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REVIEW ARTICLE

Cognitive Load Theory and Its Relationships with Motivation: a Self-Determination Theory Perspective

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Abstract

Although cognitive load theory research has studied factors associated with motivation, these literatures have primarily been developed in isolation from each other. In this contribution, we aimed to advance both fields by examining the effects of instructional strategies on learners' experience of cognitive load, motivation, engagement, and achievement. Students (N = 1287) in years 7–10 in four Australian high schools completed survey measures of motivation, engagement, cognitive load, and their teachers' perceived instructional strategies and motivating style. Results suggest that teachers' load-reducing instructional strategies were related to lower cognitive load and were positively associated with relative autonomous motivation, engagement, and achievement. Teachers' motivating styles characterized by autonomy support and structure were also associated with reduced extraneous and intrinsic cognitive load, as well as motivation and engagement. We conclude that by using load-reducing strategies and a motivating style characterized by structure and autonomy support, teachers can reduce students' cognitive load and improve their self-regulated motivation, engagement, and achievement. In so doing, we discuss a number of future avenues for the joint study of self-determination theory and cognitive load theory, with the aim of refining and extending both perspectives.

Keywords Cognitive load theory · Self-determination theory · Motivation · Engagement · Disengagement · Circumplex

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At the heart of a teacher's role are teaching strategies and learning activities that contribute to students' effective attainment of their learning goals. In parallel, teachers also take an interest in other outcomes, such as enjoyment of classes and of school, an interest in the subject matter, and the creation of a cooperative and prosocial class atmosphere. Yet, programs of research on teaching strategies that optimize the use of limited cognitive resources and teaching strategies that foster optimal motivation have occurred mostly independently. The few attempts to draw upon both fields of research are theoretically fragmented and inconclusive (Martin, 2023). In the following sections, we review research grounded in cognitive load theory (Sweller et al., 2011) and self-determination theory (SDT; Ryan & Deci, 2017). We argue that SDT can serve as an integrative theoretical framework for understanding and generating research questions about the role motivation plays in cognitive load theory. We then present the findings of a study conducted in a large sample of students in years 7 to 10 at school that shed light on the link between both frameworks, thereby providing initial evidence for a more integrative understanding of the relationships between cognitive load and motivation.

Cognitive Load Theory

Cognitive load theory is a theory of instruction based on human cognitive architecture (Sweller, 2011; Sweller et al., 1998, 2011). It assumes that unlike biologically primary knowledge, which is acquired readily and autonomously under normal circumstances, biologically secondary knowledge is generally acquired through interactions with others (Sweller, 2008) and requires conscious processing of information in working memory and alignment with information already encoded and stored in long-term memory. Because of this, learning from a teacher can be more or less effective based on how the information presented to the learner affects working memory and how it interacts with long-term memory. Working memory resources are limited (Baddeley, 2012; Cowan, 2010), and when they are exceeded, learning is unlikely to occur because less cognitive resources are available for processing the information and encoding it into long-term memory.

Cognitive load theory has produced a range of robust effects based on testing hypotheses derived from the characteristics and limitations of human cognitive architecture, especially the limitations of working memory capacity (Atkinson & Shiffrin, 1967; Baddeley, 2012; Cowan, 2014). The effects relate to the load of information in working memory, which is classified as *intrinsic cognitive load*, when it relates to the task at hand and contributes to learning, or *extraneous cognitive load*, when it consumes working memory without contributing to learning. For example, the split attention effect refers to the need to search for and integrate information from different locations (e.g., from both a diagram and a textual explanation), which is extraneous because the searching and integrating does not contribute to learning as such; in contrast, visually integrated material frees working memory resources for comprehending and encoding information (Sweller et al., 2011). Cognitive load theory generally favors a style of instruction characterized by high levels of instructional support and guidance (Evans & Martin, 2023a; Kirschner et al., 2006; Sweller, 2015).

Complementing a large body of experimental work, researchers have recently made use of large-scale surveys to examine student perceptions of their teacher's instructional strategies. *Load reduction instruction* (Martin, 2016; Martin & Evans, 2018) integrates the findings of cognitive load theory to propose a framework of instructional principles hypothesized to reduce cognitive load: reduce difficulty, provide support and scaffolding, create opportunities for practice, give useful feedback, and design guided, independent projects when learners have sufficient prior knowledge to experience success. Load reduction instruction was found to be reliably measured in student surveys, and as predicted by cognitive load theory, it was negatively correlated with student-reported extraneous cognitive load and, to a lesser extent, intrinsic cognitive load (Martin & Evans, 2018). Load reduction instruction is also positively associated with motivation and engagement (Martin, Ginns, Burns, Kennett, & Pearson, 2021a).

Cognitive Load and Motivation

The theoretical scope of cognitive load theory does not extend to motivation, but researchers have recognized the importance of understanding how cognitive load may affect motivational processes (e.g., Feldon et al., 2019; Hawthorne et al., 2019; Mayer, 2014; Moreno, 2006). Empirical work can be classified into one of two broad propositions. The first is that extraneous cognitive load could be beneficial because it prompts the leaner to invest more mental effort to resolve confusion or dissonance, leading ultimately to better learning. Experimental studies (e.g., Eitel et al., 2020; Likourezos & Kalyuga, 2017; Rey & Buchwald, 2011) have used strategies such as problem-solving to instigate this process, with disappointing results. These studies have not been able to detect benefits of extraneous cognitive load for either motivation or learning.

The second and more fruitful line of work highlights the negative motivational consequences of the experience of extraneous cognitive load. It seems almost obvious that having excessive cognitive load is not an enjoyable experience. Accordingly, most research has conceptualized motivation as an outcome or consequence following from cognitive load. Feldon et al. (2019) proposed that cognitive load would yield a motivational cost—a source of psychological stress that is likely to affect motivational beliefs, which may, in turn, exacerbate the effects of extraneous load by further limiting the amount of mental effort a learner is willing to invest in a task. An experimental study of undergraduate science students (Feldon et al., 2018) concluded that when students experienced extraneous cognitive load, it undermined self-efficacy beliefs over a semester of study, independent of actual performance. Conversely, experimentally reducing extraneous load was found to positively affect motivation (Nebel et al., 2017; Skulmowski et al., 2016; Wang et al., 2022). Survey research on load reduction instruction converges with these findings. Load reduction instruction was positively correlated with academic motivation, engagement, and school achievement in a study of high school mathematics students (Martin

& Evans, 2018). In a study of high school science students, engagement mediated the effects of load reduction instruction on achievement, with large effects at both student and classroom levels (Martin, Ginns, Burns, Kennett, Munro-Smith, et al., 2021b).

It is reasonable to conclude from research thus far that when learners experience extraneous load, their motivation deteriorates, and in conditions that reduce extraneous load, motivation is maintained or even increased. Some additional observations suggest areas for further research. Much of the cognitive load theory research on motivation has adopted a range of individual constructs (emotions, self-efficacy beliefs, interest, or unitary measures of motivation) without unifying theoretical frameworks of motivation or operationalizing the dimensionality of motivation. One exception to this is the work cited above by Feldon et al. (2018, 2019) using expectancy-value theory, which demonstrates how attention to theorized motivational processes, rather than simply explaining variance in individual constructs, can yield insights into the nature of the relationship between cognitive load and motivation beliefs. Another characteristic of cognitive load theory research is that it is methodologically dominated by experimental studies, which, by design, can be more conclusive, but less able to model the real-world variability evident in classroom teaching strategies, including strategies the teacher uses both to reduce cognitive load and to support student motivation. The following section presents self-determination theory as a framework of motivation that can address these limitations and to potentially allow for a richer and more nuanced understanding of the relation between cognitive load and motivation.

Self-Determination Theory

SDT is a theory of human motivation (Deci & Ryan, 1985; Ryan & Deci, 2017). Among a range of mini-theories that explain motivation, development, and psychological well-being, two key mechanisms relate to motivation and learning. The first is concerned with the fulfillment of basic psychological needs of competence, relatedness, and autonomy. The fulfillment of these needs provides necessary nutrients for psychological growth, integration, and flourishing (Deci et al., 1996). The second is a continuum of motivation and behavioral regulation. The continuum ranges from amotivation, an absence of motivation, through controlled motivation, where behavior is perceived to be regulated by forces external to the self, to autonomous motivation, where behavior is perceived to be regulated from within the self (Ryan & Deci, 2020). The fulfillment of basic psychological needs is said to facilitate the internalization of reasons for studying and to promote autonomous self-regulation, whereas the frustration of basic psychological needs leads to more controlled regulation and disengagement (Vansteenkiste et al., 2018).

Although any of a range of theories of motivation may be adopted, several features of SDT make it an attractive framework to understand cognitive load and motivation. The motivation continuum focuses on the quality of motivation, and in educational settings, this motivational quality is explained in large part by the motivating style of the teacher. Previous SDT work has focused on ways that a teacher's instructional style affects motivation, and the experience of cognitive load may provide an explanation for why this is the case. In the present study, as the following sections outline, we focused on the role of the teacher's motivating style.

Teachers' Motivating Styles

SDT research has characterized teachers' motivating styles on the dimensions of autonomy support (vs. control) and structure (vs. chaos) (Aelterman & Vansteenkiste, 2023). Autonomy-supportive teaching is theorized to support basic psychological needs, and to promote the internalization of regulation towards more autonomous motivation. When autonomy-supportive, teachers take an interest in students' perspectives, attempt to harnessing students' interests, curiosity, and enjoyment, and acknowledge students' negative affect. In contrast, when controlling, teachers rely on external sources of motivation such as incentives or directives, use controlling language and an interpersonal tone of pressure, and regard students' negative affect as unacceptable (Reeve, 2009; Reeve et al., 1999). Autonomy-supportive teaching is associated with greater interest and deeper learning (Ryan & Connell, 1989), engagement (Patall et al., 2018; Reeve et al., 2004), interest in pursuing further learning (Bonneville-Roussy et al., 2017; Freer & Evans, 2019), internalized motivation (Ratelle et al., 2007), and achievement (Jang et al., 2009; Vansteenkiste et al., 2004; for a review, see Vansteenkiste et al., 2018).

As research on autonomy support became established, it was clear to SDT researchers that autonomy support alone might not be sufficient for effectively facilitating self-regulation and learning (Jang et al., 2010). Structure was introduced as a concept in SDT research initially as a form of support for fulfilling the psychological need for competence (Skinner & Belmont, 1993), characterized by setting and communicating learning goals, setting clear expectations, and providing process-oriented feedback and encouragement during learning activities. Alongside autonomy support, it is clear that a classroom environment high in structure supports motivation and engagement (Hornstra et al., 2021; Hospel & Galand, 2016; Jang et al., 2010; Mouratidis et al., 2022; Pitzer & Skinner, 2017; Sierens et al., 2009; Vansteenkiste et al., 2012) including in a range of contexts such as language classes (Oga-Baldwin & Nakata, 2015), observations of mathematics classes (Stroet et al., 2015), teaching children with sensory loss (Haakma et al., 2016, 2017), physical education classes (Aelterman et al., 2016; Delrue et al., 2019), parenting (Raftery-Helmer & Grolnick, 2016; Ratelle et al., 2021), and in team sports (Reynders et al., 2020). Teachers can effectively learn about strategies to provide autonomy support and structure to their students (Su & Reeve, 2010).

These avenues of research have converged more recently on a circumplex model (see Fig. 1). In a circumplex model, phenomena (e.g., teacher's motivating style) are depicted by their proximity on a circular pattern around a two-dimensional plane (Gurtman & Pincus, 2003). Circumplex models are often used in other areas of psychological research to study the structure of affect (Russell, 1980), personality (Plutchik & Conte, 1997), and leadership styles (Redeker et al., 2014). In the case of teachers' motivating styles, the circumplex comprises two orthogonal dimensions:

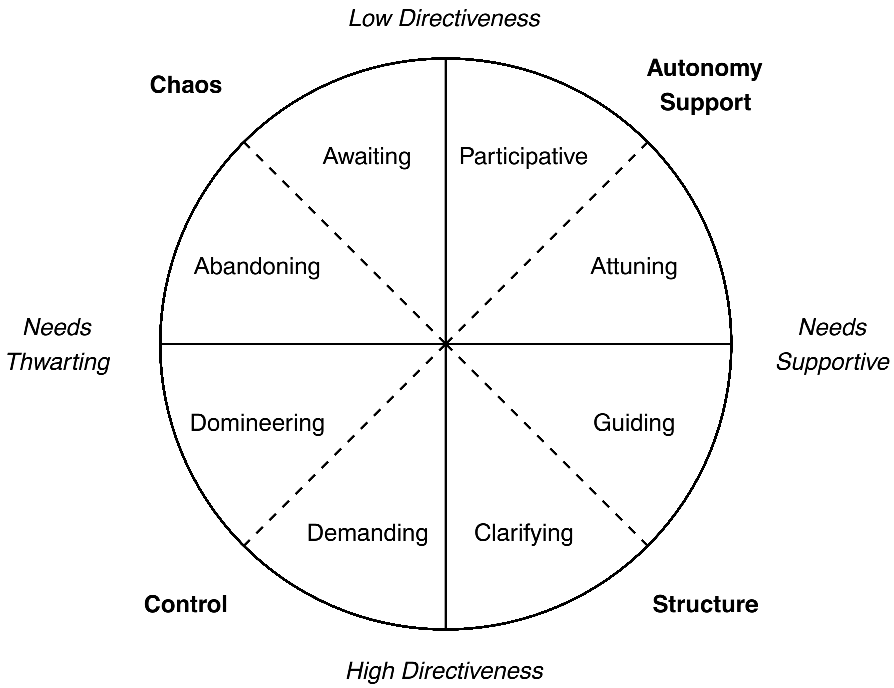

Fig. 1 Circumplex model of teachers' motivating styles (Aelterman et al., 2019b; Aelterman & Vansteenkiste, 2023)

the support, relative to the thwarting, of basic needs and the extent to which the teacher takes the lead and is directive or instead transfers the lead to students (Aelterman & Vansteenkiste, 2023). The four quadrants of the circumplex represent the four overarching teaching styles, with each style falling apart in two subareas. This theorizing and measurement (see "Measures") has been validated in studies of high school students and their teachers (Aelterman et al., 2019b), in higher education (Vermote et al., 2020), and in sports coaching (Delrue et al., 2019). The findings support the structure of the circumplex by demonstrating sinusoidal patterns of correlations among the eight discerned variables in the model itself as well as with external variables (e.g., motivation, achievement, self-regulation, oppositional behavior). Specifically, in relation to desirable outcomes, a peak in the correlational pattern is observed for the need-supportive areas, with the strength of the correlation becoming decreasingly positive and even negative when moving along the circumplex to the need-thwarting areas.

Autonomy Support, Structure, and Cognitive Load

Teachers' motivating styles, characterized in terms of autonomy support and structure, may be informative in relation to the experience of cognitive load. Autonomy support is associated with engagement, which suggests that it directs attention towards activities that are necessary for learning, thus reducing the proportion of cognitive load that is extraneous. Autonomy support is generally a positive affective experience, which means that it may influence self-regulation beliefs and promote the investment of mental effort (Plass & Kalyuga, 2019). For example, autonomy support was shown to increase study effort and decrease procrastination over a school year (Mouratidis et al., 2018). In contrast with autonomy-supportive teaching, controlling teaching results in behaviors and affective responses that require attentional resources and impede learning. Under controlling conditions, students have to be concerned with avoiding trouble, not upsetting the teacher, complying with expectations, and managing the negative effects of psychological needs thwarting (Patall et al., 2018; Reeve & Tseng, 2011b; Soenens et al., 2012), none of which contributes directly to learning.

Structure fulfills the psychological need for competence (Hospel & Galand, 2016; Skinner & Belmont, 1993; Aelterman & Vansteenkiste, 2023) and may minimize extraneous cognitive load through making the experience of classrooms more predictable and optimizing attentional and processing resources, thus affording more cognitive resources for self-regulation. The concept of structure is inherent in many cognitive load theory effects where extraneous cognitive load is minimized by structuring information (e.g., structuring information in a way that reduces split attention; structuring a series of worked examples; communicating the structure of the knowledge itself through explaining its element interactivity). Conversely, a teaching style that is high in chaos (and low in structure) might impose additional cognitive load, as students have to navigate the uncertainty and unpredictability of a lesson and work out for themselves what kind of behaviors is necessary to attain the learning goals. In the absence of high levels of motivation, students in chaotic environments are unlikely to exert the efforts required to self-regulate in this way. Structure is akin to the concept of guidance (vs. minimal guidance) described by Kirschner et al. (2006), who claimed that minimal guidance is generally associated with higher extraneous cognitive load.

Aims of the Study

The present study pursued two aims related to the potential for SDT to understand relationships between instruction, cognitive load, and self-regulated motivation. Aim 1 was to extend load reduction instruction research to understand the influence of teaching strategies that reduce extraneous cognitive load on motivation and engagement. We studied load reduction instruction as an instructional style, its association with intrinsic and extraneous cognitive load, and in turn, its relation with motivation and engagement as well as learning outcomes. Aim 2 was to investigate the teacher's motivating style and its associations with cognitive load, motivation, engagement, and achievement. Moving along the circumplex in Fig. 1, we expected that teaching styles characterized by autonomy support and structure would be associated negatively with extraneous cognitive load, with these correlates gradually shifting and becoming positive in the case of control and especially chaos.

Method

Participants and Procedure

Procedures for recruitment, consent, and study participation were approved by the Human Research Ethics Committee at the first author's institution. Participants in the study were students in four secondary schools in the greater metropolitan area of Sydney, Australia, recruited by convenience. Two of the schools were government schools, two were independent, and all were co-educational. The Index of Community Socio-educational Advantage for each school was slightly above the national average (between 1025 and 1075) but within a standard deviation of the national average ($M = 1000$, SD = 100).

The schools distributed parental consent forms 2 weeks prior to the study, explaining that participation in the study involved completing a survey during class time. Schools were asked to nominate a specific class time at their convenience where all classes in years 7–10 would complete the survey. This resulted in the survey being completed in 88 classes in a range of school subjects representing humanities (29 classes), STEM (27 classes), creative arts (21 classes), and health and physical education (11 classes). A total of 1349 students participated in the study from years 7 (409 students), 8 (332 students), 9 (282 students), and 10 (264 students). Students were aged between 12.3 and 17.2 years ($M = 14.38$, SD = 1.17). They reported their gender as female (616 students, 47.9%), male (491 students, 38.2%), or "prefer not to say" (180 students, 14%). In preliminary data screening, a threshold of less than 4 s per item was deemed to indicate inattentive or careless response behavior; as a result, 62 cases (4.6%) were removed from the dataset. This left a total of $N = 1287$ students from 88 classes that were used for analysis.

Measures

For all survey measures, participants indicated agreement with items using a 7-point scale ranging from 1 "strongly disagree" to 7 "strongly agree." Descriptive statistics, including reliability coefficients (omega; McNeish, 2018) and intra-class correlations (ICCs), are shown in Table 1.

Load Reduction Instruction Scale (LRIS)

The load reduction instruction scale (LRIS) was used to measure student perceptions of their teacher's instructional strategies theorized to minimize cognitive load (Martin & Evans, 2018). The LRIS measures load reduction instruction as a higher-order factor, indicated by five principles, each indicated by responses to five survey items (for a total of 25 items): (1) reduce difficulty (e.g., "when we learn new things in class, the teacher makes it easy at first"), (2) provide support and scaffolding (e.g., "as we work on tasks or activities in this class, the teacher gives good assistance"), (3) structure opportunities for practice (e.g., "in this class, the teacher makes sure we

Table 1 Descriptive statistics and correlations

Descriptive statistics and correlations.	1	2	3	4	5	6	7	8
1. Load reduction instruction								
2. Extraneous cognitive load	−.679	–						
3. Intrinsic cognitive load	−.207	.512	–					
4. Motivation (RAI)	.551	−.519	−.370	–				
5. Engagement	.646	−.517	−.385	.772	–			
6. Disengagement	−.384	.463	.203	−.496	−.402	–		
7. Student-reported grade	.251	−.324	−.404	.354	.473	−.186	–	
8. School-reported grade	.132	−.184	−.252	.182	.229	−.203	.389	–
Age	−.094	.028	−.001	−.066	−.094	.020	−.016	−.034
Gender	−.036	.001	.061	.002	−.053	−.101	−.058	.108
SES	.093	−.060	−.044	.043	.111	−.137	.140	.071
M	5.026	3.058	3.511	17.854	4.886	2.542	73.137	2.789
SD	1.356	1.584	1.483	4.979	1.083	1.383	13.472	.862
ICC	.299	.242	.125	.119	.177	.098	.178	.453
ICC2	.861	.822	.675	.664	.758	.612	.744	.887
Omega	.922	.936	.916	.955	.857	.842	–	–

get enough practice before moving on to new tasks or activities”), (4) provide effective feedback on learning (e.g., “in this class, the teacher gives us lots of feedback on our work”), and (5) provide opportunities for independent learning that is guided by the teacher (e.g., “once we know what we’re doing in this class, the teacher gives us schoolwork to figure it out by ourselves”). The LRIS has been validated with high school students (Martin & Evans, 2018) and is associated positively with motivation and achievement in a range of school subjects (Martin et al., 2023; Martin, Ginns, Burns, Kennett, Munro-Smith, et al., 2021b; Martin, Ginns, Burns, Kennett, & Pearson, 2021a).

Cognitive Load

Cognitive load was measured using an adaptation of the scale developed by Leppink et al. (2013). This measure models intrinsic and extraneous cognitive load in relation to students’ perceptions of instruction in a class or by a teacher. Intrinsic and extraneous cognitive load are latent factors each indicated by responses to six survey items. The items for intrinsic cognitive load relate to task difficulty in the subject area (e.g., “the work in this class is very difficult for me”), while the items for extraneous cognitive load relate to difficulty associated with instruction and the presentation of information (e.g., “the way information is presented in this class is too complex”). Respondents indicated agreement with each item using a 7-point scale labeled “strongly disagree” and “strongly agree” at each end. Variations on this cognitive load measure are validated with university students studying health sciences and statistics (Leppink et al., 2013) and language learning (Leppink et al., 2014); it performs as expected with high school science students (Cook et al., 2017) and high school mathematics students (Martin & Evans, 2018). A review of this approach to measuring cognitive load in experimental studies (Krieglstein et al., 2022) found strong evidence for internal consistency and construct validity.

Teacher's Motivating Style

The teacher's motivating style was measured using the situations in schools (SIS) measure (Aelterman et al., 2019b), developed to model four hypothesized teaching styles and eight hypothesized subareas. To assess respondents' perception of each style, the SIS measure presents 15 brief vignettes for different real-world situations that occur in classrooms (e.g., for planning: "as your teacher prepares for class, he/she creates a lesson plan. His/her top priority would be…"; for classroom management: "A couple of students have been rude and disruptive. To cope, your teacher…"). Within each vignette, respondents then indicate their level of agreement with four items, each corresponding to a hypothesized teaching style (e.g., structure: "the teacher communicates which learning goals he/she expects you to accomplish by the end of the lesson;" chaos: "the teacher doesn't plan or organize too much. The lesson will just happen;" autonomy support: "the teacher offers a very interesting, highly engaging lesson;" control: "the teacher insists that you have to finish all your required work—no exceptions, no excuses"). Each style also distinguishes between two subareas as shown in Fig. 1. This results in a total of 60 items, each representing one of eight subareas nested within four overarching styles, assessed across 15 vignettes. Multidimensional scaling (MDS) of items as well as subarea scale scores confirmed the circular arrangement around the two dimensions of need support (i.e., horizontal axis) and directiveness (i.e., vertical axis), comparable to results in previous research using the SIS (Aelterman et al., 2019b; Delrue et al., 2019; Vermote et al., 2020).

Motivation

Motivation was assessed using an adapted version of the Self-Regulation Questionnaire-Academic (Ryan & Connell, 1989). The item stem asks why respondents do a particular school-related activity (in this case, "These questions are about putting effort into [subject]. I am motivated to put effort into this class because…"). Participants then respond to items relating to the motivation types on the SDT continuum (e.g., intrinsic motivation, "…because I am highly interested in this class;" identified regulation, "…because I want to learn new things;" introjected regulation, "…because I would feel guilty if I wouldn't do so;" external regulation, "…because I am supposed to;" amotivation, "…I don't know, I can't understand why I'm studying"). The instrument is widely used in educational settings with high school–aged students, and its validity and factor structure are supported by extensive psychometric work and meta-analysis (Bureau et al., 2023; Howard et al., 2017; Litalien et al., 2017; Sheldon et al., 2017). To operationalize self-determined motivation as a single latent factor, we computed a relative autonomy index (Ryan & Deci, 2017) where the motivation types are weighted based on their position on the continuum (Sheldon et al., 2017).

Engagement

Engagement was modeled using the three-factor structure comprising behavioral, emotional, and cognitive engagement (Fredricks et al., 2004), extended to include the dimension of agentic engagement (Reeve, 2013; Reeve et al., 2022). Respondents indicated their agreement on five items in relation to each type of engagement. Behavioral engagement (e.g., "I try hard to do well") and emotional engagement (e.g., "I feel good") items were drawn from the engagement versus disaffection measure (Skinner et al., 2009). Cognitive engagement items (e.g., "I usually try to summarize what we learn in my own words") were drawn from the learning strategy items of the Metacognitive Strategies Questionnaire (Wolters, 2004). Agentic engagement items (e.g., "I let my teacher know what I need and want") were drawn from a validation study of Reeve and Tseng (2011a).

Disengagement

To operationalize disengagement, we used *controlled non-participation*, an SDT construct that reflects a defensive basis for acting out or disengaging from class activities, specifically in relation to feeling controlled (Vansteenkiste & Mouratidis, 2016). The items for controlled non-participation were those used by Aelterman et al. (2019a) with high school students. Respondents indicated agreement with six statements following the stem "Think about a time recently when you haven't put effort in or didn't cooperate in class. I did not in effort or cooperate in [subject] because…" (e.g., "…because the teacher should not have interfered with what I was doing").

Grades

We used both student-reported and school-reported grades to indicate student achievement. For student-reported grades, students responded to one item: "What mark do you think you will get at the end of the year for this subject" with a number from 1 to 100. For school-reported grades, participating schools were asked to supply students' current grades in each subject. Three of the four schools supplied grades. The grades are recorded as A, B, C, or D (represented by values 4, 3, 2, and 1, respectively) that are calculated from school-based assessments using a standard set of criteria used across the state education system. The correlation (r) between students' self-reported grade and the school-reported grade was .53 ($p < .001$).

Data Analysis

We conducted the analysis in three main parts according to the research aims. To address Aim 1, we studied outcomes of load reduction instruction as an instructional style characterized by strategies known to optimize cognitive load on students. We tested a structural equation model (SEM) in which motivation, engagement, disengagement, and achievement were predicted by cognitive load and, in turn, load reduction instruction. Age, gender, and SES were included in the model as covariates (i.e., predicting all other factors in the model). The model was estimated first as a measurement model (confirmatory factor analysis (CFA)) with all latent correlations freely estimated, before imposing regression (structural) constraints. We did not make any hypotheses (or findings) in relation to mediation as the model is based on cross-sectional data, but for completeness, we also report indirect effects. To address Aim 2, we studied teacher's motivating style. Using the circumplex structure of the teacher's motivating style, we correlated the different subareas within the circumplex model with load reduction instruction, intrinsic and extraneous cognitive load, motivation, engagement, and achievement. We expected a sinusoidal pattern of correlations between the discerned styles in the circumplex and the different assessed outcomes.

For latent variable models, we used the robust maximum likelihood estimator (MLR), with full-information maximum likelihood (FIML) to handle missing data. Standard errors were corrected for the clustering of students in classes. We evaluated the fit of the models as good using the following criteria: CFI $>.95$ and RMSEA $<.08$ (Hu & Bentler, 1999). We conducted all analysis in the R programming environment (R Core Team, 2022) using the package smacof (Mair et al., 2022) for multidimensional scaling and the package lavaan (Rosseel, 2012) for CFA and SEM models.

Results

Aim 1: Motivational Outcomes of Load Reduction Instruction

The CFA model comprising latent constructs of motivation, engagement, disengagement, cognitive load, and load reduction instruction (LRI) fit the data well ($\chi^2(423) = 1515.837$, CFI = .952, RMSEA = .051). Latent variable correlations (see Table 1) were all significant and in the expected direction. Using the CFA as a basis, we imposed structural constraints to represent the hypothesized model. The SEM fit the data well, with identical fit statistics to the CFA model. Significant ($p < .05$) coefficients are described here and in Fig. 2; all model parameters and confidence intervals are shown in Table S1. Extraneous cognitive load related negatively to motivation ($\beta = -.113$) and related positively to disengagement ($\beta = .383$), and intrinsic cognitive load related negatively to motivation ($\beta = -.226$), engagement ($\beta = -.275$), and achievement (−.241). Load reduction instruction predicted extraneous cognitive load ($\beta = -.684$) and intrinsic cognitive load ($\beta = -.205$) and had direct effects on motivation ($\beta = .428$), engagement ($\beta = .608$), and disengagement ($\beta = -.122$).

Based on the structural model, several significant indirect effects were observed. LRI indirectly predicted motivation via extraneous cognitive load ($\beta = .077$) and via intrinsic cognitive load ($\beta = .046$). LRI indirectly predicted engagement via intrinsic cognitive load ($\beta = .056$). LRI indirectly predicted disengagement via extraneous cognitive load ($\beta = -.262$) and via intrinsic cognitive load ($\beta = -.078$). LRI

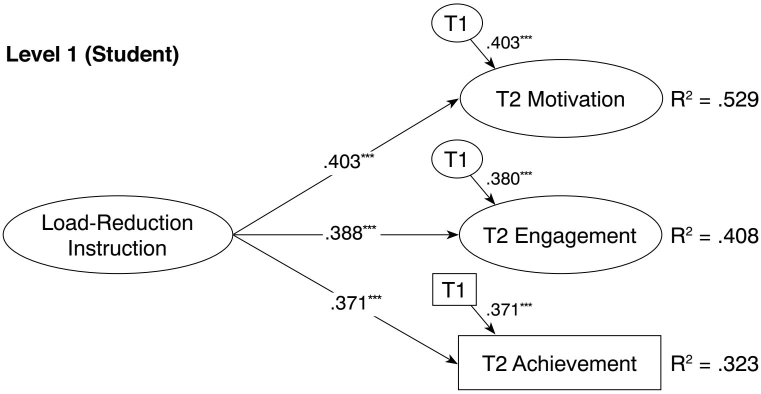

Fig. 2 Structural equation model. For simplicity, the measurement model, covariates (age, gender, SES), and nonsignificant paths are omitted from the diagram (for full model parameters, see Table S1). Parameters are standardized regression (beta) coefficients

indirectly predicted achievement via intrinsic cognitive load ($\beta = .049$). All indirect and total effects are also shown in Table S1.

Aim 2: Effects of Teacher's Motivation Style on Cognitive Load

The expected sinusoidal pattern of correlations with the subareas of the circumplex model was observed with extraneous cognitive load, intrinsic cognitive load, and load reduction instruction (see Fig. 3; all correlations are shown in Table S2). Extraneous cognitive load showed the highest positive correlations with the teaching style of chaos (awaiting, abandoning) and the domineering subarea of control, and negative correlations with the styles of autonomy support (attuning, participative) and structure (clarifying, guiding). The demanding subarea showed a nonsignificant correlation. For intrinsic cognitive load, a similar but more attenuated pattern of correlations was observed. Load reduction instruction was strongly associated with the teaching style of structure (clarifying, guiding), and autonomy support (attuning and, to a lesser extent, participative). A positive correlation was also observed between LRI and the demanding subarea of control.

Turning to motivation and engagement, the pattern of correlations also reflected the expected sinusoidal pattern, with similar shape and magnitude (see Fig. 2). Positive correlations were observed with the teaching styles of autonomy support (attuning, participative) and structure (clarifying, guiding), and negative correlations with chaos (awaiting, abandoning) and the domineering subarea of control. The demanding subarea was more ambiguous (small positive correlation with engagement, near-zero correlation with motivation). For disengagement, an inverse pattern was observed, with the lowest levels of disengagement in autonomy support (attuning, participative) and structure (clarifying, guiding), and highest levels of

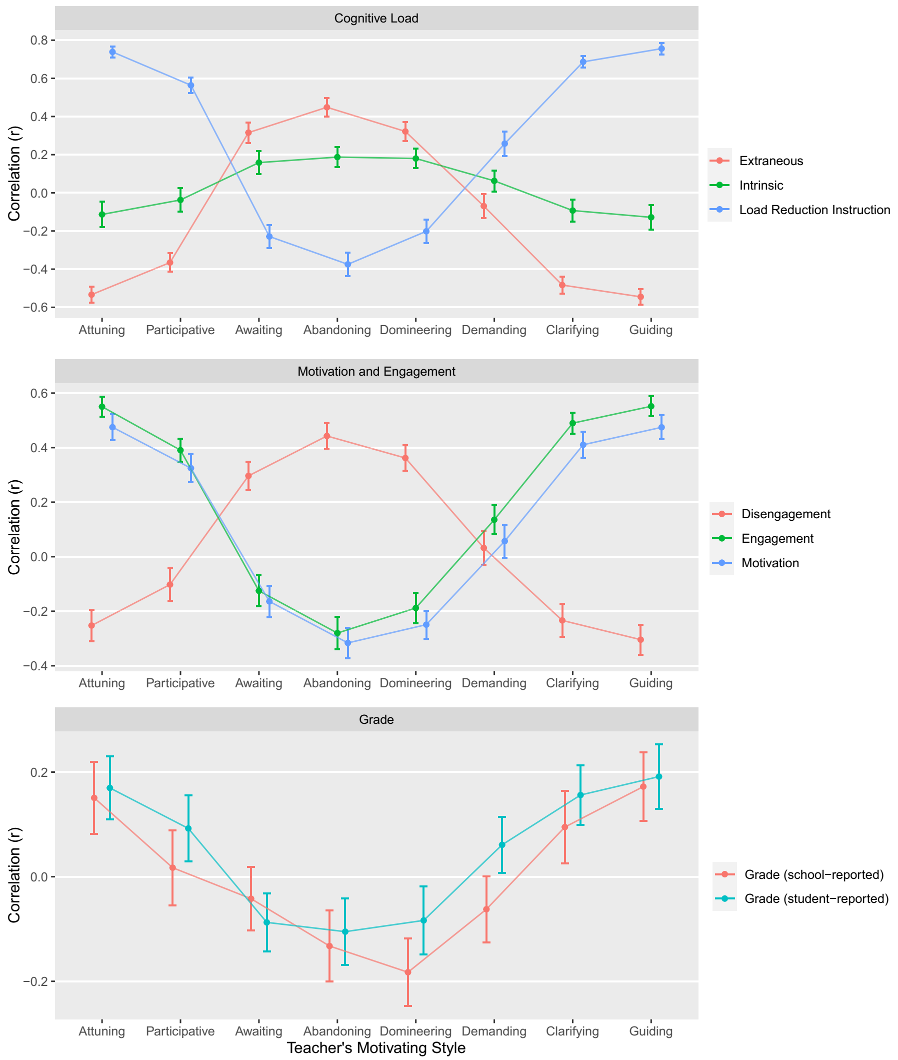

Fig. 3 Correlates of SIS subareas with motivation, engagement, achievement, and cognitive load. Error bars represent 95% confidence intervals

disengagement with chaos (awaiting, abandoning) and the domineering subarea of control. Again, a near-zero correlation was observed with the demanding subarea.

Finally, school-reported grades also followed a sinusoidal pattern of correlates (see Fig. 3). Positive correlations were observed with structure (clarifying, guiding) and the attuning subarea of autonomy support, and negative correlations with the abandoning subarea of chaos and the domineering subarea of control.

Student-reported grades followed a similar pattern, with no significant differences observable from school-reported grades.

Discussion

Although studies have responded to the call for understanding the role of motivation and self-regulation in cognitive load theory, proposed theoretical relationships and empirical findings have been mixed. To understand this relationship more deeply, this study positioned self-determination theory (SDT; Ryan & Deci, 2017) as a framework for understanding the multidimensional nature of motivation and the mechanisms that might be involved among teaching strategies, teaching styles, cognitive load, motivation, engagement, and achievement. We operationalized some of those potential mechanisms and found that teachers' use of load reduction instruction strategies is effective in reducing students' perceptions of cognitive load, and the benefits extend to learning (as indicated by school-reported grades), autonomous motivation, engagement, and (lower) disengagement. In addition to instructional strategies, we found that the teachers' motivating style itself is associated with perceptions of cognitive load: teaching styles characterized by autonomy support and structure were associated with reduced cognitive load, while control and chaos were associated with higher cognitive load. Collectively, these findings suggest that strategies for motivating students and strategies for reducing cognitive load are not antagonistic. Instead, the same strategies that support students' autonomous motivation can also be those that minimize extraneous cognitive load, and the reduction in cognitive load is associated with autonomously motivated engagement in learning.

Cognitive Load as an Antecedent to Motivation, Engagement, and Learning

In pursuing Aim 1, we extended research on load reduction instruction into the theoretical domain of SDT. We found general alignment with previous load reduction instruction research in relation to its positive associations with motivation and engagement (Evans & Martin, 2023b; Martin et al., 2023; Martin, Ginns, Burns, Kennett, & Pearson, 2021a; Martin & Evans, 2018), extending this to also model effects on extraneous and intrinsic cognitive load, as well as disengagement. The findings also corroborate the body of experimental research on the negative effects of extraneous cognitive load on motivation (Feldon et al., 2018; Nebel et al., 2017; Skulmowski et al., 2016; Wang et al., 2022). Our model overall supported the benefits of load reduction instruction and the experience of minimized cognitive load for motivation, engagement, and learning.

In relation to motivation, lower extraneous cognitive load was associated with more autonomous motivation—reasons for participating in class that are self-regulated, more volitional, aligned with students' interests, and enjoyable, compared with reasons that are related to avoidance, shame, or regulation by others. These findings are aligned with previous research in relation to the negative effects of cognitive load on motivation (Feldon et al., 2018; Wang et al., 2022). Feldon et al., for example, suggested that the experience of extraneous cognitive load may influence motivational beliefs—specifically appraisals of cost, because of the increased effort that would be required on subsequent interactions with learning activities (Feldon et al., 2019) and self-efficacy beliefs (Feldon et al., 2018). Both constructs are concerned with outcome expectations and perceived effort. By operationalizing the SDT construct of autonomous motivation, the present study shows that reducing cognitive load may also facilitate the internalization of value and the alignment of learning tasks with the self.

The findings for engagement and disengagement were more nuanced. Some studies have suggested that extraneous cognitive load could instigate engagement because it motivates the learner to resolve confusion. Although this could be possible under certain circumstances, the present finding showed this not to be the case, with no positive (or negative) association with engagement. Instead, extraneous cognitive load was associated with disengagement—acting out in defiance in response to perceived control (Vansteenkiste & Mouratidis, 2016). On the other hand, load reduction instruction was strongly associated with engagement, with only a small (negative) effect for disengagement. Together, these findings suggest that load reduction instruction strategies promote engagement in learning and, to some extent, reduce disengagement, which occurs instead in response to the experience of extraneous cognitive load. Positive effects of extraneous cognitive load on motivation and engagement thus seem unlikely. Future research may find moderators (e.g., situations where extraneous cognitive load can be used to instigate engagement) but, as noted in the introduction, previous work has not successfully supported this idea.

Achievement (in the form of school-reported grades) was associated with extraneous and intrinsic cognitive load, but not directly with load reduction instruction. This finding is consistent with previous theorizing that achievement (as an indicator of learning) would be higher when extraneous cognitive load is lower because cognitive resources are focused on learning, and also when intrinsic load is lower, because the work is perceived as less difficult. However, the limitation of the data and of the cross-sectional design suggests more caution for this finding than for others. The analysis corrected parameter estimates for the clustering of students in classes, but achievement data are more complex because students are also clustered within both school subjects and school year, and many schools use streaming (or "setting") to cluster some (but not all) subject areas based on student ability. Conclusions in relation to learning could be more confidently made with a longitudinal design, tracking changes in learning across the school year with changes in load reduction strategies and perceived cognitive load, and ensuring reliable measurement of learning (e.g., by limiting to a single school subject area or analyzing subject areas separately and by using a consistent measure of learning related to the curriculum of the class).

The Teacher's Motivating Style and Cognitive Load

In Aim 2, we extended our focus on the teacher beyond the teacher's instructional style (load reduction instruction) to look at the teacher's motivating style—the teacher's efforts to take an interest in the students' perspectives, communicate the structure and rationale of learning activities to students, and to nurture students' progress towards learning goals. The circumplex model of teachers' motivating styles (Aelterman & Vansteenkiste, 2023) was supported by the data, identifying a two-dimensional plane (i.e., crossing the level of need support with the level of directiveness) situating eight identifiable subareas. As hypothesized, the discerned styles were correlated in an ordered (i.e., sinusoidal) manner, with subareas situated next to each other being positively correlated and the pattern becoming decreasingly positive and even negative when moving to the opposite subarea in the circumplex (Gurtman & Pincus, 2003). In implementing this measure, we upheld the reliability of this new instrument (i.e., the SIS) beyond its previous use in Belgian samples (Aelterman et al., 2019b) to an English version with Australian students.

The pattern of correlations further pointed to the benefits of motivating styles of autonomy support (attuning, participative) and structure (clarifying, guiding)—they were positively associated with engagement, motivation, and achievement (both self-reported and school-reported), and negatively associated with disengagement and intrinsic and extraneous cognitive load. Conversely, the pattern of correlations pointed to the negative effects of a motivating style characterized by chaos (subareas of awaiting and abandoning). In the motivating style of control, the pattern was more differentiated, with the domineering subarea yielding clear undesirable correlates, but the results for the demanding subarea were being more ambiguous. Demanding teaching is characterized by the use of controlling language, commands, and external incentives and threats to activate students. The correlations for this subarea with motivation, engagement, and achievement were much closer to (or indistinguishable from) zero than for the domineering subarea of teacher control, suggesting the possibility of moderation effects (e.g., a demanding style of teaching may be harmful depending on whether a teacher is demanding all or some of the time, on characteristics of the student, or on other classroom variables). This differentiated pattern of correlates observed for both subareas of teacher control logically flows from the circumplex ordering of styles, with the domineering subarea being directly thwarting of students' basic psychological needs and the demanding subarea being characterized by low need support but not necessarily the present of need thwarting (Vansteenkiste et al., 2019).

The findings extend SDT research to understanding the negative consequences of a controlling or chaotic teaching style in terms of the cognitive load experienced by students. This supports our expectation that students in classes that are high in chaos have more to process in working memory that does not directly contribute to their learning: they have to navigate uncertainty, discern or create lesson goals for themselves, and deal with a teacher whose responses and behavior are unpredictable. It is well known that these conditions have negative effects on motivation and engagement (Aelterman et al., 2019b), and the current findings suggest they also impose cognitive load on students that does not contribute to learning. This is further supported by the relationships with intrinsic cognitive load, which, as expected, were much more attenuated—the teacher's motivating style has much less of an impact on the perceived inherent difficulty of the work, which is usually less associated with the teacher and more with prior knowledge, student developmental characteristics, school-wide programs, and state-wide curricula.

A Note on Theories of Motivation

SDT was adopted in the present study as it is a broad theory of human motivation applicable in diverse fields, including extensive work in educational settings. The breadth of prior empirical work in SDT provides tools and measures that can be readily operationalized along with measures of cognitive load in correlational research. SDT has a range of theoretical postulates relating to learning, development, the internalization of values and beliefs, and general well-being, thus suggesting ways in which cognitive load may adversely affect individuals beyond school or achievement-related outcomes. Further research using SDT may yield more nuanced results on relationships between motivation and cognitive load theory beyond the present findings. For example, the experience of basic psychological needs was not included in this study, but the need for competence (and the experience of competence fulfillment or competence frustration) is a strong candidate for explaining the effects of extraneous cognitive load on a fundamental psychological process that affects motivation.

It is worth noting that motivation is complex, and without strong theory, empirical work is unlikely to yield convincing explanations about motivation. As mentioned in the introduction, most previous research on cognitive load theory and motivation has operationalized motivation as a single, unitary construct, limiting the ability to generate theoretical understandings of the motivational processes involved in the experience of cognitive load. One exception to this is the work cited earlier by Feldon et al. (2018, 2019) using expectancy-value theory, which concluded that cognitive load is experienced as a motivational cost that affects subsequent self-efficacy beliefs and the investment of further effort. The present findings complement this work, showing that additional motivational processes that affect internalization of motivational beliefs and values may be at play. While noting the advantages of SDT as a theory of motivation, we make no claims in relation to whether one motivation theory or another should be preferred. It may be that diverse empirical work using a range of approaches converges on a particularly satisfying theoretical understanding.

Limitations and Directions for Future Research

Several methodological limitations apply to the findings reported here. First, the clustered nature of the data (students in classes, year levels, subjects, and schools) means that adjustments have to be made to model parameters. Moreover, many of the effects we studied were on students, but they were predicted by the instructional and motivating style of a teacher who is, by definition, a classroom-level influence. In the analyses we conducted, we corrected for the clustering of students within classes, but the ability to perform any statistical modeling at that level was limited due to the relatively small number of clusters (classrooms). Nonetheless, between-student variability proved to be meaningful, as would be expected, due to the variance in the way individual students perceive the use of instructional strategies, and due to differentiation—the deliberate between-students variation in teachers' instructional strategies (Domen et al., 2020). Thus, for future research, we recommend studies that include sufficient sample size at the classroom level to account for variability between both students and classrooms.

Second, the cross-sectional nature of the study design limits the findings by precluding any causal relations among variables, and in relation to understanding variation in instructional and motivating style over time. The principles in load reduction instruction vary in their effectiveness depending on the prior knowledge of the learner (Kalyuga, 2007). Presumably, teachers also move into different motivating styles depending on their students' development—for example, they might move from a more clarifying, attuning style early on in a unit of work and shift to a more guiding, attuning style when students are sufficiently prepared for success (Aelterman & Vansteenkiste, 2023). Understanding these dynamics could provide new, fine-grained insights into the dynamics of instructional and motivating teaching styles. For future research, we suggest methods that can uncover the degree to which these variables fluctuate over time, taking these fluctuations into account using longitudinal designs. Stronger conclusions may be made in relation to causality, especially in relation to indirect or mediation effects, using study designs with data from three or more timepoints.

Third, we relied on student reporting of all variables in the study (besides grades reported by the school). For some measures (such as motivation and perceptions of cognitive load), self-report is the ideal methodology. For example, previous survey measures of cognitive load have displayed the expected structure and correlation between intrinsic and extraneous load and with external correlates (Leppink et al., 2013, 2014; Martin & Evans, 2018), and the measure used in the present study aligns with recommendations of a recent review of cognitive load measures (Krieglstein et al., 2022). For other measures, especially for student ratings of their teachers' instructional and motivating styles, there is potential for bias to influence the results. Previous research suggests that the measures may be robust to potential bias: for example, the dimensionality and factor structure of the SIS was the same for teachers and students, and there was modest agreement among teacher and student ratings (Aelterman et al., 2019b). And, as noted above, there is indeed variability to be expected between student ratings, even of the same teacher. To investigate this limitation further, future research could adopt multilevel modeling using aggregates of scores (e.g., aggregating student scores to study between-classroom variability in instructional and motivational strategies, or aggregating scores over time). Alternative methodological approaches, such as observations, incorporating teacher self-report, or qualitative approaches, may be able to uncover and address the nature and extent to which bias applies to student self-report of these measures.

Conclusion

What is the relationship between cognitive load theory and motivation? In this study, we aimed to extend previous research attempts to address this question. Based on the findings of the present study as well as previous research, it seems clear that the experience of extraneous cognitive load is not generally motivating, does not prompt learners to engage more deeply in their learning, and may even prompt learners to become frustrated and disengage. The present findings also have implications for teachers and their use of teaching strategies: load reduction instruction strategies reduce cognitive load and are themselves motivating and engaging. Based on these findings, it seems that there is minimal risk posed for motivation and engagement by using explicit teaching strategies to reduce cognitive load. Outside of instructional strategies, the teacher's motivating style itself has consequences: attempts to motivate students using external contingencies, excessive demands, or a lack of structure pose risks to students in terms of increased cognitive load and reduced motivation and engagement.

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