61$, 95% CI [0.17, 0.85], r ranges from −0.32 to 0.98. However, when curiosity and interest were not measured at the same level (e.g., trait curiosity and task interest), their correlation was modest-to-low, $r = 0.25$, 95% CI [0.13, 0.36], r ranges from −0.02 to 0.52. Importantly, even after accounting for the factor of measurement level, the heterogeneity of correlation was moderate to high, 53%–98%.

Furthermore, we included multiple moderators together in a meta-regression model to control for potential confounding effects. Here measurement level was dummy-coded according to whether curiosity and interest were assessed at the same level (1) or not (0). After all moderators as well as publication year were included (see Table S2), a significant effect of measurement level was found. Studies that examined curiosity and interest at a situational/task level (estimate = 0.60, SE = 0.28, $p = .03$) or at a trait/stable level (estimate = 0.54, SE = 0.24, $p = .03$) showed higher correlations when comparing to studies that examined curiosity and interest at cross-level (i.e., the measuring of curiosity and interest was not at the same level).

When curiosity was examined by two common types: interest- and deprivation-type curiosity, the correlations with interest were dramatically weaker (see Table 1). For both interest-type curiosity and deprivation-type curiosity, the correlations were modest-to-low ($r = 0.34$, 95% CI [0.06, 0.57], $I^2 = 84\%$, $Q\,(4) = 24.93$, $p < .001$; $r = 0.20$, 95% CI [0.04, 0.35], $I^2 = 69.6\%$, $Q\,(4) = 13.14$, $p = .01$; respectively).

2.3. Discussion

Our meta-analysis showed that the correlations between existing curiosity and interest scales are moderate ($r = 0.53$, 95% CI [0.38, 0.66]). Importantly, however, the correlation substantially varied among the studies ($-0.32 \leq r \leq 0.98$). Indicator of heterogeneity was large (96.8%). This means that between-study difference accounts for most of the variance in the correlation between curiosity and interest scales. As there is no consensus on the measurements of two constructs, and researchers use different scales to assess them, it is not surprising to observe these results. Moreover, when curiosity and interest were both

Table 1
Relation between curiosity and interest.

Variables	k	**Correlation (Pearson's r) [95% CI]**	**Between-study sampling variance (τ^2)**	**Heterogeneity percentage (I^2)**	Subgroup differences test
Average effect	31	.53 [.38, .66]	.28	96.9%	–
Age group					Q = .00; $p = .96$
1. Children and Youth	7	.54 [.41, .64]	.03	83%	
2. Adult	24	.53 [.33, .69]	.36	97%	
Measurement level					Q = 12.88; $p < .01$
1. Situational/task level	8	.61 [.17, .85]	.57	97%	
2. Cross-level	9	.25 [.13, .36]	.02	53%	
3. Trait/stable level	14	.63 [.45, .76]	.23	98%	
Study scope					Q = .28; $p = .59$
1. non-Achievement focus	19	.50 [.28, .67]	.32	97%	
2. Achievement-focus	12	.58 [.36, .74]	.25	97%	
Curiosity dimensions					–
1. Interest-type curiosity	5	.34 [.06, .57]	.09	84%	
2. Deprivation-type curiosity	5	.20 [.04, .35]	.02	69.6%	

measured either at a trait level or at a situational level, the correlations were higher but still fell into the moderate range. The heterogeneity of the correlation was still large even when measurement level was accounted for. Further analysis showed that the association between curiosity and interest was consistent across other features such as age and publications features (e.g., year of study, focus of study). These results suggest that the correlation between curiosity and interest depends on the nature of the scales, indicating the inherent difficulty in interpreting values in terms of the general relationship between curiosity and interest.

Importantly, in many studies where curiosity was assessed at the trait/stable level (see Table S1), curiosity items always included terms such as "interested", "like", "love", or "enjoy" that have been used extensively for interest assessments as well. For instance, in one scale that aims to assess science curiosity (Harty & Beall, 1984), there are items such as "Science magazines and stories are interesting", or "I like to watch magic shows". Studies that used this scale also reported high correlation ($r = 0.73$) between curiosity and interest (Harty, Samuel, & Beall, 1986). In other words, when there are more common terms that have been used for the measurement of curiosity and of interest, not surprisingly the correlation between two constructs is high. Of course, if the developer of the scale theorized that trait curiosity entails feelings of interest, such overlap is theoretically justified. However, this example illustrates the inherent difficulty of using existing questionnaires to specify the relationship between curiosity and interest.

As discussed in the introduction, one option is to focus on the subjective feelings of curiosity and interest as the first step for examining the similarities/distinctions between them. Individuals usually have an intuitive grasp of the feelings of "curiosity" and "interest" (Donnellan et al., 2022). Theories on the relation between curiosity and interest should also be (at least partly) based on this common understanding. With this in mind, the next two studies used an experience sampling method (ESM) to examine individuals' feelings related to the momentary experience of curiosity and interest.

3. Study 2: curiosity and interest networks in school-wide situations

In Studies 2 and 3, we focus on the subjective feelings of curiosity and feelings of interest and examined the relationship between them using ESM, given that ESM has been shown to be suitable for assessing and investigating momentary subjective feelings which occur over a short period of time (Ainley & Ainley, 2019; Berkel et al., 2017; Hektner et al., 2007). We use ESM to understand the extent to which the two subjective feelings are similar or distinct in the presence of other emotions and motivations (see Appendix for a full listing). The emotions and motivations examined are derived from various theories/frameworks, such as epistemic emotions (Pekrun et al., 2017), expectancy-value motivation theory (Wigfield & Eccles, 2000), optimal learning moments framework (Schneider et al., 2016), positive and negative affect, and others (e.g., persistence and engaging experiences; Salmela-Aro et al., 2020; Tang, Wang, Guo, & Salmela-Aro, 2019). These theories/-frameworks, however, only address either curiosity or interest, and have not discussed the potential differences/similarity of these emotions. For example, expectancy-value theory and optimal learning moments only address the role of interest, and curiosity is not discussed in these frameworks. On the other hand, the framework of epistemic emotions focuses on curiosity, not interest. Consequently, although studies informed by these theories/frameworks may suggest correlates for either curiosity or interest, they are not informative for examining their similarities and differences. In other words, each of these theories/-frameworks alone only provides an incomplete picture of the relation among curiosity, interest and other emotional or motivational variables. For example, studies of epistemic emotions showed that surprise is a strong correlate of curiosity (Pekrun et al., 2017; Vogl et al., 2020), however, it is still unknown whether this link to surprise is also observed in interest. Again, studies from expectancy-value theory suggests that self-efficacy is closely related to interest (e.g., Gaspard et al., 2018), yet we do not know if self-efficacy is also related to the feeling of curiosity.

In Study 2, we report specifically on students' feelings of curiosity and of interest in daily school life in- and outside-of-school. We used a psychological network approach to examine the motivational and emotional correlates of the subjective feelings of curiosity and of interest in a comprehensive and holistic manner. We examined how these feelings are related to other situational emotions and motivations, and compared the differences between the networks associated with the networks of each. To provide informed understanding of the networks, we analyzed these data using two different types of network analyses: co-occurrence network (e.g., Moeller, Ivcevic, Brackett, & White, 2018) and correlation-based network (Epskamp et al., 2017).

3.1. Method

3.1.1. Participants and procedure

The sample in this study consisted of 59 first-year high school students (age 16–17; 70% girls) from four classes in three academically oriented schools in Helsinki, Finland. Students were selected for attendance in these schools based on their prior academic achievement. Based on validated information from our sample, 84.78% (39/46) of the students' female guardians and 95.12% (39/41) of their male guardians had received tertiary education (including trade schools, polytechnics, and universities). The data were collected as part of a larger international study that focused on science learning from 2017 fall to 2018 spring. Students were asked to report their situational emotions and motivations via smartphones over a period of two weeks (including evenings). The phones were programmed to signal the students randomly 3–4 times per day (at least once when they had science lessons). The data on situational emotions and motivations were obtained via ESM questionnaires delivered via smartphones. In total, the data comprised 1689 responses/situations (average response per person was 28.63). Given the broad scope of this study, 48.50% situations occurred outside of school. For 51.50% school-based situations, 14% were in science class, 13.7% were in non-classroom situations (e.g., break, school restaurant), the rest were classroom situations such as math class, English class, or others (range from 2.5% to 6.9%).

3.1.2. Measures

The ESM questionnaire first asked students to indicate what kinds of activities (e.g., listening, discussion) they were doing. Then they were asked to report their subjective feeling and experience (a total of 37 items) when they received the alert. Curiosity was measured by reporting "Do you feel curious?" and interest was measured by reporting "Are you interested in what you did?". A full list of the subjective feeling and experience prompts can be found in the Appendix. All the items were rated on a scale of 1 (not at all) to 4 (very much). The descriptive and individual intra-class correlations of study variables (Table S3) can be found in supplementary materials. The classroom-level intra-class correlations were small across variables (average = 0.03, ranges from 0.00 to 0.10).

3.1.3. Data analysis approach

Two types of network analysis were conducted. The first was the co-occurrence network analysis (e.g., Moeller et al., 2018) and the second was the correlation-based network analysis (Epskamp et al., 2017). Both type of network analyses offer unique information and are complementary (Moeller et al., 2018). In co-occurrence network analysis, the instances in which two variables co-occur at a high level (e.g., above scale midpoint) are recorded. This analysis relies on the assumption that scale midpoint is meaningful to determine the occurrence of psychological experience (which is often criticized; see Blanton & Jaccard, 2006) and often conflates the between-person and within-person relations (as the co-occurrent events are aggregated across participants).

However, according to Moeller et al. (2018), it has two remarkable strengths. First, co-occurrence analysis may avoid misinterpretation of correlations in some special cases. Typically, when interpreting high positive correlations between two variables (e.g., A & B), researchers conclude that variable A is "high" when variable B is "high", even though in the reality both A and B might be rated at a low level on the original scale. Because correlations address how consistently the ratings of two variables are aligned, the extent to which the two variables occur together at a high level is not necessarily revealed. Second, frequent co-occurrence may occur even when two variables correlate negatively, which could only be detected using co-occurrence analysis. In this study, to perform co-occurrence analysis, we dichotomized situational emotions and motivations at the scale midpoint (i.e., 2.5), thus scores of 1 and 2 were recoded as 0, and scores of 3 and 4 were recoded as 1. In order to compare the feelings of curiosity and of interest in the co-occurrence network, a relative index of edge weight was calculated. That is, the co-occurrence of the variable pair was divided by the total occurrence of a target variable $\frac{Kij}{Ki}$. Note that edge weights are asymmetric with this definition (i.e., weight from nodes *i* to *j* and nodes *j* to *i* are different). Here the target variable is feelings of curiosity or feelings of interest. To examine the close correlates of the two variables, a community detection algorithm within the co-occurrence network analysis was also applied. The Louvain community detection algorithm was employed as it has shown better performance than the Walktrap algorithm (see suggestions from Christensen, Golino, & Silvia, 2020). The analyses of co-occurrence were conducted using R-package *igraph* (Csardi & Nepusz, 2006).

Correlation-based network analysis was performed using Exploratory Graph Analysis (EGA; Golino & Epskamp, 2017; Golino et al., 2020) with R-package *EGAnet*. In correlation-based network analysis, the connections between nodes (i.e., variables) are typically (regularized) partial correlations while all other nodes are accounted for (Epskamp et al., 2017). In using EGA, we analyzed the network based on the Gaussian Graphical Model and the graphical least absolute shrinkage and selection operator (GLASSO) was used to fine tune the expression of the edges. Fixed-effects within-person correlations were subjected to analysis. Tuning parameter lambda was optimized by comparing models based on extended Bayesian Information Criterion (EBIC; Chen & Chen, 2008). EGA is specialized to find the potential groups among the nodes (i.e., identifying the close correlates of feelings of curiosity and of interest) using the community detection algorithm. Again, Louvain algorithm was used. In addition, to providing further insight about the differences between the feelings of curiosity and of interest, the edge difference tests were conducted to compare the feelings of curiosity edges and the corresponding feelings of interest edges. This was performed using R-package *bootnet* (Epskamp, Borsboom, & Fried, 2018). All analyses codes can be found here: https://osf.io/8rj26/.

3.2. Results

3.2.1. Co-occurrence network

Tables 2 and 3 depict the co-occurrence network results of feelings of curiosity and of interest, respectively. The results concerning the curiosity network (see Table 2) showed that, in total, high-level curiosity occurred 741 times. When feelings of curiosity occurred, feelings of interest (edge = 658; 88.8%), control (edge = 637; 85.96%), enjoyment

Table 2
Co-occurrences and Zero-order correlations of Curious-emotion and motivation pairs in the study 2.

Rank	Node1	Node2	Edge weight	% of all edges	% of Curious self-edge[1]	Within-person correlation	Between-person correlation
	Curious						
1		interest	658	4.15%	88.80%	0.38**	0.37**
2		control	637	4.01%	85.96%	0.16**	0.33*
3		enjoy	631	3.98%	85.16%	0.32**	0.52**
4		inquisitive	621	3.91%	83.81%	0.61**	0.90**
5		selfexpect	612	3.86%	82.59%	0.22**	0.40**
6		happy	602	3.79%	81.24%	0.34**	0.56**
7		importantyou	599	3.77%	80.84%	0.29**	0.38**
8		success	596	3.75%	80.43%	0.18**	0.36**
9		concentrate	588	3.70%	79.35%	0.31**	0.34*
10		cooperative	560	3.53%	75.57%	0.33**	0.80**
11		skill	558	3.52%	75.30%	0.16**	0.37**
12		otherexpect	556	3.50%	75.03%	0.18**	0.49**
13		knowmore	555	3.50%	74.90%	0.51**	0.78**
14		confident	538	3.39%	72.60%	0.25**	0.69**
15		excited	529	3.33%	71.39%	0.43**	0.66**
16		active	512	3.23%	69.10%	0.44**	0.76**
17		grit	501	3.16%	67.61%	0.29**	0.55**
18		examination	496	3.12%	66.94%	0.36**	0.68**
19		time	467	2.94%	63.02%	0.25**	0.38**
20		importantfuture	443	2.79%	59.78%	0.19**	0.38**
21		ideas	411	2.59%	55.47%	0.33**	0.58**
22		effort	369	2.32%	49.80%	0.23**	0.63**
23		imagination	355	2.24%	47.91%	0.27**	0.50**
24		proud	347	2.19%	46.83%	0.33**	0.62**
25		challenge	311	1.96%	41.97%	0.12**	0.12
26		exploring	310	1.95%	41.84%	0.19**	0.50**
27		questions	296	1.86%	39.95%	0.29**	0.62**
28		solutions	268	1.69%	36.17%	0.18**	0.36**
29		competitive	215	1.35%	29.01%	0.20**	0.44**
30		context	202	1.27%	27.26%	0.22**	0.50**
31		stress	185	1.17%	24.97%	−0.08**	−0.13
32		confused	175	1.10%	23.62%	0.13**	0.18
33		anxious	124	0.78%	16.73%	−0.07*	−0.06
34		bored	118	0.74%	15.92%	−0.30**	−0.36**
35		giveup	102	0.64%	13.77%	−0.11**	−0.20
36		lonely	85	0.54%	11.47%	−0.08**	−0.32*

Note. [1]Number of Curious self-edges is 741.
*$p < .05$, **$p < .01$.

Table 3
Co-occurrences and Zero-order correlations of Interest-emotion and motivation pairs in the study 2.

Rank	Node1	Node2	Edge weight	% of all edges	% of Interest self-edge[1]	Within-person correlation	**Between-person correlation**
	Interest						
1		enjoy	1029	4.47%	85.47%	0.66**	0.79**
2		control	1016	4.41%	84.39%	0.33**	0.64**
3		success	957	4.15%	79.49%	0.39**	0.70**
4		importantyou	954	4.14%	79.24%	0.51**	0.74**
5		concentrate	948	4.11%	78.74%	0.52**	0.72**
6		selfexpect	937	4.07%	77.82%	0.31**	0.46**
7		skill	902	3.92%	74.92%	0.44**	0.60**
8		happy	896	3.89%	74.42%	0.47**	0.52**
9		otherexpect	867	3.76%	72.01%	0.20**	0.34*
10		confident	756	3.28%	62.79%	0.29**	0.48**
11		excited	747	3.24%	62.04%	0.51**	0.61**
12		inquisitive	746	3.24%	61.96%	0.34**	0.52**
13		time	745	3.23%	61.88%	0.46**	0.42**
14		cooperative	733	3.18%	60.88%	0.19**	0.43**
15		grit	730	3.17%	60.63%	0.38**	0.60**
16		knowmore	704	3.06%	58.47%	0.39**	0.41**
17		importantfuture	692	3.00%	57.48%	0.18**	0.48**
18		examination	682	2.96%	56.64%	0.21**	0.41**
19		curious	658	2.86%	54.65%	0.38**	0.37**
20		active	648	2.81%	53.82%	0.34**	0.51**
21		ideas	554	2.40%	46.01%	0.27**	0.30*
22		effort	542	2.35%	45.02%	0.24**	0.48**
23		imagination	513	2.23%	42.61%	0.26**	0.31*
24		challenge	473	2.05%	39.29%	0.06*	0.18
25		proud	429	1.86%	35.63%	0.26**	0.31*
26		exploring	427	1.85%	35.47%	0.14**	0.17
27		solutions	393	1.71%	32.64%	0.16**	0.14
28		questions	378	1.64%	31.40%	0.17**	0.30*
29		stress	318	1.38%	26.41%	−0.15**	−0.06
30		competitive	275	1.19%	22.84%	0.14**	0.25
31		context	254	1.10%	21.10%	0.10**	0.23
32		confused	226	0.98%	18.77%	−0.09**	−0.09
33		bored	225	0.98%	18.69%	−0.48**	−0.28*
34		anxious	176	0.76%	14.62%	−0.23**	−0.07
35		giveup	163	0.71%	13.54%	−0.30**	0.03
36		lonely	142	0.62%	11.79%	−0.11**	−0.26

Note. [1]Number of Interest self-edges is 1204.
*$p < .05$, **$p < .01$.

(edge = 631; 85.16%), inquisitiveness (edge = 621; 83.81%), and meeting self-expectations (edge = 612; 82.59%) typically occurred at the same time. Moreover, the feelings of loneliness (edge = 85; 11.47%), giving up (edge = 102; 13.77%), boredom (edge = 118; 15.92%), anxious (edge = 124; 16.73%), and confusing (edge = 175; 23.62%) were least likely to be identified with the feeling of curiosity.

In contrast, when the feeling of interest occurred (self-edge = 741; see Table 3), feelings of enjoyment (edge = 1029; 85.47%), control (edge = 1016; 84.39%), success (edge = 957; 79.49%), importance to self (edge = 954; 79.24%) and concentration (edge = 948; 78.74%) were the top five co-occurring motivations/emotions. In addition, the feelings of loneliness (edge = 142; 11.79%), giving up (edge = 163; 13.54%), anxious (edge = 176; 14.62%), boredom (edge = 225; 18.69%), and confusing (edge = 226; 18.77%) were least likely to co-occur with feelings of interest. It is important to note that when feelings of interest occurred, feelings of curiosity co-occurred only at a probability of 0.55 (edge = 658; 54.65%).

Furthermore, when compared to feelings of interest, feelings of curiosity had higher co-occurrences with inquisitiveness (83.81% vs. 61.96%), happiness (81.24% vs. 74.42%), eagerness to know more (74.90% vs. 58.47%), exploration (74.90% vs. 58.47%), examination (66.94% vs. 56.64%), generating new ideas (55.47% vs. 46.01%), and question asking (39.95% vs. 31.40%). These findings were reconfirmed with community detection results (see Fig. S3). Feelings of curiosity were in the same group with the feelings/experience of inquisitiveness, knowing more, being excited, pride, cooperation, and activeness. Feelings of interest were in the same group with feelings of concentration.

3.2.2. Correlation-based network

Multi-level zero-order Pearson correlations between feelings of curiosity, feelings of interest, and other variables were first reported in Tables 2 and 3. Note that the tables report simple correlations, not the regularized partial correlations, which were meant to be used for the following EGA community detection analysis. They show that feelings of curiosity were closer to feelings of inquisitiveness (r = .61 and .90, respectively at within- and between-person level), wanting to know more (r = 0.51 and 0.78) behaviors of question-asking (r = 0.44 and 0.60), and examination (r = 0.36 and 0.68), whereas feelings of interest were closer to enjoyment (r = 0.66 and 0.79), happiness (r = 0.47 and 0.52), feelings of being skilled (r = 0.44 and 0.60) and concentration (r = 0.52 and 0.72). The zero-order correlations between feelings of curiosity and feelings of interest were 0.38 and 0.37 respectively, at both the within- and between-person level.

Fig. 1 shows the network structure based on the regularized partial correlations and EGA community detection analysis. The analysis confirmed that feelings of curiosity, inquisitiveness, imagination, wanting to know more and behaviors such as providing multiple solutions to a problem, exploration, proposing new ideas, asking questions, and examination were in the same community (community 3), whereas feelings of interest, skill, enjoyment, having control, success, happiness, and excitement fall into the same community (community 1). The edge differences of the curiosity node and the interest node were then compared, and were consistent with the above findings (see Table S4). Feelings of cooperation, confusion, activeness, inquisitiveness, and knowing more (by closing a knowledge gap) were more related to feelings of curiosity than to feelings of interest. In contrast, the feelings

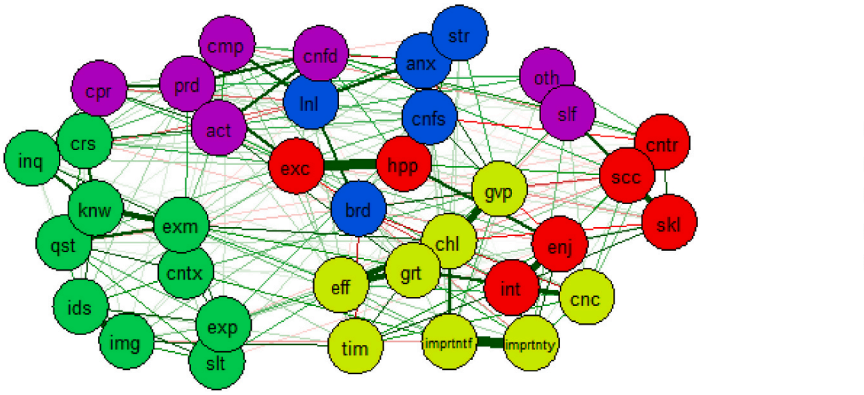

Fig. 1. Network communities in study 2.
Note. The first community: int = interest, skl = skill, enj = enjoy, cntr = control, scc = success, hpp = happy, exc = excited. The second community: chl = challenge, gvp = giveup, cnc = concentrate, imprtnty = importantyou, imprtntf = importantfuture, tim = time, grt = grit, eff = effort. The third community: crs = curious, img = imagination, slt = solutions, exp = exploring, ids = ideas, cntx = context, qst = questions, knw = knowmore, exm = examination, inq = inquisitive. The fourth community: anx = anxious, lnl = lonely, str = stress, brd = bored, cnfs = confused. The fifth community: oth = otherexpect, slf = selfexpect, cmp = competitive, prd = proud, cpr = cooperative, cnfd = confident, act = active.

of being skilled, concentration, enjoyment, attainment value (i.e., important for self), being immersed had significantly stronger unique relations with feelings of interest as compared to feelings of curiosity.

3.3. Discussion

This study reports on findings that are helpful for elucidating the differences between curiosity and interest. First, our results showed a discrepancy in the co-occurrences of curiosity-interest between the two networks. That is, when students reported feeling curious, they were very likely to report feeling interested at the same time, but when they reported feeling interested, they only felt curious half of the time. Second, the correlation network analysis also showed some differences between the feelings of curiosity and of interest. More specifically, the closest correlates to feelings of curiosity were the feelings of inquisitiveness, eagerness to know more in order to close a knowledge gap, and behaviors of question-asking and exploring. In contrast, feelings of interest were more closely related to feelings of enjoyment, excitement, happiness, skill, and success. It is also worth noting that the correlations between the feelings of curiosity and of interest were only modest both at the within-person and between-person levels, suggesting that these two subjective feelings are overlapping but distinct.

4. Study 3: curiosity and interest networks in science classrooms

In Study 2, momentary feelings of curiosity and of interest were assessed in students' daily lives, which included academic (e.g., science class, math class, English class) and nonacademic situations (e.g., school yard, restaurant, at home). In Study 3, we focused on students' feelings of curiosity and interest in science classrooms; the design replicated that of Study 2.

4.1. Method

4.1.1. Participants and procedure

Two hundred eighty-two first-year high school students (age 16–17; 65% girls) from nine classes in three schools in Helsinki participated in Study 3 (from the fall of 2018 to the spring of 2019). The students were in the same schools as those in Study 2. A total of the 88.53% (193/218) of the students' female guardians and 82.02% (178/217) of the students' male guardians had tertiary education. The study addressed students' experience of six (x 75 min) project-based learning (PBL) science unit lessons over two months. In each lesson, the students were asked to respond to an ESM questionnaire using a smartphone three consecutive times: at the beginning phase, the middle phase, and the end phase of lesson. Each student had 18 opportunities to answer the questionnaire (in one group only 17, due to a programming error). In total, 3882 responses were recorded (average response per person was 13.77).

4.1.2. Measures and analyses

All ESM items used in Study 2 were retained in Study 3. Two items were added due to an additional research focus in the larger study from which these data are drawn: "Do you feel surprised?" and "Do you feel frustrated?". Thus, a total of 39 items were assessed in Study 3. The data analytical techniques remained the same as in Study 2. The descriptive and individual intra-class correlations (Table S3) can be found in the supplementary materials. The classroom-level intra-class correlations were small across variables (average = 0.03, ranges from 0.01 to 0.07).

4.2. Results

4.2.1. Co-occurrence network

The co-occurrence analysis results are reported in Table 4 and Table 5 separately for feelings of curiosity and of interest. The co-occurrence network (see Table 4) for feelings of curiosity showed that it occurred 1954 times in total. When feelings of curiosity occurred, feelings of inquisitiveness (edge = 1809; 92.58%), concentration (edge = 1708; 87.41%), feelings of interest (edge = 1691; 86.54%), wanting to know more (edge = 1642; 84.03%), and cooperation (edge = 1630; 83.42%) typically occurred at the same time. Meanwhile, the feelings of loneliness (edge = 133; 6.81%), giving up (edge = 255; 13.05%), anxiousness (edge = 296; 15.15%), frustration (edge = 382; 19.55%), and boredom (edge = 396; 20.27%) were less likely to be identified together with feelings of curiosity.

In contrast, when feelings of interest occurred (self-edge = 2334; see Table 5), feelings of concentration (edge = 2020; 86.55%), inquisitiveness (edge = 2008; 86.03%), control (edge = 1938; 83.03%), cooperation (edge = 1915; 82.05%), and enjoyment (edge = 1883; 80.68%), were the top five co-occurring motivations or emotions. In addition, feelings of loneliness (edge = 136; 5.83%), giving up (edge = 293; 12.55%), anxiousness (edge = 328; 14.05%), frustration (edge = 437; 18.72%), and boredom (edge = 444; 19.02%) were least likely to occur with feelings of interest. When feelings of interest occurred, feelings of curiosity co-occurred at a probability of 0.72 (edge = 1691; 72.45%).

Feelings of curiosity co-occurred more frequently than feelings of interest with feelings of inquisitiveness (92.58% vs. 86.03%), wanting to know more (84.03% vs. 78.79%), stress (30.91% vs. 27.72%), confusion (24.51% vs. 21.21%), surprise (24.51% vs. 21.21%), and in the behavior of question asking (36.13% vs. 32.90%), examination (81.93% vs. 79.01%), and exploration (51.74% vs. 48.71%). The community detection analysis within the co-occurrence network (see Fig. S4) also showed that feelings of curiosity formed a group with the feelings of inquisitiveness and wanting to know more. In contrast, feelings of interest could be grouped with the feelings of happiness, enjoyment, and excitement.

4.2.2. Correlation-based network

The multi-level zero-order Pearson correlations are reported in

Table 4
Co-occurrences and Zero-order correlations of Curious-emotion and motivation pairs in the study 3.

Rank	Node1	Node2	Edge weight	% of all edges	% of Curious self-edge[1]	Within-person correlation	Between-person correlation
	Curious						
1		inquisitive	1809	4.14%	92.58%	0.49**	0.86**
2		concentrate	1708	3.91%	87.41%	0.30**	0.62**
3		interest	1691	3.87%	86.54%	0.41**	0.84**
4		knowmore	1642	3.76%	84.03%	0.35**	0.83**
5		cooperative	1630	3.73%	83.42%	0.27**	0.51**
6		control	1612	3.69%	82.50%	0.18**	0.44**
7		examination	1601	3.67%	81.93%	0.23**	0.70**
8		otherexpect	1589	3.64%	81.32%	0.25**	0.49**
9		selfexpect	1586	3.63%	81.17%	0.23**	0.45**
10		enjoy	1548	3.54%	79.22%	0.36**	0.79**
11		happy	1516	3.47%	77.58%	0.31**	0.58**
12		excited	1478	3.38%	75.64%	0.39**	0.78**
13		success	1466	3.36%	75.03%	0.26**	0.53**
14		importantyou	1387	3.18%	70.98%	0.21**	0.72**
15		grit	1377	3.15%	70.47%	0.28**	0.67**
16		active	1367	3.13%	69.96%	0.29**	0.63**
17		confident	1282	2.94%	65.61%	0.24**	0.49**
17		importantfuture	1282	2.94%	65.61%	0.17**	0.56**
19		skill	1263	2.89%	64.64%	0.24**	0.54**
20		ideas	1198	2.74%	61.31%	0.25**	0.70**
21		effort	1146	2.62%	58.65%	0.18**	0.60**
22		time	1132	2.59%	57.93%	0.24**	0.57**
23		exploring	1011	2.32%	51.74%	0.16**	0.60**
24		imagination	984	2.25%	50.36%	0.23**	0.59**
25		solutions	830	1.90%	42.48%	0.17**	0.53**
26		proud	773	1.77%	39.56%	0.22**	0.55**
27		context	748	1.71%	38.28%	0.12**	0.45**
28		challenge	731	1.67%	37.41%	0.03	0.27**
29		questions	706	1.62%	36.13%	0.14**	0.51**
30		stress	604	1.38%	30.91%	−0.07**	0.07
31		surprised	542	1.24%	27.74%	0.25**	0.45**
32		competitive	536	1.23%	27.43%	0.14**	0.43**
33		confused	479	1.10%	24.51%	0.03	0.13*
34		bored	396	0.91%	20.27%	−0.21**	−0.44**
35		frustrated	382	0.87%	19.55%	−0.17**	−0.08
36		anxious	296	0.68%	15.15%	−0.06**	0.06
37		giveup	255	0.58%	13.05%	−0.14**	−0.15*
38		lonely	133	0.30%	6.81%	0	0.02

Note. [1]Number of Curious self-edges is 1954.
*$p < .05$, **$p < .01$.

Tables 4 and 5 for feelings of curiosity and of interest. The correlations between feelings of curiosity and of interest were moderate-to-high; they were .41 at the within-person level and 0.84 at the between-person level. For feelings of curiosity, the highest correlate was inquisitiveness ($r = 0.49$ and 0.86) while feelings of interest was the second-highest correlate. Feelings of interest had high correlation with enjoyment ($r = 0.49$ and 0.93, respectively at the within- and between-person level), inquisitiveness ($r = 0.43$ and 0.85), and excitement ($r = 0.42$ and 0.85). Exploration Graphic Analysis (EGA) showed that subjective feelings/experiences of curiosity, interest, happiness, excitement, inquisitiveness, enjoyment, self-importance, future-importance, engagement (i.e., time), eager to know more and examination were in the same community (see Fig. 2). Edge differences tests (see Table S6) showed that the feelings of boredom, surprise, inquisitiveness, having new ideas were significantly closer to feelings of curiosity than to feelings of interest, whereas feelings of being skilled, enjoyment, and utility value were related stronger to feelings of interest than to feelings of curiosity.

4.3. Discussion

When the study setting was changed from the more general, daily in-and-out of school context (Study 2) to the science classroom (Study 3), there were some differences, but the underlying relation between feelings of curiosity and feelings of interest was the same. The co-occurrence of curiosity-interest was higher in the feelings of interest occurrences network in Study 3, than had been reported in Study 2. However, the discrepancy between curiosity-interest co-occurrences in the feelings of curiosity network and in the feelings of interest network still existed. When students reported feeling curious, they were very likely to also feel interested, whereas when feelings of interest were reported in the science classrooms, the students recorded no feelings of curiosity a third of the time. Furthermore, the Pearson correlations between feelings of curiosity and feelings of interest were also greater than those of Study 2. At the within-person level, the correlations were moderate, but at the between-person level, they were strong (over 0.80). Finally, the EGA demonstrated that feelings of curiosity and feelings of interest fall into a same community based on the correlation, however co-occurrence analysis showed that feelings of curiosity and feelings of interest were in different communities. This is not surprising as the correlations between feelings of curiosity and feelings of interest became higher when situations were centered on the learning activities, even though the co-occurrence discrepancy between them remained.

Moreover, throughout the results in both studies, the communities identified by the co-occurrence network analysis were not a perfect match to the communities from the correlation network analysis. This may be partly because the two analyses rely on different types of information to create the networks, and thus are complementary as each provides unique information. The co-occurrence network focuses on the cases that are over the threshold and counts the frequency of cases (Moeller et al., 2018). The correlation network covers all data points and is based on the linear associations among them (Epskamp et al., 2017). However, feelings of curiosity, inquisitiveness, wanting to know more were consistently in the same community. It should be noted that given

Table 5
Co-occurrences and Zero-order correlations of Interest-emotion and motivation pairs in the study 3.

Rank	Node1	Node2	Edge weight	% of all edges	% of Interest self-edge[1]	Within-person correlation	**Between-person correlation**
	Interest						
1		concentrate	2020	4.01%	86.55%	0.36**	0.68**
2		inquisitive	2008	3.99%	86.03%	0.43**	0.85**
3		control	1938	3.85%	83.03%	0.28**	0.54**
4		cooperative	1915	3.81%	82.05%	0.28**	0.58**
5		enjoy	1883	3.74%	80.68%	0.49**	0.93**
6		selfexpect	1878	3.73%	80.46%	0.29**	0.53**
7		otherexpect	1870	3.72%	80.12%	0.28**	0.54**
8		examination	1844	3.66%	79.01%	0.29**	0.66**
9		knowmore	1839	3.65%	78.79%	0.37**	0.83**
10		happy	1815	3.61%	77.76%	0.35**	0.73**
11		success	1775	3.53%	76.05%	0.35**	0.66**
12		excited	1697	3.37%	72.71%	0.42**	0.85**
13		curious	1691	3.36%	72.45%	0.41**	0.84**
14		importantyou	1647	3.27%	70.57%	0.27**	0.80**
15		active	1610	3.20%	68.98%	0.32**	0.70**
16		grit	1603	3.19%	68.68%	0.33**	0.70**
17		skill	1529	3.04%	65.51%	0.34**	0.68**
18		confident	1527	3.03%	65.42%	0.26**	0.59**
19		importantfuture	1518	3.02%	65.04%	0.22**	0.65**
20		time	1342	2.67%	57.50%	0.30**	0.61**
20		effort	1342	2.67%	57.50%	0.22**	0.62**
22		ideas	1325	2.63%	56.77%	0.27**	0.63**
23		exploring	1137	2.26%	48.71%	0.19**	0.56**
24		imagination	1077	2.14%	46.14%	0.22**	0.53**
25		solutions	934	1.86%	40.02%	0.17**	0.46**
26		proud	871	1.73%	37.32%	0.23**	0.58**
27		context	849	1.69%	36.38%	0.17**	0.42**
28		challenge	840	1.67%	35.99%	0.04**	0.19**
29		questions	768	1.53%	32.90%	0.12**	0.48**
30		stress	647	1.29%	27.72%	−0.09**	−0.09
31		competitive	575	1.14%	24.64%	0.13**	0.42**
32		surprised	539	1.07%	23.09%	0.14**	0.33**
33		confused	495	0.98%	21.21%	−0.01	−0.08
34		bored	444	0.88%	19.02%	−0.28**	−0.59**
35		frustrated	437	0.87%	18.72%	−0.21**	−0.27**
36		anxious	328	0.65%	14.05%	−0.08**	−0.09
37		giveup	293	0.58%	12.55%	−0.17**	−0.27**
38		lonely	136	0.27%	5.83%	−0.04**	−0.13*

Note. [1]Number of Interest self-edges is 2334.
*$p < .05$, **$p < .01$.

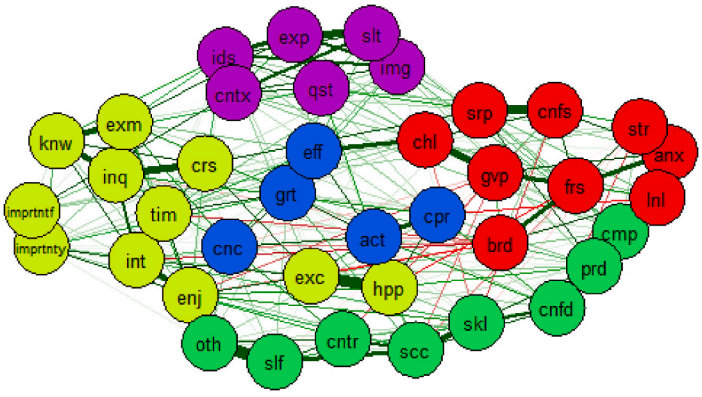

Fig. 2. Network communities in study 3.
Note. The first community: anx = anxious, lnl = lonely, str = stress, brd = bored, cnfs = confused, chl = challenge, gvp = giveup. The second community: hpp = happy, exc = excited, crs = curious, inq = inquisitive, int = interest, enj = enjoy, imprtnty = importantyou, imprtntf = importantfuture, tim = time, knw = knowmore, exm = examination. The third community: cmp = competitive, prd = proud, cnfd = confident, skl = skill, cntr = control, scc = success, oth = otherexpect, slf = selfexpect. The fourth community: cpr = cooperative, act = active, cnc = concentrate, grt = grit, eff = effort. The fifth community: img = imagination, slt = solutions, exp = exploring, ids = ideas, cntx = context, qst = questions.

our research questions we primarily focus on community results regarding curiosity and interest.

5. General discussion

This research offers rich insight into the relationships between curiosity and interest. In general, as shown in the meta-analysis of Study 1, the curiosity scale scores and interest scale scores were moderately related, but their correlations were affected by measurement. Our ESM findings in Studies 2 and 3 demonstrated that feelings of curiosity, compared to feelings of interest, are more aligned with feelings of inquisitiveness, eagerness to know more and the behaviors of question asking, exploration, or examination. In contrast, feelings of interest are closer to enjoyment, excitement, or happiness. The results also indicate that after controlling for other emotions and motivations comprehensively, feelings of curiosity, compared to feelings of interest, are more frequently associated with negative emotions such as frustration, or confusion.

5.1. The closeness and heterogeneity of correlations between interest and curiosity

Our meta-analysis describes the aggregated Pearson correlation between curiosity and interest measured on the basis of self-report questionnaires. The overall correlation was moderate and increased when curiosity and interest were measured at the same measurement level (either trait-level or situational-level). However, the correlation was only moderate and not as strong as the one reported by Schmidt and Rotgans (2020). Importantly, our analysis showed that there is a very high heterogeneity among the correlations. This is largely due to the huge variety of scales that have been used in studies. This finding is not surprising as there is no consensus on assessments of curiosity or interest to date, and the same items have been used in scales for each (see summaries from Schmidt & Rotgans, 2020; Shin & Kim, 2019). Our meta-analysis confirmed the findings of heterogeneity across different scales of curiosity and interest. Moreover, our summary and analysis revealed that there are many terms that have been used in both curiosity and interest scales whichs may complicate researchers' efforts to distinguish between curiosity and interest.

Studies 2 and 3 focused on the subjective feelings of curiosity and of interest, and examined the differential/overlapping correlates of these feelings by utilizing ESM data. The findings showed that the within-person correlations between subjective experiences of curiosity and of interest were modest. These results are consistent with previous studies examining within-person relationships between curiosity and interest using distinct stimuli (e.g., trivia questions; Fastrich, Kerr, Castel, & Murayama, 2018; McGillivray, Murayama, & Castel, 2015; Ozono, Komiya, Kuratomi, Hatano, & Fastrich, 2020). Thus, they provide convergent evidence that curiosity and interest represent distinct subjective feelings, or in other words, have unique aspects with some overlap. However, it should be noted that the subjective feelings being reported by participants are not meaning-free from a semantic perspective (Fiske, 2020; Jackson et al., 2019). For curiosity and interest, each person has their own semantic interpretations of these terms (Donnellan et al., 2022), suggesting that caution in interpreting evidence from self-reports is warranted.

5.2. The distinctions between feelings of curiosity and feelings of interest

If feelings of curiosity and of interest are overlapping but distinct, then what are their distinctive parts? In the following, based on findings from Studies 2 and 3, we individually consider affective experiences, epistemic emotions, motivational experiences, creativity and knowledge acquisition behaviors, and the asymmetrical relation of curiosity and interest occurrences.

5.2.1. Affective experiences

We found that feelings of interest, compared to feelings of curiosity, were closer to positive affective experiences. Feelings of interest consistently co-occurred with feelings of enjoyment, excitement, and happiness. This finding is line with previous discussions that have described interest as primarily associated with positive affect, and curiosity as associated with aversive states (Markey & Loewenstein, 2014; Renninger & Hidi, 2022 2016; Shin & Kim, 2019). Recent research (Donnellan et al., 2022) has also demonstrated that people tend to regard interest as pleasurable and that they assign more positive affective words (e.g., enjoy, like, excited) to interest than to curiosity. Moreover, we did not find that feelings of curiosity and feelings of interest were distinct in their relation to general negative emotions[2] (e.g., anxiety, loneliness). This finding is not surprising given that prior research reported connections between aversive feelings and feelings of curiosity (Di Leo, Muis, Singh, & Psaradellis, 2019; Loewenstein, 1994; Noordewier & Dijk, 2017), due to the state of a knowledge-gap (e.g., feeling of deprivation).

5.2.2. Epistemic emotions

Our findings indicated that many of the epistemic emotions such as feelings of inquisitiveness, boredom, surprise, frustration, or confusion (Pekrun et al., 2017) have distinct relations to feelings of curiosity and feelings of interest. Feelings of curiosity have been found to be closer than feelings of interest to: feelings of inquisitiveness, surprise, boredom, and confusion. Some of these findings echo the argument that curiosity is associated with aversive feelings (Jepma, Verdonschot, van Steenbergen, Rombouts, & Nieuwenhuis, 2012; Loewenstein, 1994; Shin & Kim, 2019). The findings of Studies 2 and 3 further suggest that feelings of curiosity are states that are closely linked to seeking novel information, whereas feelings of interest are not as likely to be linked to novelty.

Feelings of curiosity were found to be related to surprise and confusion, and they jointly elicited exploration behaviors for new knowledge (Vogl et al., 2020). These findings are also aligned with previous research in which individuals assigned the term "unknown/-don't know" to their definition of curiosity, and the term "already know" to that of interest (Donnellan et al., 2022). While the knowledge/-information acquisition process involves both positive and negative epistemic emotions (Pekrun et al., 2017), negative epistemic emotions are likely when the knowledge-gap state has not been resolved (Di Leo et al., 2019), and positive epistemic emotions characterize the end of the process as the knowledge-gap has been resolved and interest may be triggered and supported to develop.

5.2.3. Motivational experiences

Concerning the motivational and engagement experiences, several motivational factors (e.g., feelings of being skilled [i.e., efficacy experience], feelings of importance [i.e., attainment and utility values], or feelings of being fully engaged) played key roles in differentiating the feelings of curiosity and feelings of interest. Across the results, feelings of interest, in contrast to feelings of curiosity, were significantly closer to feelings of efficacy. That is, participants felt more efficacious in what they do when reporting on feelings of interest than feelings of curiosity. As Eccles and Wigfield (2020) also have pointed out, when students feel efficacious, they are more likely to succeed in what they do. Our findings indicate that they also are more likely to experience positive emotions that are associated with feelings of interest.

Furthermore, we also found that feelings of importance, either for self or the future, were closer to feelings of interest than feelings of curiosity. Golman and Loewenstein (2018) highlighted the critical role of importance in determining the extent of curiosity in the "information gap" framework of information seeking and avoidance curiosity (see also Markey & Loewenstein, 2014). While importance can be instrumental or non-instrumental, curiosity about a question tends to be stronger when it is more important (Golman & Loewenstein, 2018). On the other hand, there also is evidence that interest (or intrinsic value) is closely linked with importance (e.g., attainment or utility values; Gaspard, Häfner, Parrisius, Trautwein, & Nagengast, 2017; Salmela-Aro et al., 2020). Our findings showed that feelings of importance may be more salient in its relationship to feelings of interest than feelings of curiosity. This may due to the association of automatic processes with curiosity (Kidd & Hayden, 2015), whereas interest is largely shaped by experiences and environments (Hidi & Renninger, 2006).

5.2.4. Creativity and knowledge-acquisition

Lastly, we found that many differences between feelings of curiosity and feelings of interest were related to behaviors associated with creativity and knowledge-acquisition. Our studies showed that feelings of curiosity were often grouped together with eagerness to know more, question asking, examination, idea generation and exploration. As

[2] Their distinctive associations with negative epistemic emotions will be discussed in the later section.

curiosity has been shown to have a critical role in epistemic activities and in knowledge-acquisition process (Di Leo et al., 2019; Vogl et al., 2020), it is not surprising that feelings of curiosity, in comparison to feelings of interest, were found to be closer to creativity and knowledge-acquisition. This finding contrasts with those of van Schijndel, Jansen, and Raijmakers (2018), however, who reported that high curious children did not have a higher quality of exploration. They also differ from those of Clark, Harbaugh, and Seider (2019) who showed that teaching question asking positively influenced students' curiosity, but had a negative impact on students' cognitive engagement and feelings of self-efficacy. As Renninger & Hidi, 2022 (2020; Renninger & Hidi, 2022 in press) explained, learners who are curious seek only to close a knowledge gap, whereas the information search associated with interest is ongoing, and has been found to benefit learners' knowledge acquisition in particular.

5.2.5. *Asymmetrical pattern of curiosity-interest occurrence*

In addition to finding distinctive correlates for feelings of curiosity and feelings of interest, our co-occurrence network analysis provides new evidence of the differences between these variables. That is, we found an asymmetrical pattern of the curiosity-interest co-occurrence. When feelings of curiosity occurred, it was likely that feelings of interest were co-occurring, whereas feelings of interest did not always accompany feelings of curiosity. The findings suggest that curiosity may be part of the process of interest development (Hidi & Renninger, 2019; Renninger & Hidi, 2022 2016). Actually, given that feelings of curiosity co-occur less frequently with feelings of interest, and that feelings of interest occur without feelings of curiosity, it appears that curiosity may be a precursor of the development of interest. As Bergin (2016) has observed, there are multiple sources for interest development in the school context, knowledge thriving is only one of them. This finding is also in line with Pekrun's (2019) conceptual analysis suggesting that curiosity is a special case of interest. That is, while interest describes engaging broadly, as well as for specific topics, curiosity is a desire to close an information gap. The change of co-occurrences from Study 2 to Study 3 also implies that the feelings of curiosity and of interest became closer in learning situations. Probably due to this, earlier research found that epistemic curiosity and situational interest were highly correlated in two learning task situations (Schmidt & Rotgans, 2020). Prior exploratory analyses also showed that the co-occurrences of curiosity and interest (estimated as optimal learning moments) were higher in school situations than outside-of-school situations (74.38% vs. 50.82%; Tang, Lavonen, Schneider, Krajcik, & Salmela-Aro, 2020). Previous study of epistemic emotions in learning activities also treated curiosity and interest emotions under the same latent factor (Pekrun et al., 2017).

5.3. *A heuristic model on the relationships between feelings of curiosity and feelings of interest*

Based on the above findings, we propose a heuristic model (see Fig. 3) that summarizes the possible relationships between curiosity and interest at the level of subjective feelings by integrating other research findings and ideas (Di Leo et al., 2019; Grossnickle, 2016; Murayama et al., 2019; Pekrun, 2019; Renninger & Hidi, 2015b; Shin & Kim, 2019; Vogl et al., 2020).

In the model, each construct is represented with a rectangle that indicates their coverage. The overlapping of the rectangle represents the strength of connections between constructs. The centerpiece is the feelings of interest that include feelings of curiosity. There are many other aspects of interest experience that cannot be explained by curiosity. This corresponds to the asymmetrical pattern we found for feelings of curiosity and feelings of interest. Thus, feelings of interest are broad and are not restricted to feelings of curiosity, whereas feelings of curiosity are largely associated with the feelings of interest and may transition into feelings of interest. In addition, each construct has other relationships. Feelings of curiosity are tied closely to epistemic emotions, particularly the ones concerning information seeking. In contrast, feelings of interest are closely related to positive emotion, such as enjoyment. By having feelings of curiosity as part of feelings of interest, findings showing that psychological state of interest involves the desire and search for more information explain that the enjoyment and happiness reported in the present study reflects the developing knowledge and value of developing interest (see Renninger & Hidi, 2022). Exploration/examination behavior is depicted as a key factor that links feeling of curiosity and of interest. When knowledge exploration reaches its goal—the knowledge gaps have been satiated—positive emotion follows. However, when the knowledge gaps are unresolved, negative emotions remain.

5.4. *Implications*

Our studies provide several practical implications for learning and instruction. First, although curiosity may only result in the closing of a knowledge gap, Studies 2 and 3 suggest that feelings of curiosity could also be a potential trigger for feelings of interest that can be sustained (Fig. 3; see also Murayama, 2022). In other words, in the classroom,

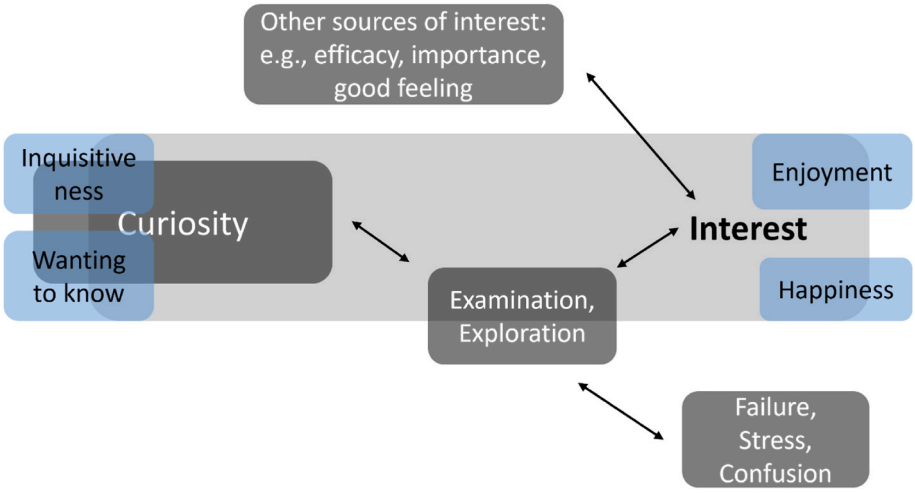

Fig. 3. Feelings of curiosity-interest process at situational level.
Note. As there were 39 constructs on which to draw, only a few are included in this figure. It is important to recognize that there are many associated constructs for both feelings of curiosity and of interest.

promoting curiosity and further supporting the development of interest could maximize learning (see Renninger, Qui, & Hidi, 2022). Second, once people identify as being interested in an activity, it is less likely that their information search is a sign of curiosity. Given that interest often occurs without curiosity as well, it would be important to follow-up to examine the proccesses that inform interest development. Are individuals interested because of their knowledge construction process, because they are in a good mood, or because they are being treated well? (Bergin, 2016). Third, negative emotions that are accompanied by feelings of curiosity should be expected by teachers and students. Some negative epistemic emotions such as confusion, or frustration, may be natural components of knowledge acquisition processes and may have beneficial effects on learning. Thus, it is suggested that teachers and students might embrace them in learning situations (Jirout, Vitiello, & Zumbrunn, 2018; Lamnina & Chase, 2019). In addition, teachers could also prepare students to accept these emotions as part of their learning process, enabling them to feel less stressed when experiencing aversive feelings.

The measurement of interest may benefit from including items assessing, for example, feeling of inquisitiveness. Most measures of interest (e.g., Linnenbrink-Garcia et al., 2010; Marsh, Trautwein, Lüdtke, Köller, & Baumert, 2005; Vinni-Laakso et al., 2019) have focused on positive affect, such as enjoyment, fun, liking, and have not assessed inquisitiveness, wonderment, or aversion feelings. If future interest scales include items assessing curiosity, we would suggest scores not be aggregated as a single scale. Findings from the current research suggest that epistemic affects and positive affects should be separate analyses. This would lead to more nuanced results, and provide more evidence about the epistemic and affective components of interest.

5.5. Limitations and future directions

There are a few limitations of this research. First, most studies in the meta-analysis and our Studies 2 and 3 assessed curiosity and interest using self-reported questionnaires. Although self-report may be an indispensable way to access emotional state, affect evaluation, or cognitive appraisal (Pekrun, 2020), there are some inherited problems with self-report measures such as bias or inaccuracy. Self-report measures of curiosity and interest may be affected by semantic issues related to the two concepts. When reporting feelings of curiosity and of interest, individuals' semantic understandings of the two terms adds to the complexity of identifying the similarities or differences between them and could be the focus of subsequent studies (Donnellan et al., 2022; Fiske, 2020). Such studies should also consider the effects of age, scientific disciplines, and cultures (Fiske, 2020; Frenzel, Pekrun, Dicke, & Goetz, 2012; Jackson et al., 2019). In addition, it is expected that in the future, behavioral as well as neuroscientific research will provide triangulation for self-reports (Hidi & Renninger, 2019). Future research also is needed to understand the association between feelings of curiosity and feelings of interest in different types of situations (e.g., in-school *vs.* off-school, in-class *vs.* off-class, in-studying *vs.* non-studying, math studying *vs.* language studying). Finally, the roles of trait-curiosity or dispositional interest were not considered in studies 2 and 3. It is likely that the networks of feelings of curiosity and feelings of interest vary between high curious and low curious people, or between people with high individual interest or low interest. Future research can fill this gap by examining the influence of trait-level curiosity/interest on the network of them at the state level.

CRediT author statement

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Acknowledgement

The study has been supported by the Academy of Finland (298323 [PIRE], 340794[ClimComp] and 336138[AP]) to Katariina Salmela-Aro. The first and last author also receive the support from the Business Finland, AI in learning project. This research was also supported by Jacobs Foundation Advanced Research Fellowship (to Kou Murayama); and the Leverhulme Trust Research Leadership Award (Grant Number RL-2016-030, to Kou Murayama).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.learninstruc.2022.101628.

Appendix

Emotions and motivations ESM items measured in the study

What do you feel and think about the activity you did (1 Not at all ….. 4 Very Much)

- Do you feel happy?
- Do you feel excited?
- Do you feel anxious?
- Do you feel competitive?
- Do you feel lonely?
- Do you feel stress?
- Do you feel proud?
- Do you feel cooperative?
- Do you feel bored?
- Do you feel confident?
- Do you feel confused?
- Do you feel active?
- Do you feel frustrated? (only in Study 3)
- Do you feel surprised? (only in Study 3)
- Do you feel curious?
- Do you feel inquisitive?
- Are you interested in what you did? (interest)
- Did you feel skilled in what you did? (skill)
- Was your work challenging? (challenge)
- Did you feel that you wanted to give up? (giveup)
- How well did you focus? (concentrate)
- Did you like what you did? (enjoy)
- Did you manage your work? (control)
- Did you succeed? (success)
- Was it what you did important to you? (importantyou)
- Was it what you did important for your future? (importantfuture)
- Did your performance meet the expectations of others? (otherexpect)
- Did you do follow your own expectations? (selfexpect)
- Were you immersed in what you did not notice the passage of time? (time)
- How persistent are you while working? (grit)
- How many efforts did you put when working? (effort)
- While working … I used my imagination (imagination)
- While working … solving problems with multiple answers (solutions)
- While working … I tried different solutions for exploring (exploring)
- While working … got new ideas (ideas)
- While working … I combined the contents of different subjects in context (context)
- When I was working … I asked a lot of questions (questions)

- While working … I wanted to know more/do more (knowmore)
- While I was working … I studied and examined what I did (examination)

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